Jour. Agric. Physics, Vol. 1, No. 1, pp. 17-19 (2001)

Space-borne Hyperspectral Imaging of Crop Environment

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Introduction

Imaging Spectrometry of the earth, or hyperspectral imaging, from spaceborne platform has come into the existence only recently with the successful operationalisation of IRS-P3 imaging spectrometer MOS-B. This step beyond multispectral imaging is defined as the acquisition of images in a large number of registered, continuous spectral bands such that for each pixel a complete radiance spectrum can be acquired. This development has made it possible to identify the surface materials directly rather than just separate them into classes and to quantify the relative abundance of these materials within a single pixel. Applications of this sensor technology have been not only in geology and mineral exploration but also in vegetation research.

Studies on crop canopy reflectance acquired with laboratory spectrometers and aircraft mounted spectrometers demonstrate that high spectral resolution data contain more information on subtle spectral features than broad band data. For example, the spectral shift of the chlorophyll absorption edge associated with crop phenological state and nutrient stressed vegetation is not accessible with broad band sensors and was discovered through simultaneous investigation of controlled laboratory experiments and field acquired high resolution spectral measurements. A history of foliar analysis using near infrared (NIR) spectroscopy lends further support to the concept of high information content in the fine structure of reflectance spectrum. Further, studies suggest that certain classes of macro-molecules, especially proteins and complex polyphenolegrin are important components of biospheric functioning and quantifiable based on reflectance spectra in the NIR region. The observation of vegetation reflectance addresses predominantly biochemical and physical properties, such as content of water, foliar nitrogen, cellulose and lignin in leaves and their dynamic range. Relating biophysical plant canopy processes and characteristics to carbon and nitrogen turnover produces valuable information on biosphere processes and their rates. Species diversity, environmental stress, physiological features such as photosynthetic activity, plant productivity, biomass and plant transpiration are some crucial issues for imaging spectrometric observations.

The near infrared reflectance region between 680 and 780 nm, called the red edge is of crucial importance as far as the vegetation application of high spectral resolution space-borne imaging spectrometer is concerned. While there have been many investigations on red edge and its interlinkages to plant growth and stress parameters some of the significant studies are the biomodal first derivatives (Horler *et al.*, 1983; Boochs *et al.*, 1990), and simple parameters (Miller *et al.*, 1990). The studies revealed that an inverted Gaussian red edge reflectance modal (IGM) is more appropriate and better correlated with biophysical and biochemical parameters. However, IGM has not been found appropriate in case of heterogeneous crops. In a significant study, Belanger *et al.* (1995) established the relationship between chlorophyll and red edge characteristics of decidious trees. All these studies, as reported above, are based on high spectral resolution spectrometer data from ground/aerial platform. The present investigation aims at examining the space-borne imaging spectrometer data from IRS-P3 MOS-B in terms of its effectiveness to address vegetation growth and stress.

Materials and Methods

While calibrating and validating the IRS-P3 imaging spectrometer MOS-B to facilitate its agricultural applications, concurrent *in situ* field and laboratory experiments were conducted in predominantly rice based agro-ecosystems of Cuttack (Orissa) region to realise the potential of spaceborne imaging spectrometer MOS-B.

Field experiments were conducted at the test sites near Central Rice Research Institute (CRRI), Cuttack (85^{0}45'15"N & 20^{0}30'10"E) Orissa, India.

While test site 1 represents the irrigated/non-stressed field conditions (moisture status at par with field capacity), test site 2 represents upland rice with moderate stress conditions (moisture level below 15-20% of field capacity). Agro-meteorological and biophysical parameters such as Leaf Area Index (LAI), chlorophyll content, soil moisture, photo-synthetically active radiation (PAR) etc. were collected fortnightly. Agromet parameters were recorded by automatic weather stations, LAI was measured by LI-COR LAI 2000 Plant Canopy Anayser, chlorophyll by chlorophyll-meter, soil moisture by gravimetric method and PAR was measured by quantum sensor. In the field experiments data were collected on 12th June 1997 to obtain the above parameters, which was nearly concurrent to IRS-P3 satellite pass date. These measurements were used to validate the radiance and biophysical parameters obtained from IRS-P3 MOS-B.

The spectral reflectivities of rice crops in stressed and unstressed conditions were measured by non-imaging spectro-radiometer. The instrument facilitated the simultaneous measurements of the incoming global radiation and the energy reflected by the targets. The spectral resolution of 10 nm corresponding to that of IRS-P3 MOS-B was achieved by the use of a grating monochrometer.

The instrument registers the data in all the 5 channels with the central wavelengths of 615±10, 685±10, 750±10, 815±10 nm, similar to that of MOS-B channels. Reflectance/radiance measurements were derived finally from independent measurements of rice crops in different growth and environmental conditions of the ground truth-sites located in the experimental fields of CRRI. After calibration a mean spectrum was calculated and a moderate low-pass filter was applied to remove high-frequency instrument noise.

