

Characteristics of AVIRIS Band Measurements in Desert Agroecosystems in the Area of Blythe, California: I. Studies of Cotton Spectra

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ABSTRACT

AVIRIS data from Blythe, California, were acquired in June 1997 to study agricultural spectra from different crops and to identify crops in other areas with similar environmental factors and similar spectral properties. The main objectives of this study are: 1) to compare the spectral and radiometric characteristics of AVIRIS data from agriculture crops with ground spectra measured by a FieldSpec[®] ASD spectrometer; 2) to explore the use of AVIRIS spectral images for identifying agricultural crops; 3) to study the spectral expression of environmental factors on selected crops; and 4) to build a spectral library for the crops that were studied. A long-term goal is to extend the spectral library for different vegetation or crops in different stages of growth.

To support our study, on July 18 and 19, 2000, we collected spectra using the FieldSpec[®] spectrometer from selected fields with different crops in the Blythe area of California (longitude 114° 33.28 W and latitude 33° 25.42 N to longitude 114° 44.53 W and latitude 33° 39.77 N). These crops were cotton in different stages of growth, varieties of grass pure or mixed, Sudan grass, Bermuda grass, Teff grass, and alfalfa. Some of the fields were treated with different types of irrigation (i.e., wet to dry conditions). Additional parameters were studied such as the soil water content (WC), pH, and organic matter (OM).

The results of this study showed that for crops known to be similar, there is a significant correlation between the spectra that were collected by AVIRIS in 1997 and spectra measured by the FieldSpec[®] spectrometer in 2000. This correlation allowed development of a spectral library to be used in ENVI-IDL analysis software. This library was used successfully to identify different crops. Furthermore, using IDL algorithms of Spectral Angle Mapper classification (SAM), spectral feature fitting (SFF) and spectral binary encoding (SPE) showed that there is excellent agreement between the predicted and the actual crop type (i.e., the correlation is between 85–90% match). Further use of the AVIRIS images can be of a value to crop identification or crop yield for commercial use.

INTRODUCTION

The goal of this research project was to explore the use of spectral measurement for agricultural crops, using AVIRIS data that were collected from the Blythe, California area, in June 1997. Another goal was to evaluate the temporal and spatial behavior of the spectral signatures for different crop types. In addition, for this research, ground spectral measurements were made using a handheld spectrometer to compare with the remotely sensed data of AVIRIS. This study explores several additional factors affecting crops. These include a water stress experiment, with several water treatments over a range of crop-development stages. An additional aspect of the study was to develop a spectral library for the different crops studies, to be used in the IDL_ENVI program. These measurements and analyses may be used in future studies of the spectra characteristics of the crops.

MATERIALS AND METHODS

Studied sites

The study sites were located in the area of Blythe, on the eastern border of California, at 114° 33.28 to 114° 44.53 W and at 33° 25.42 N to 33° 39.74 N (the details of location of selected crops are presented in Table 1 [all tables are at the end of this paper] and Plate 1). The Blythe agricultural area is characterized by high temperatures that often exceed 46 C during the summer season. The fields are irrigated regularly at specific intervals (i.e., every one to two weeks). The field sites were selected with the help of the farm advisor of the Riverside County Extension Research Facility. The field plots that were selected have been planted with Bermuda grass, Sudan grass, Alfalfa, Kenaf grass, Teff grass, and cotton. Bare soil data also were taken for the comparison between vegetated fields. The studied fields include a range of water irrigation treatments, and varieties of crops at different stages of maturity. Spectral data are planned to be analyzed for every crop and every treatment. The work presented in this paper is concentrated on the cotton crop.

Characteristics of the Cotton crop

Cotton (*Gossypium hirsutum*) is a perennial, tropical plant that has been bred and adapted for annual crop production in temperate climates. Cotton develops on a somewhat predictable schedule, although water and temperature stress have effects on the rate of growth. The cotton plantation depends on adequate soil moisture and warm soil temperature. In addition, cotton requires considerable care in the field with treatments of fertilizer and insecticides.

Spectral Field Measurements

Spectral data were collected with an ASD FieldSpec[®] hand-held spectrometer unit that measures the wavelength range from 350 nm to 2500 nm. The reported spectral sampling is 1 nm. For analysis, the data were resampled to 5 nm. For crop and soil target measurements, the instrument operator walked the length of the plot and pointed the spectrometer probe at the area to be measured. For the reflectance standard measurements, the probe was positioned approximately 10–15 cm above the surface and pointed straight down. The position of the operator and probe relative to the spectralon was chosen to minimize shadowing and reflection from the operator.

AVIRIS Data Collections

AVIRIS data were measured over Blythe, California, on June 26, 1997. The data were acquired at the altitude of 20 km during the dry season. The data were collected in 224 channels (10 nm in width) in the range of 369–2500 nm spectral interval (Green et al., 1998). AVIRIS uses a scanning mirror to sweep back and forth in a whiskbroom fashion, producing 614 pixels for each scan. Each pixel produced by the instrument covers approximately 20 x 20 m² on the ground (with some overlap between pixels). The ground swath width is approximately 10 km for an ER-2 flight altitude of 20 km (Vane, 1987 and Vane et al., 1984). The effects of atmospheric absorption and scattering on the calibrated radiance data were compensated for by using a MODTRAN-based method (Green et al., 1993).

