NARROW BAND RATIO VEGETATION INDICES AND ITS RELATIONSHIPS WITH RICE AGRONOMIC VARIABLES

Fumin Wang , Jingfeng Huang [*]

Institute of Agricultural Remote Sensing & Information Application Huajiachi Campus, Zhejiang University Hangzhou 310029, P. R. China

[*] *Corresponding author, Address: College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310029, Zhejiang Province, P. R. China, Tel: +86-571-86971830, Fax: +86-571-86971831, Email: Email:hjf@zju.edu.cn*

Abstract: The present study aims to determine spectral bands that are best suited for characterizing rice agronomic variables. The data for this study came from ground-level hyperspectral reflectance measurements of rice at different stage. Reflectance was measured in discrete narrow bands between 350 and 2500 nm. Observed rice agronomic variables included leaf area index (LAI), wet biomass (WBM including aboveground wet biomass-AGWBM, leaf wet biomass-LWBM, stem wet biomass-SWBM), and dry biomass(DBM: including aboveground dry biomass-AGDBM, leaf dry biomass-LDBM, stem dry biomass.) Firstly, narrow band ratio vegetation index (NBRVI) involving all possible two bands combinations of discrete channels were tested. The second part of the paper describes a rigorous search procedure to identify the best NBRVI predictors of rice agronomic variables. Special narrow band lambda (λ1) versus lambda (λ2) plots of R2 values illustrates the most effective wavelength combinations (λ1 and λ2) and band-widths (Δλ1 and Δλ2) for predicting rice agronomic variables at different development stages. The best of the NBRVI models explained 58% to 83% variability rice agronomic variables at different development stage. A strong relationship with rice agronomic variables is located in red-edge, 700 nm to 750 nm, the longer portion of red (650nm to 700nm), the shorter portion of green (500nm to 550nm), a particular portion of NIR (800nm to 850nm). They are followed by moisture-sensitive NIR(1150nm to 1200nm), and two portions of SWIR (1600nm to 1650nm).

Keywords: hyperspectral remote sensing, narrow band ratio vegetation indices, rice agronomic variables

1. INTRODUCTION

Recent literature has shown that the narrow bands may be crucial for providing additional information with significant improvements over broad bands in quantifying biophysical and biochemical variables of agricultural crop. These hyperspectral studies were conducted for rice yield (Shibayama and Akiyama, 1991), chlorophyll content of plants (Blackburn, 1998), coniferous forest LAI (Gong et al., 1995), pinyon pine canopy LAI (Elvidge and Chen, 1995), and photosynthesis and stomatal conductance in pine canopies (Carter, 1998). The indices discussed in this paper involve two bands. According to Lawrence and Ripple (1998) and Gong et al.(1995), the use of two-band vegetation indices unnecessarily constrains the regression analysis. They argue that if one requires knowledge of an ecological variable (e.g., above-ground biomass or LAI), the researchers must ultimately analyze the relationship between the spectral index used and the ecological variable through a regression analysis. As the crop conditions vary due to factors such as management conditions, soil characteristics, climatic conditions, and cultural practices, different band combinations can be used (Shibayama and Akiyama, 1991; Shibayama et al., 1993). In the same time, theoretical models concerning the indices have been developed to describe the reflectance from single leaves to complete canopies. Many investigations demonstrated that reflection of red, green, and near-infrared radiation contains considerable information about crop biomass owing to the contrast between soil and vegetation. Thenkabail et al(1999) describe a rigorous search procedure to identify the best narrow band NDVI predictors of crop biophysical variables.

During the past several years, estimates of biomass, ground cover and leaf area indices (LAI) as a function of spectral reflectance measurements have shown promising results (Leblon et al.,1991; Clevers,1989).However, paddy rice being grown in continuously flooded fields, is a special crop which deserves particular consideration, as the layer of water on the soil surface modifies the spectral reflectance of the soil-plant system (Patel et al.,1985).