In order to calculate the first derivative spectra of rice crops in the channels similar to MOS-B the derivative as signal change between two adjacent spectral channels was used, as suggested by Boochs *et al.* (1990).

$$Dr\,(i) = r\,(i) - r\,(i-1),\ i = 1 \text{ to } 5$$

with

$$\lambda[r(1)] = 615 \text{ nm}$$

$$\lambda[r(5)] = 815 \text{ nm}$$

The first and second order derivative analysis were carried out with the reflectance measurement of unstressed and stressed rice crop by MOS-B channels 6 (615 nm) to 10 (815).

Reflectance spectra generated from *in situ* field measurements were compared with IRS-P3 MOS-B derived spectra. First and second order derivative analyses were carried out to identify the spectral shift towards blue band region. Both the spectra were quite comparable in terms of its shape, inflection point and sensitivity to soil moisture stress. In spite of the fact that IRS-P3 MOS-B is primarily designed for oceanographic applications, by virtue of its high spectral and radiometric resolution, it has been possible to detect red edge phenomena in case of rice crop grown under the different stress conditions.

Results and Discussion

As the transition from red (r=5%) to near infrared (r=25%) takes place, the shape of red edge shows a continuous slope change, the derivative spectrum has a parabolic shape with a peak making the inflection point dr max at the wavelength λp. The considerable qualitative changes in derivative spectra of rice crop are linked with moisture stress conditions in the crop environment. A visible shift of about 10 nm towards the blue region can be seen due to soil moisture deficit of about 5-10%. Thus the blue shift of the red edge, which indicates the varying moisture stress conditions in the diverse rice agro-ecosystems, has been obtained using IRS-P3 MOS-B data.

In order to substantiate the red edge phenomenon as seen by IRS-P3 MOS-B data, the field spectroradiometer data were analysed to detect these shifts. There is a shift of 10 nm towards shorter wavelength. Extreme right curve showing inflection point λp=690 nm represents the extremely stresssed rice condition with soil moisture availability of less than about 35-40% of the field capacity, while the curve in centre represents the soil moisture availability to the level of about 20% less than field capacity. It is important to note here that inflection points as seen by MOS-B are coinciding with that of the point obtained from field data. It shows : (i) the shift towards shorter wavelength is closely associated with soil moisture stress, and (ii) the invariant nature of the shift, whether seen by field data or by spaceborne imaging spectrometers. However, this conclusion is not based on extensive field data representing various types of crops in different agroecological zones. A more comprehensive study is called for to re-affirm this finding.

It is well-known that the factor determining the shape of the red edge and the wavelength position of the inflection point therein is the amount of chlorophyll. Collins (1978) described the red edge to be formed by chlorophyll absorption. It was shown that with the increase in chlorphyll and the associated establishment of polymerization products which absorb longer wavelength photons, there is a definite shift in the position of red edge towards longer wavelength. This interpretation holds good in the present case also with dr (710 nm). On examining the amplitude of dr (710 nm) with varying moisture stress, unstressed rice conditions lead to higher flank amplitudes, while stressed rice conditions are coinciding with lower amplitudes. In terms of growth parameters of the rice crops, the interpretation lies in the fact that there is a overall increase in chlorphyll content and hence, the beginning from red to near infrared reflectance is shifted towards longer wavelength. In fact increasing chlorphyll content extends the absorption peak towards the infrared part of the spectrum. Similarly, a loss of vitality expressed in reduction of chlorophyll content, either due to stress or growth, lowers the absorption in the red part of the spectrum. In that case, what has been seen is the starting point of the red to near infrared transition, is located at shorter wavelengths and the amplitude of dr attains lower values.

The spectroscopic measurements of the red edge of reflectance spectra of rice crops using space-borne IRS-P3 MOS-B data allow the detection of small qualitative difference in its chemical and morphological status. The derived specral values have shown very strong dependence on chlorophyll content and Leaf Area Index (LAI). In the present case, blue shift has been found to be associated with lower LAI. Using the red edge shape along with blue and red shifts, crop growth and stress conditions could be monitored more efficiently.

Conclusion

In spite of the fact that IRS-P3 MOS-B is primarily designed for oceanographic applications, by virtue of its high spectral and radiometric resolutions, it has been possible to detect red edge phenomena in case of rice crop grown under the different stress conditions. It has been unique to observe the spatial invariant nature of this phenomenon. As there has not been any distortion in the shape and position of inflection points, whether it is seen by field spectroscopic measurements or by space-borne IRS-P3 MOS-B data, remote sensing of spectral shifts in shorter or long wavelength regions would provide new dimensions to address the crop stress and growth parameters more precisely.

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