Methodology

Exploration of Reflectance Factors and Vegetation Indices

There are many commonly used vegetation indices (VI): perpendicular (PVI) (Richardson and Wiegand, 1977), normalized difference (NDVI) (Rouse et al., 1974), NIR/RED ratio (RVI) (Tucker, 1979; Pearson and Miller, 1972), and soil adjustment (SAVI), which includes a soil-adjustment factor (L) to account for first-order soil background variations (Huete, 1988), transformed soil adjusted (TSAVI) (Baret et al., 1989), ATSAVI (Baret and Guyot, 1991), and water band (WBI). They were calculated as follows:

$$\begin{aligned} \text{NDVI} &= (\text{R750}-\text{R600})/(\text{R750} + \text{R600}) & (1) \\ \text{WBI} &= (\text{R900}/\text{R970}) & (2) \\ \text{PVI} &= (\text{NIR}-\text{RED}) & (3) \\ \text{RVI} &= (\text{NIR}/\text{RED}) & (4) \\ \text{SAVI} &= ((\text{NIR}-\text{RED})/(\text{NIR} + \text{RED} + \text{L}))\text{X} (1-\text{L}) & (5) \\ \text{TSAVI} &= a[\text{NIR}-a(\text{RED})-b]/[\text{RED} + a(\text{NIR})-ab] & (6) \\ \text{ATSAVI} &= a[\text{NIR}-a(\text{RED})-b]/[a(\text{NIR}) + \text{RED} - a*b + \text{X}(1 + a^2)] & (7) \\ \text{NIR} &= a (\text{RED}) + b & (8) \end{aligned}$$

where Rxxx represents reflectance at the indicated wavelength (xxx in nm). Data were analyzed using statistical analysis software (SAS) package.

RESULTS AND DISCUSSION

Table 1 represents the collected spectra data from different crops and different treatments, in the area of Blythe, California, on July 18 and 19, 2000. The table also shows the latitude and longitude of the field sites and also the time of spectral collection. The collection of data comes from healthy cotton, wilted cotton, and cotton at the bloom stage without open bolls. These spectra provide a basis for building a library to explore the cotton vegetation from the AVIRIS images (Plates 1-4). Table 2 shows the soil parameters that were collected. This table shows stressed conditions of the soil moisture as 0.96-1.4 % and unstressed conditions of the soil moisture as 8.0 %. The pH was 8.35; organic matter (OM%) was 1.9–2.5%. The plants were in a mature stage, dry, and some of the bolls and leaves were green. The time of collected data and the reflectance and wavelength of the cotton in different maturity stages are presented in Tables 3 and 4. The reflectance and wavelength were organized according to different spectral regions. The selected ranges of wavelengths are 350–650, 650–950, 950–1250, 1250–1550, 1550–1850, 1850–2150, and 2150–2500 nm.

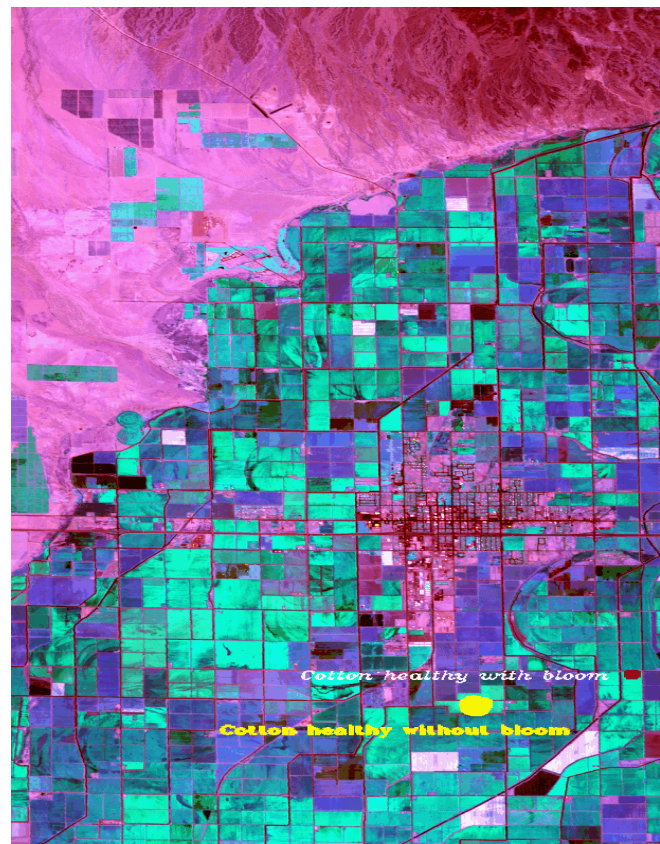


Plate 1. AVIRIS Image

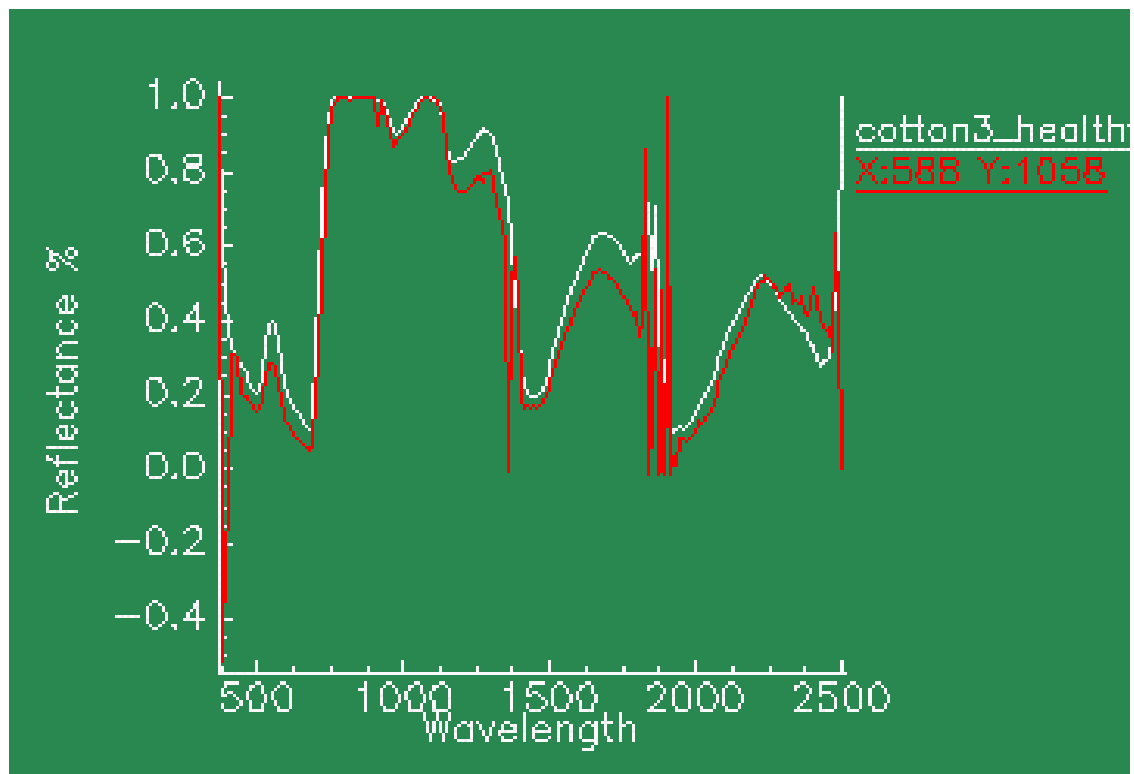


Plate 2. Spectral data from AVIRIS compared with cotton healthy bloom (a)