Based on the above background, the main goal of this research is to evaluate the performance of NBRVI in characterizing rice agronomic variables. The final goal is to determine and recommend an optimal number of hyperspectral bands, their centers and widths, in the visible, NIR portion and short-wave infrared portion of the spectrum (350–2,500 nm) required to best study rice, thus reducing the redundancy in hyperspectral data. A rigorous and exhaustive approach is adopted in computing and evaluating narrow band ratio vegetation index. Rice variables used are leaf area index (LAI), wet biomass (WBM: including aboveground wet biomass—AGWBM, leaf wet biomass –LWBM, stem wet biomass—SWBM, and root wet biomass—RWBM), dry biomass (DBM: including aboveground dry biomass—AGDBM, leaf dry biomass –LDBM, stem dry biomass—SDBM, and root dry biomass—RDBM), which are the best indicators of rice growth and yield (Bartlett et al., 1988; Wiegand and Richardson, 1990; Shibayama et al., 1993; Thenkabail et al., 1995; Fassnacht et al., 1997).

2. EXPERIMENT SITE

The study area is at Zhejiang University Experiment Farm, Hanghou, Zhejiang province, China, located 30° 14´ N，120° 10´ E. The data were obtained from three nitrogen fertilizer levels and five species treatments of rice in 2002 growing seasons. Rice cv. ‘Xiushui 110(S1),Xieyou 9308(S2), Jiayu 293(S3), Jiazao 312(s4) and Z00324(S5)’ were selected for the investigation. Xieyou 9308, Jiayu 293, Jiazao 312 and Z00324 are indica rice, and Xiushui japomica rice. Xieyou 9308 is a hybrid rice, others common rice. The three nitrogen fertilizer treatments(N0,N1,N2) of rice are fertilized 0,140, 240kg/ha pure nitrogen respectively. Each treatment has four repeats. A completely randomized design consisting of 60 plots of 4.81m×4.68m was used, and 12 plots for each variety. Each plot was planted in east-west. The experiment area is characterized by monsoon climate with a hot summer and a cool winter, marked seasonal variations in precipitation. The average annual rainfall is 1374.7 mm from 1961 to 1990. The sandy loam paddy soil had the following properties: pH 5.7, organic matter with 16.5g/kg and total N with 1.02g/kg.

3. METHODOLOGY

Spectral and agronomic variables data were gathered during the growing season of rice from June to October. A spectroradiometer with a range from 350 nm to 2500 nm, manufactured by Analytical Spectral DevicesTM (FieldSPEC, 2002), was used to gather spectral data of rice at different stages. Due to severe noise in the water absorption regions, only the data gathered in 350 nm through 1330 nm and in 1480 through 1780 nm and 1990 nm through 2400 nm were used. The spectroradiometer unit consisted of a main spectrometer, a personal computer, fiber optic cable, a pistol grip, and different field of view (FOV) cones. Inside the spectrometer instrument, light is projected from the fiber optics onto a holographic diffraction grating where wavelength components are separated and reflected for independent collection by the detector(s) (FieldSPEC, 2002).

Rice Spectra and agronomic variables were observed seven times totally at their distinctive growth stages. These growth phases were: tillering, elongation, booting, heading, flowering, milk ripe, ripe, and harvest. At each plot, 10 reflectance measurements were consistently taken, with a nadir view from a height of 1.0 m above canopy, using a 25° FOV. This resulted viewing an area of 6,939 cm2 at the canopy level. Spectroradiometer data of rice were analyzed using Data Processing System (DPS) version 6.12 (Tang, and Feng, 2002)

At the field of rice, a representative area was chosen for all measurements. The same rice sample was taken for laboratory analysis. In the laboratory, rice samples were analyzed for leaf area, wet weight, and dry weight. Rice samples were weighed on a simple weighing machine. Leave areas measurements were also made for all the rice samples, and then LAI were acquired.

Narrow band ratio vegetation indices(NBRVI) were computed using 1690 spectral channels of percentage reflectance data from the spectroradiometer. The performance of these indices in establishing rice agronomic variables were then evaluated and compared with the well-known reference Landsat TM broadband indices.

$$NBRVI=R_i/R_j$$

where i,j=1,N is reflectance(percent) of narrow bands with N=narrow bands=1690 R=reflectance of narrow bands