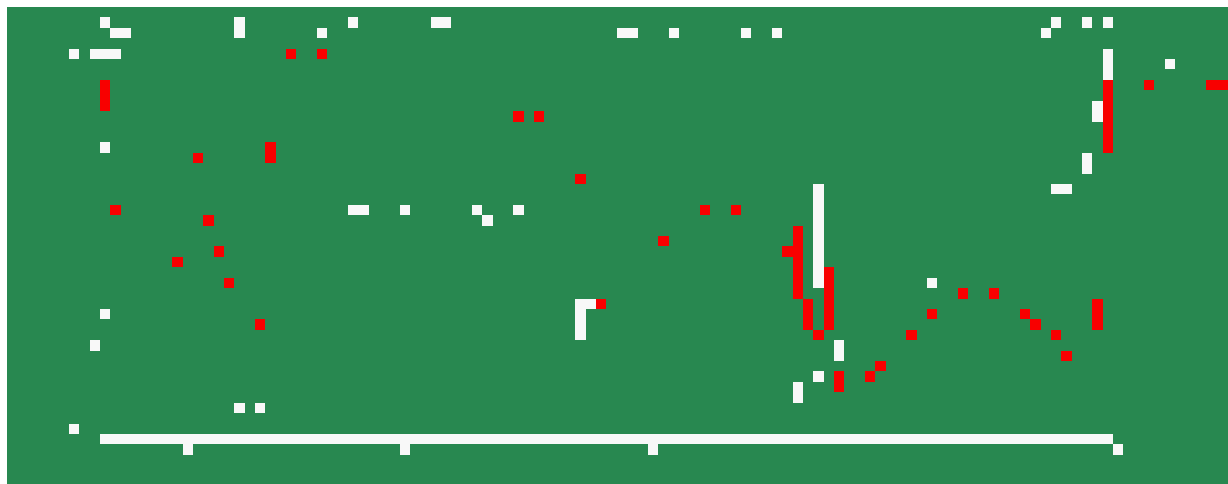


Plate 3. Spectral data from AVIRIS compared with cotton healthy bloom (b)

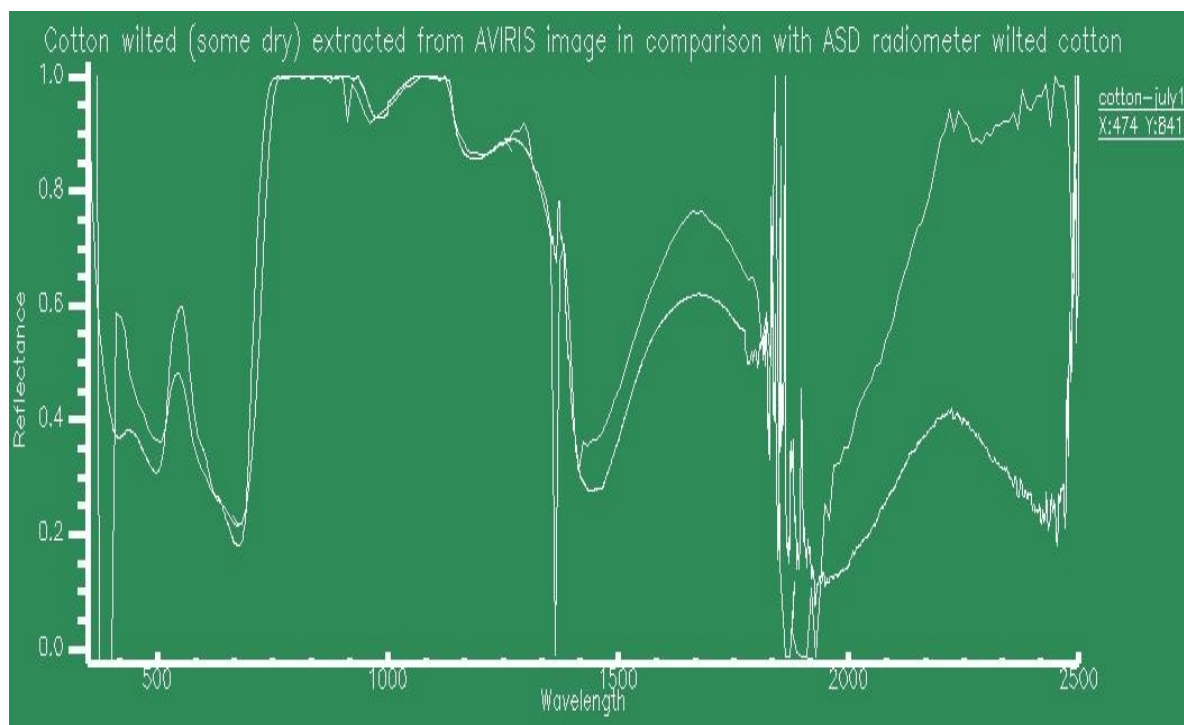


Plate 4. Cotton wilted (Some Dry) extracted from AVIRIS Image in Comparison with Data from ASD radiometer wilted cotton

Characteristics of Cotton Spectra

The wavelength range reflectance values of healthy cotton were analyzed (Table 3). The vegetation indices were analyzed as well. The normalized difference vegetation index (NDVI) and water band index (WBI) (Fig.1) showed a positive correlation ($r^2 = 0.86$ $P < 0.01$). The indices NIR, NDVI, RVI, PVI also were calculated using the relationship between the reflectance of NIR and RED spectra in the acquired reflectance from the healthy cotton and relatively stressed cotton using the spectrometer data. The factors (a) and (b) were calculated using a regression procedure (Table 4). These factors represent the slope and intercept, respectively, of the soil line. From these results L is calculated, which is used for the vegetation indices TSAVI, PVI, NDVI, and RVI.

Analysis of AVIRIS Image

Significant correlation was found between the AVIRIS 1997 data and spectral data collected by the FieldSpec[®] spectrometer. This allowed development of a spectral library to be used in ENVI-IDL analysis software. This allowed identification of different crops using primarily the visible part of the spectra. The AVIRIS data are in agreement with FieldSpec[®] spectrometer data (Figures 2–4). Regression analysis gave positive correlation coefficients ($r^2 = 0.80$ - 0.87). Crop identification was explored using Spectral Angle Mapper classification (SAM), spectral feature fitting (SFF) and spectral binary encoding (SPE). Excellent agreement as found between the predicted and the actual crop type (i.e., the correlation is between 85–90% match). Additional analysis of the healthy cotton showed six local maxima.

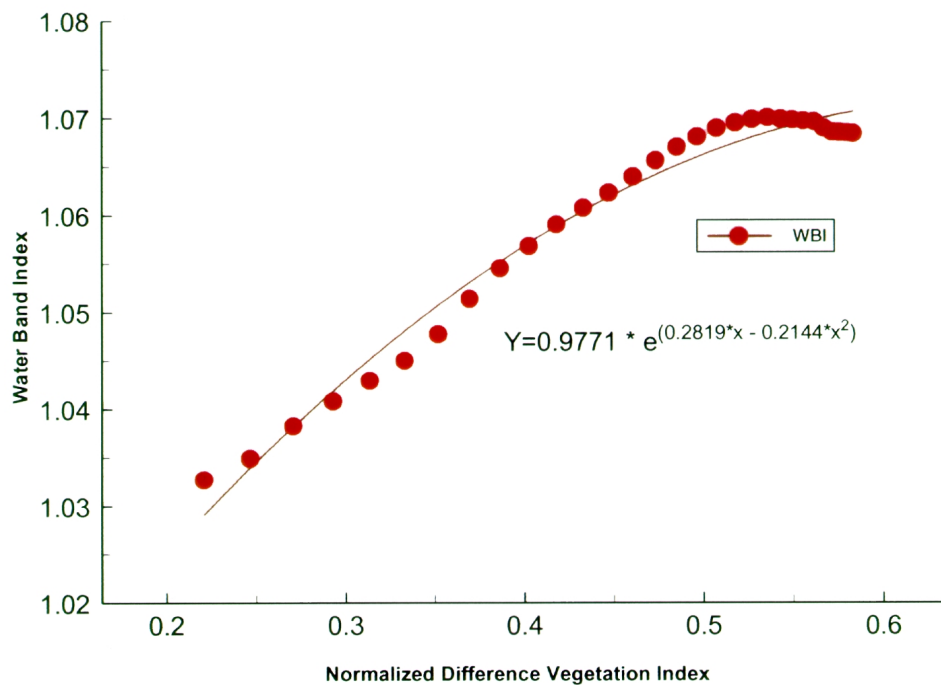


Fig. 1. Relationship between NDVI and WBI in healthy cotton in the area of Blythe, California, at longitude 114° 44.53 W and latitude 33° 25.42 N full-bloom cotton and no bolls open

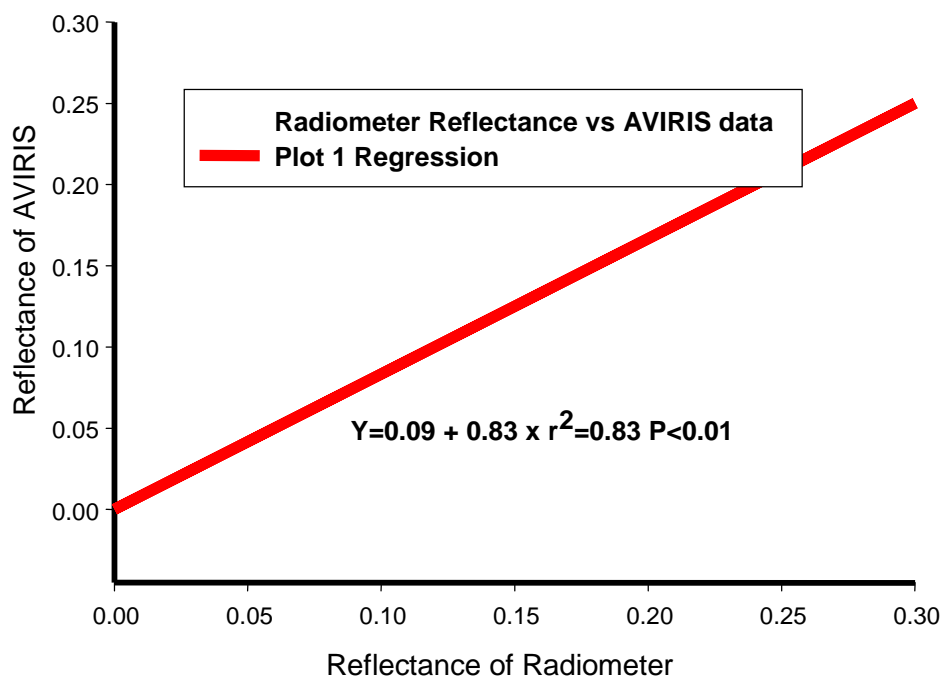


Fig. 2. Relationship between reflectance extracted from AVIRIS images for healthy cotton and reflectanced data obtained from the ASD Radiometer