4. RESULTS AND DISCUSSION

4.1 Narrow band RVI relationships with rice agronomic variables

As many literatures depicted, RVI can give good prediction to LAI and WBM. Compared with NDVI, RVI is a simple, practical index. The availability of hyperspectral data in 1690 (N) discrete narrow bands allowed the computation of N×N=2856100 NBRVIs for any rice agronomic variable. Regression coefficients R^2 between all possible two-band NBRVIs and rice agronomic variables were determined. Therefore, the matrixes were obtained. The results of this comprehensive analysis are illustrated in contour plots of R^2 values for all the pairs of wavelength. We determined a contour interval of 0.05 for R^2 values. Based on the criterion, contour plots were made for all the agronomic variables of rice (Fig. 1). Since the R^2 values are not symmetrical, the whole diagonal was occupied to display the matrix. Then band centers and band widths that combine to form the best nine indices were determined for rice biophysical variables of each observation date. After the results for various rice variables were evaluated, a strong relationships were showed, which centered in red-edge portion (700nm to 750nm), the longer portion of red (650nm to 700nm), the shorter portion of green (500nm to 550nm), a particular portion of NIR (800nm to 850nm). They are followed by moisture-sensitive NIR, and two portions of SWIR (1150nm to 1200nm, 1600nm to 1650nm). For the precise R^2 values, visually scan through 1690(N) by 1690(N) matrix of R^2 values. Identify the λ1 and λ2 band centers having highest R^2 value. This is the band center for the index, which has highest correlation. Observe the R^2 values in the immediate vicinity of these band centers (λ1 and λ2) .Often the R^2 values remain the same or nearly the same for a few narrow bands in immediate vicinity of λ1 and λ2. This range of similar or near-similar spectral response to rice variable will constitute the bandwidth. Using the method, nine best he band centers (λ1 andλ2) and band widths (Δλ1and Δλ2) determined, only part of them are presented here (Table 1).

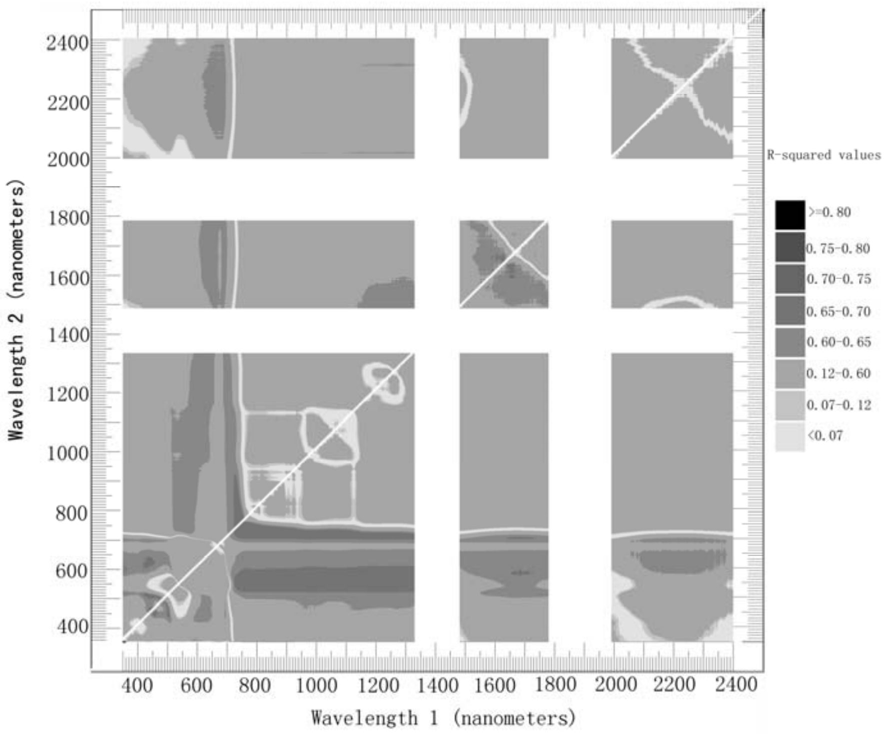

Fig. 1. Contour plot showing the correlation (R^2) between AGWBM and narrow band RVI values on 31st ,August calculated for 1690 narrow bands spread across λ1 (350 nm to 2500 nm) and λ2 (350 nm to 2500 nm).