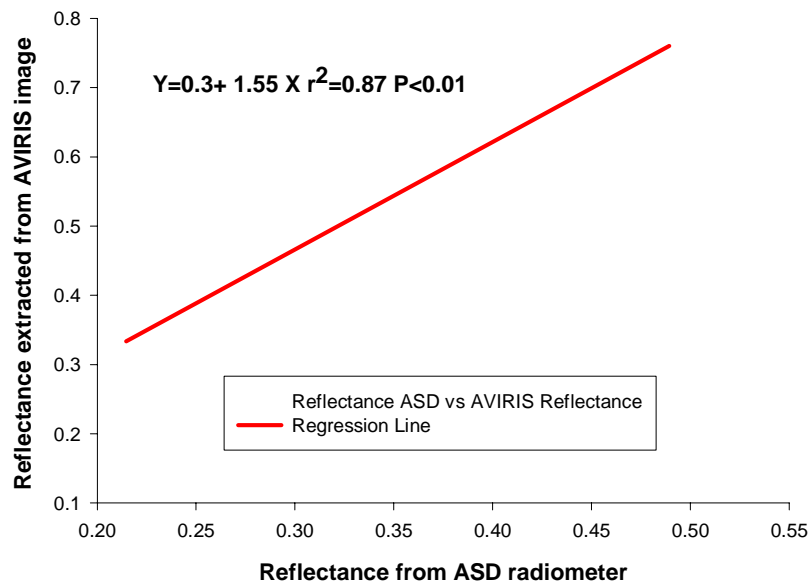


Fig. 3. Relationship between reflectance extracted from the AVIRIS image for healthy cotton with bloom and reflectanced data obtained from the ASD Radiometer

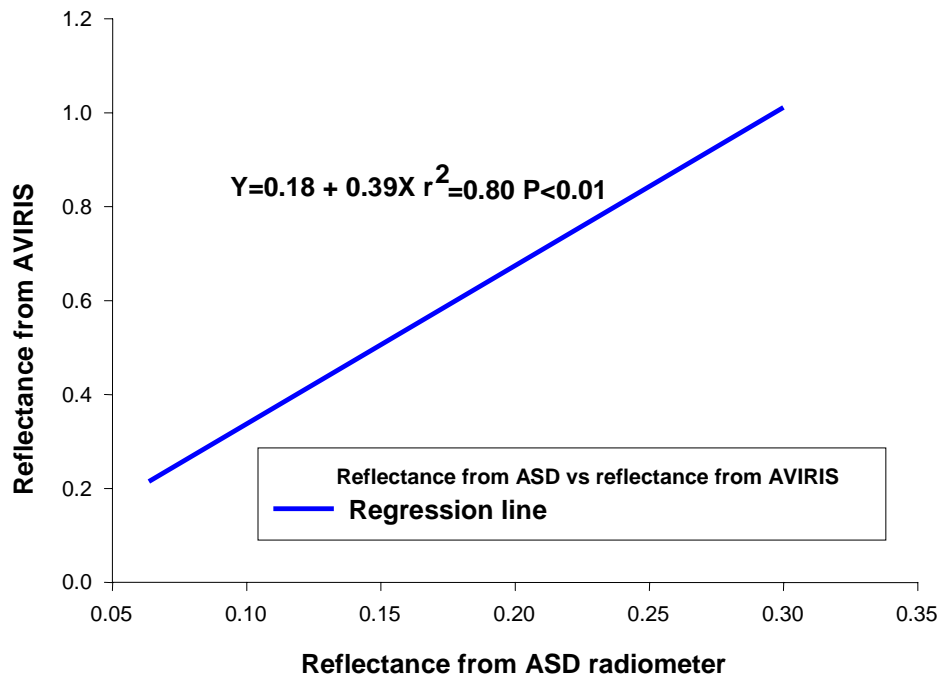


Fig. 4. Relationship between reflectance extracted from the AVIRIS image for wilted cotton and reflectanced data obtained from the ASD radiometer

These peaks are in the wavelength regions of 486.58, 780.57, 880.31, 1043.6, 1851.6, and 2500 nm. In these regions healthy cotton has lower reflectance in the visible and higher peak reflectance in the RED and NIR.

The spectral peaks of healthy cotton from the AVIRIS image and from the ASD FieldSpec[®] (Figs. 5 and 6) are consistent with analyses that have shown high information content for vegetation spectra (Collins, 1978). The spectral reflectance of vegetation in this wavelength region is characterized by low reflectance in the red part of the spectrum and high reflectance at 780-880 nm wavelengths. This is generally referred to as the “red edge.” Several studies have shown that measures based on the red edge position or shape are well correlated with biophysical parameters at the canopy level, but less sensitive to noise effects caused by the soil background and the atmosphere effects (Baret et al., 1992; Demetriades et al., 1990; Guyot et al., 1989; and Mauser and Bach, 1995).

Healthy cotton in the ground has a dense vegetation canopy completely covering the soil. In the spectral region beyond 1000 nm, water has a dominant effect, but has little effect on the spectral properties in the visible (VIS) and NIR regions short of this wavelength. However, variations of leaf dry matter content in relatively stressed cotton vegetation (Figs.7 and 8) may affect canopy reflectance. It is assumed that for studies in remote sensing, this affect is negligible, because the within-crop variation of leaf dry matter content is stable. In summary, the data that were collected from the fields using the ASD FieldSpec[®] showed general agreement with the data acquired from the AVIRIS Images.

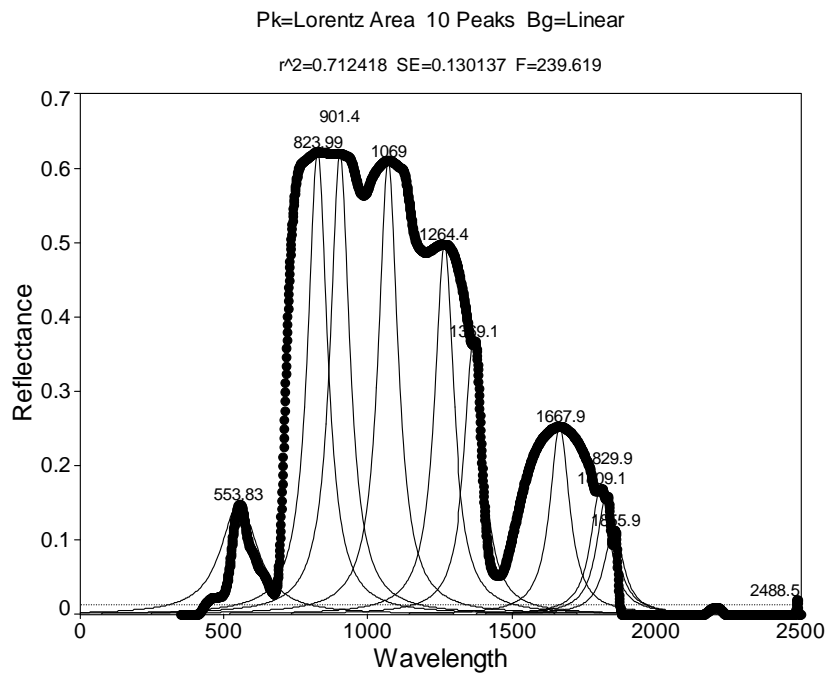


Fig. 5. Healthy cotton peaks that were collected by the ASD FieldSpec[®].

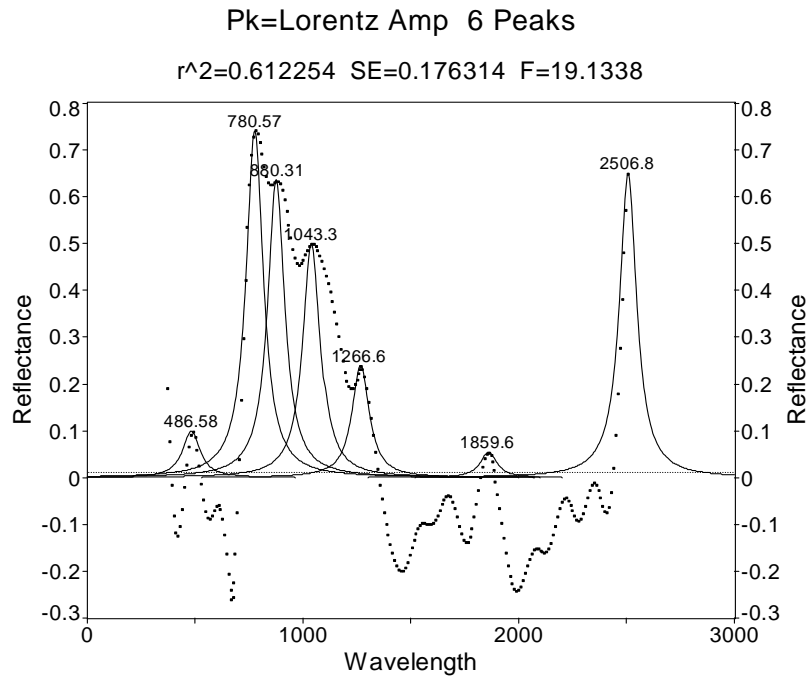


Fig. 6. AVIRIS image: healthy cotton peaks of reflectance against wavelength in the Blythe area.

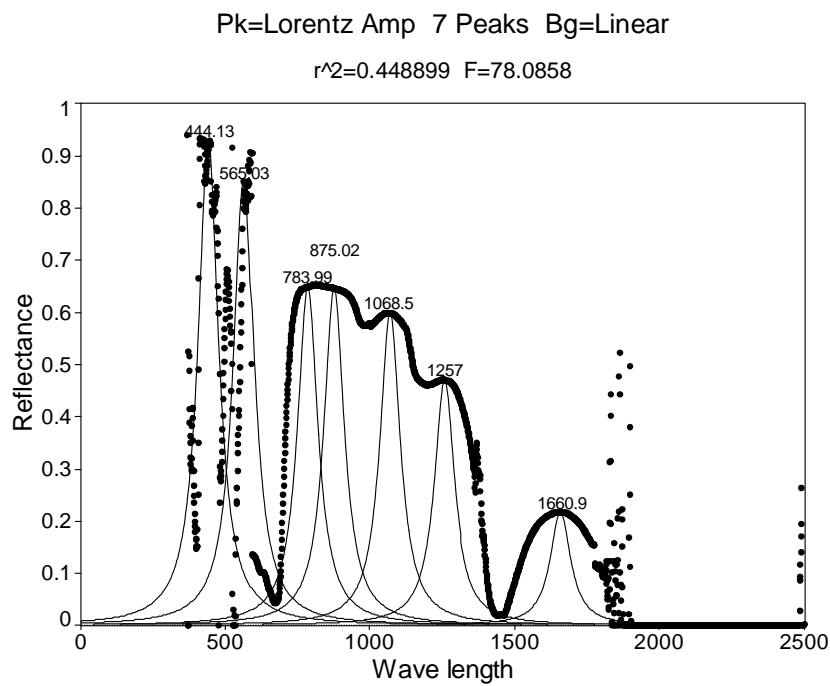


Fig. 7. Data extracted from AVIRIS image on relatively stressed cotton.

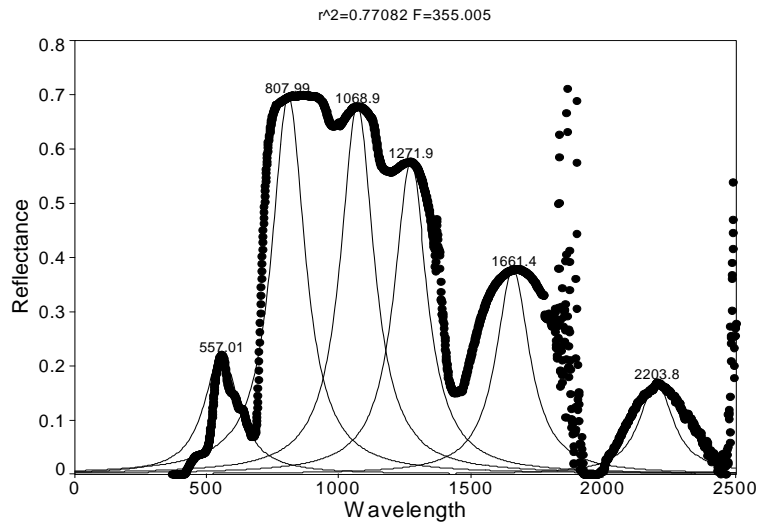


Fig. 8. Data collected from the ASD FieldSpec[®] radiometer on relatively stressed cotton.