Table 1. Nine best NBRVIs band centers (λ1 and λ2) and band widths (Δλ1 and Δλ2) in nm for the linear NBRVI models for the different rice variables

date		Band Centers(λ1 and λ2) and Band Widths((Δλ1 and Δλ2) for NBNDVI							
		LAI				LWBM			
		λ1	Δλ1	λ2	Δλ2	λ1	Δλ1	λ2	Δλ2
23th, Jul.	Index 1	726	27	990	107	730	12	984	60
	index 2	722	26	1233	191	728	8	1236	181
	index 3	716	20	1630	297	720	16	1629	294
	index 4	708	10	2189	321	712	7	2274	29
	index 5	523	14	613	54	523	7	589	34
	index 6	574	111	2003	24	889	107	731	23
	index 7	901	76	726	13	1071	63	726	19
	index 8	1074	5	723	8	755	26	727	14
	index 9	598	46	525	9	591	23	521	6
30th Jul.	Index 1	689	10	1515	67	698	5	1190	41
	index 2	617	93	1515	67	699	9	1318	18
	index 3	519	27	1529	96	567	82	1319	17
	index 4	514	18	2366	16	580	122	1630	298
	index 5	593	202	1629	298	573	23	1173	12
	index 6	517	13	1320	17	610	78	2019	6
	index 7	691	11	979	45	694	12	2313	37
	index 8	578	123	721	25	605	22	2312	34
	index 9	721	20	565	88	774	51	547	27

4.2 Frequently occurring optimum bands

To gain a broad view of the results in this paper, it is useful to consider bands that frequently appear in optimum indices. It can be said that these bands contain an overwhelming fraction of the total rice information in the full spectrum.

The results obtained using narrow band RVI models was used for determining the band centers and widths (Fig 1. Table 1). The procedure of obtaining the band centers and band widths was explained previously. The narrow bands that appear in two-band RVI type models were evaluated. The percentage of these narrow bands in every 50nm interval were established (Fig. 2)and their clusters plotted for the 350 nm to 1330 nm, 1480nm to 1780nm, and 1990nm to 2400nm. In NBRVI model type, an overwhelming proportion of crop information was in red-edge (700 nm to 750 nm), the intermediate portion of SWIR (1600 nm to 1700 nm), and a portion of green (500 nm to 550 nm). These were followed by the moisture-sensitive NIR (950 nm to 1000 nm), a particular portion of NIR (1100 nm to 1150 nm), and the longer portion of red (650 nm to 700 nm). A remarkable about 25% of all the bands that occur in RVI type model were clustered in 700 nm to 750 nm region of the spectrum (Fig. 1, Table 1).

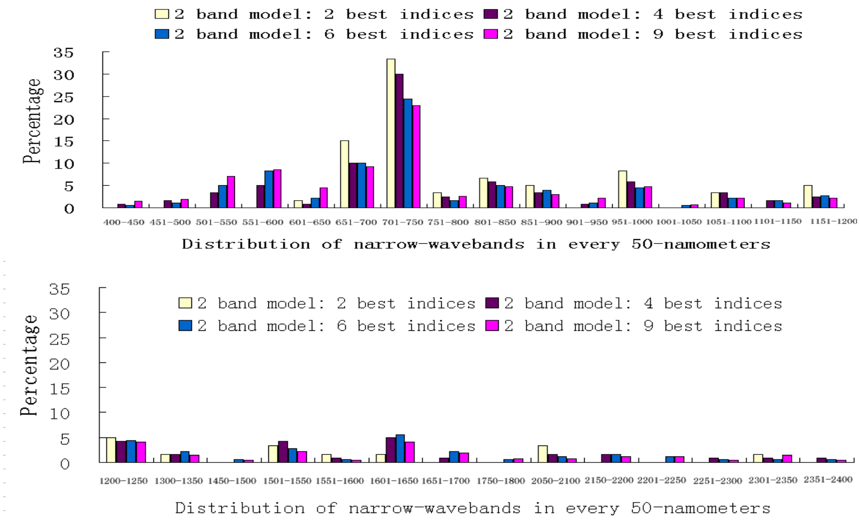

Fig. 2. Percentage of occurrences of hyperspectral narrow bands in the nine best RVI models

The band widths (Δλ1, Δλ2) were determined from the λ1 versusλ2 plots such as the ones illustrated in Fig. 1. The Δλ1 and Δλ2 of the nine best narrow bands RVI models were used to determine the frequency of occurrence of various band widths as follows:

(1) very narrow bands (1 nm to 15 nm), 49 occurrences,18.1%

(2) narrow bands (16 nm to 30 nm), 85 occurrences, 31.5%

(3) intermediate bands (31 nm to 45 nm), 25 occurrences, 9.3%

(4) broad bands (greater than 45 nm), 111 occurrences, 41.1%

It is clear from these results that nearly 50% of the bands have narrow (16 nm to 30 nm) or very narrow band (1 nm to 15 nm) widths. If we consider them as a whole, the percentage of them is 49.6% for RVI. This indicates that narrow bands are very useful to predict rice LAI and LWBM.