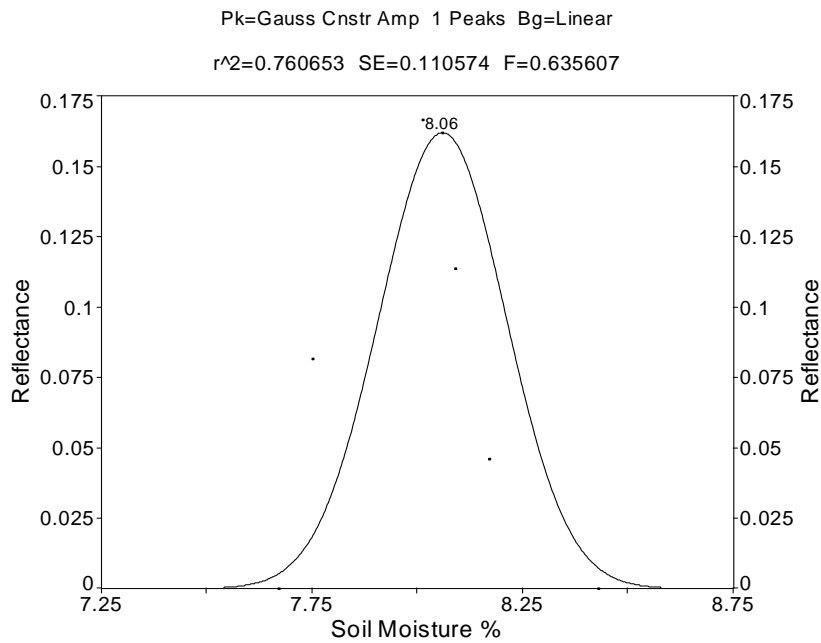


Fig. 9. Peak relationship between soil moisture and reflectance in healthy cotton.

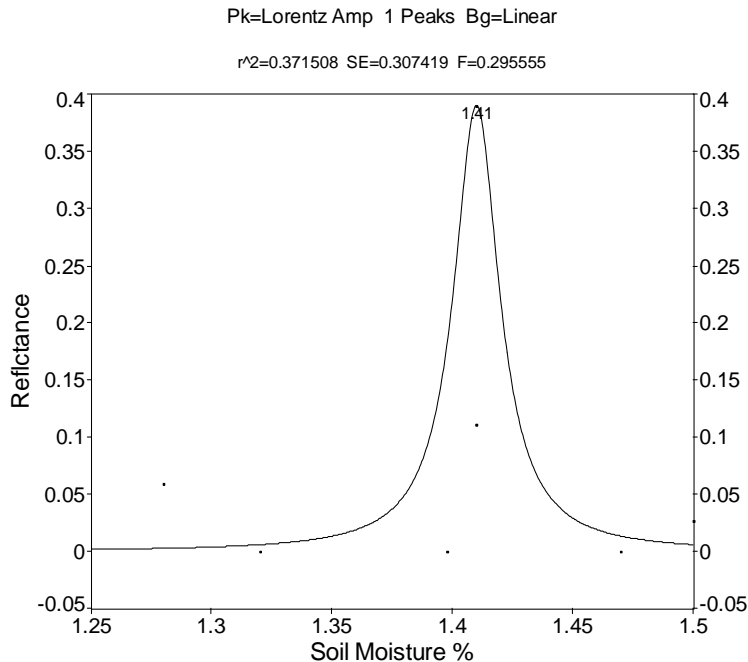


Fig. 10. Peak relationship between soil moisture and reflectance in stressed cotton.

Soil moisture can affect the reflectance signals in stressed and healthy cotton in the form of peaks (Figures 9 and 10). The graphs indicate that in the stressed cotton, the reflectance is higher (i.e., reflectance is 40%) when soil moisture reaches 1.4–1.42% than in the healthy cotton (i.e., reflectance is 17%) when the soil moisture reaches the 8% level. The higher reflectance data in stressed crops are in the area of wavelength 500–700 nm and the lower reflectance data in unstressed crop are in the 500–700 nm range. This indicates that water stress will be revealed in the region of 500–700 nm.

CONCLUSIONS

Reflectance spectra from an AVIRIS image acquired in 1997 and ground spectral data collected in the year 2000 by the FieldSpec[®] spectrometer have been examined and analyzed. Simple direct comparison of reflectance spectra for like crops in similar growth stages showed good correlation. These results support the use of these types of reflectance data for agricultural crop investigations and development of advanced applications.

In addition, these data were used to reproduce various vegetation indices. The response of these vegetation indices were examined for healthy and stressed cotton plants. Differences in the indices response were identified. The visible and near-infrared portion of the spectrum between 400 and 1000 nm was found to contain significant variation associated with vegetation type and condition. The effect of vegetation water appeared to dominate the spectrum beyond 1000 nm.

Overall, the measured spectral reflectance signatures showed variation associated with different crops at different stages of development. This supports the continued research into use of reflectance spectra in the AVIRIS spectral range for agricultural applications. Future efforts will be directed to extend this research to other crop types and agricultural regimes.

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REFERENCES

- Baret, F., Jacquemoud, S., Guyot, G. and Leprieux, C., 1992. Modelled analysis of the biophysical nature of spectral shifts and comparison with information content of broad bands. *Remote Sensing of the Environment* 41, pp. 133–142.
- Baret, F. and Guyot, G., 1991. Potentials and limits of vegetation indices for LAI and APAR assessment. *Remote Sensing of the Environment* 35, pp. 161-173.
- Baret, F., Guyot, G. and Major, D. J., 1989. TASVI: A vegetation index which minimizes soil brightness effects on LAI and APAR estimations. In: *Quantitative Remote Sensing for the Nineties*, Proc. IGARSS '89, Vancouver, Canada, Vol. 3 pp. 1355-1358.
- Collins, W., 1978. Remote sensing of crop type and maturity. *Photogrammetric Engineering and Remote Sensing* 26, pp. 43-55.
- Demetriades-Shah, T.H., Steven, M.D. and Clark, J.A., 1990. High resolution derivative spectra in remote sensing. *Remote Sensing of the Environment* 33, pp. 55-64.
- ENVI-IDL (1999). The Environment for Visualization Images. ENVI User Guide ENVI 3.2 version. Research System 864 pp.
- Guyot, G., Baret, F. and Jacquemoud, S., 1989. Imaging spectroscopy for vegetation studies. In: Toselli, F. and Bodechtel, J., Editors, 1989. *Imaging Spectroscopy: Fundamentals and Prospective Applications*, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 145-165.
- Green, R.O., Eastwood, M.L., Sature, C.M., Chrien, T.G., Aronsson, M., Chippendale, B.J., Faust, J.A., Pavri, B.E., Chovit, C.J., Solis, M., Olah, M.R. and William, O., 1998. Imaging spectroscopy and airborne visible/infrared imaging spectrometer (AVIRIS). *Remote Sens. Environ.* 65:227-248.
- Green, R. O., Conel, J.D., and Roberts, D. A., 1993. Estimation of aerosol optic depth pressure elevation, water vapor, and calculation of apparent surface reflectance from radiance measured by the airborne visible/infrared imaging spectrometer (AVIRIS) using a radiative transfer code. In proceedings of the International Society of Optical Engineering, SPIE 1937, Orlando, Florida, pp. 2-11.
- Huete, A.R., 1988. A Soil-Adjusted Vegetation Index (SAVI). *Remote Sensing of the Environment* 25, pp. 295–309.
- Mauser, W. and Bach, H., 1995. Imaging spectroscopy in hydrology and agriculture -- determination of model parameters. In: Hill, J. and Megier, J., Editors, 1995. *Imaging spectrometry -- A Tool for Environmental Observations*, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 261-283.
- Pearson, L. and Miller, L.D., 1972. In: Remote mapping of standing crop biomass for estimation of the productivity of the short-grass Prairie, Pawnee National Grasslands, Colorado, ERIM, Ann Arbor, Michigan, pp. 1357–1381.

- Richardson, A. J. and Wiegand, C.L., 1977. Distinguishing vegetation from soil background information. *Photogramm. Eng. Remote Sens.* 43:1541-1552.
- Rouse, W., Haas, R. H., Schell, J. A., Deering, D. W., & Harlan, J. C., 1974. Monitoring the vernal advancement of retrogradation of natural vegetation. NASA/GSFC, Type III, Final Report, Greenbelt, Maryland, USA, pp. 1-371.
- Tucker, C. J., 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sens. Environ.* 8:127-150.
- Vane, G., 1987. *Airborne Visible Infrared Imaging Spectrometer (AVIRIS)*. JPL Publication 87-38, Jet Propulsion Laboratory, Pasadena, California.
- Vane, G., Chrisp, M., Enmark, H., Macenka, S. and Solomon, J., 1984. Airborne Visible Infrared Imaging Spectrometer. An advance tool for Earth remote sensing. *Proc. IEEE Int'l Geosc. & Rem. Sens. Symp. SP215*, 751-757.

Table 1. Data collected from the Blythe area in California on July 18 and 19, 2000

Field	Latitude	Longitude	Time	Treatment
Bare soil	33° 39.69 N	114° 34.30 W	1:00 pm July 19,2000	Soil is empty of any vegetation
Relatively stressed cotton	33° 25.76 N	114° 44.42 W	11:00 am July 18,2000	Healthy cotton but stressed
Healthy cotton	33° 25.42 N	114° 44.53 W	12:13 pm, July 18, 2000	Full bloom, no balls of cotton yet open

Table 2. Soil moisture content: %, pH, soil organic matter, and yield of plants (kg/ha) from Blythe, California

Field	Soil Moisture%	PH	Soil organic matter%	C%	N%	C/N Ratio
Relatively stressed cotton	1.398	8.35	2.560	1.520	0.0300	50.66:1
Healthy cotton	8.013	8.35	1.990	1.158	0.0340	34.05:1

Table 3. Wavelength and reflectance data in the different fields and treatments using a hand-held radiometer from Blythe, California

Field	350.0–650nm	650–950 nm	950–1250 nm	1250–1550 nm	1550–1850 nm	1850–2150 nm	2150–2500 nm
Relatively stressed cotton, wilted cotton	0.1641	0.6502	0.7124	0.4371	0.4340	0.1810	0.2145
Healthy cotton	0.1339	0.6112	0.6889	0.4129	0.4004	0.1557	0.1875

Table 4. Soil line and vegetation index equations by site and radiometer

Field	Latitude	Longitude	Time	Treatment	Soil line and vegetation index equations
Bare soil	33° 39.69 N	114° 34.30 W	1:00 pm, July 19,2000	Soil is empty from any vegetation	Cotton healthy but relatively stressed
Cotton healthy but relatively stressed	33° 25.76 N	114° 44.42 W	11:00 am, July 18,2000	Healthy cotton but relatively stressed	$NIR=0.8171 - 0.2252 RED$ $r^2=0.84$
Cotton healthy but relatively stressed	33° 25.76 N	114° 44.42 W	11:00 am, July 18,2000	Healthy cotton but relatively stressed	$PVI=0.1666-0.6046 RED +0.74 NIR$
Cotton healthy but relatively stressed	33° 25.76 N	114° 44.42 W	11:00 am, July 18,2000	Healthy cotton but relatively stressed	$TSVI=0.8171[NIR-0.8171*RED-(-.2252)]/[0.8171*NIR+RED-(-0.1840)]$
Cotton healthy	33° 25.42 N	114° 44.53 W	12:13 pm, July 18, 2000	Full bloom, no bolls of cotton yet open	$NIR=Y=0.7865 -0.3176*RED$ $r^2=0.86$
Cotton healthy	33° 25.42 N	114° 44.53 W	12:13 pm, July 18, 2000	Full bloom, no bolls of cotton yet open	$PVI=0.2500 - 0..6193 RED +0.7874NIR$
Cotton healthy	33° 25.42 N	114° 44.53 W	12:13 pm, July 18, 2000	Full bloom, no bolls of cotton yet open	$TSVI=0.7865[NIR-0.7865*RED-(-.3176)]/[0.7865*NIR+RED-(-0.2498)]$