The red-edge portion around 720 nm which represents the maximum band of the first order derivative is the single most frequently occurring band across the variables in NBRVI type of models. This in not surprising since this wavelength has been affected by growth stage and nitrogen levels. The band widths (Δλ1 or Δλ2) for the red-edge narrow bands typically range between 5 nm to 28 nm. The best suggested band widths for any red-edge narrow band is 15 nm. The other two red narrow bands, λ4(710 nm) and λ6(730 nm), are of importance depending on type of rice, growth stage, and growing conditions, including cultural practices, wherein there is a likelihood of red-edge shifting to these bands from the most commonly occurring red-edge band (720 nm). Indeed red-edge varies significantly depending on host of these variables.

The λ2 (550 nm) is the green narrow band at the reflectance peak in the visible range. The band λ1(530 nm) is the point of greatest positive change in slope per unit change in wavelength in visible spectrum, and λ3(580 nm) is the greatest negative change in slope per unit change in wavelength in visible spectrum for most dates. Similarly, λ6 (720 nm) represents the point of greatest positive change in slope per unit change in wavelength in red-edge portion of the spectrum. The λ5 (710 nm) and λ7 (735 nm) are the possible greatest derivative values. The red absorption maximum occurs around 680 nm (λ4), which is another frequently occurring band. The NIR shoulder can be represented by a broad band or a narrow band centered at 845 nm (λ8). The λ9 =920 nm and λ11 =1080 nm represent the possible peak for maximum reflectance region of the NIR spectrum. Which band the peak reflectance will occur is dependent on a lot of conditions. The λ10 = 982 nm is the center of the moisture-sensitive "trough" portion of NIR, which is strongly related to change in rice moisture and biomass (Penuelas et al., 1993). The size of "trough" in 940 nm to 1040 nm region increases with an increase in growth stages and is strongly related to biomass. The λ12 = 1125 nm represents the sudden decrease after the second possible peak NIR reflectance. The λ13=1190 is the second center of the moisture-sensitive "trough" portion of NIR. The λ14 =1630 nm is the premaxima reflectance of intermediate SWIR. With respect to λ16 =1680 nm, it is the most particular band of high occurrence frequency in the paper. The fifteen bands were selected based on their frequency of occurrence in various models rice variables as discussed throughout this paper. The distribution of the rice information clusters in different waveband portions also shows an overwhelming proportion of quantitative rice information in the band centers of these 15 bands. Many of the optimum bands that were selected make physical sense given what we know about plant chemistry, canopy structure, and plant spectra (Elvidge,1990).

5. SUMMARY AND CONCLUSIONS

This research established the optimum number of hyperspectral bands, centers, and widths (Table 1) in the visible, near-infrared and short-wave infrared spectrum for establishing relationships with rice biophysical characteristics. This recommendation is based on the study of eight dates of observation (representing eight growth stages), and wide ranging rice characteristics. A remarkably strong relationship with rice variables is in red-edge (700 nm to 750 nm), the longer portion of red (650nm to 700nm), the shorter portion of green (500nm to 550nm), a particular portion of NIR(800nm to 850nm).They are followed by moisture-sensitive NIR, and two portions of SWIR(1150nm to 1120nm, 1600nm to 1650nm).An overwhelming proportion of these channels had band widths that were classified as: (1) very narrow (1 nm to 15 nm wide) or (2) narrow (16 nm to 30 nm wide). Most were on the order of 10 nm to 20 nm wide (narrow or very narrow). A rigorous procedure adopted here to identify the best narrow band RVI type models showed that the best two-band combinations often involve: (1) a very narrow or a narrow red-edge band and a narrow or a broad NIR band, or (2) a very narrow red-edge band and a narrow or a broad SWIR band, or (3) a broad NIR band and a narrow red band or (4) a narrow green band and a broad NIR and SWIR band.

The study recommends 15 specific narrow bands, centers, and widths, which provide optimal crop information in the whole spectra. These narrow bands include 710 nm, 720 nm, 735 nm, 680 nm, 530 nm,550 nm, 580 nm, 845 nm, 920 nm, 982 nm,1080 nm, 1125 nm , 1190 nm, 1630 nm and 1680 nm. Most of them make physical sense.

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