ASSESSMENT OF AVIRIS DATA FROM VEGETATED SITES IN THE OWENS VALLEY, CALIFORNIA

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ABSTRACT

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data were acquired for the Bishop, CA area, located at the northern end of the Owens Valley, on July 30, 1987. Radiometrically-corrected AVIRIS data were flat-field corrected, and spectral curves produced and analyzed for pixels taken from both native and cultivated vegetation sites, using the JPL SPAM software program and PC-based spreadsheet programs. Analyses focussed on the chlorophyll well and red edge portions of the spectral curves. Results include the following: AVIRIS spectral data are acquired at sufficient spectral resolution to allow detection of "blue shifts" of both the chlorophyll well and red edge in moisture-stressed vegetation when compared with non-stressed vegetation; a normalization of selected parameters (chlorophyll well and near infrared shoulder) may be used to emphasize the shift in red edge position; and the presence of the red edge in AVIRIS spectral curves may be useful in detecting small amounts (20-30% cover) of semi-arid and arid vegetation ground cover. A discussion of possible causes of AVIRIS red edge shifts in response to stress is presented.

INTRODUCTION

The detection of various types of stress in vegetation using <u>in situ</u> high-spectral resolution reflectance data has focussed on the red edge portion of the vegetation reflectance curve (Chang and Collins, 1983; Collins et al., 1983; Horler et al., 1980; Rock et al., 1986, 1988; Westman and Price, 1988). The shift of the red edge to shorter wavelengths (ie. toward the blue end of the visible spectrum) has been termed the "blue shift," and has been shown to occur in plants exposed to a variety of stress agents, including trace metals, airborne pollutants, and drying. A similar blue shift of the maximum absorption by chlorophyll pigments in the visible red, termed the chlorophyll well, has also been observed in vegetation exposed to these stress agents. These blue shifts are very subtle and range from 2-15 nm.

Datasets from airborne high-spectral resolution sensor systems have used blue shifts of red edge parameters (both red edge and chlorophyll wells) to detect and map areas of stressed vegetation (Collins et al., 1983; Milton et al., 1983; Rock et al., 1988). The airborne sensor systems used provided a large number of spectral bands, with spectral resolution on the order of a few nanometers. Rock et al. (1988) used an airborne system known as the Fluorescence Line Imager (FLI), providing 288 spectral channels covering the spectral region from 0.4-0.8 um, each 2.3 nm wide, to detect and map areas of forest decline damage in Vermont (USA) thought to be due to air pollution. The present study was conducted in part, to determine if AVIRIS datasets acquired in 210 spectral channels (for radiometrically-corrected data) in the spectral region from 0.4-2.4 um, each 9.8 nm wide, would provide adequate spectral resolution to resolve red edge parameter blue shifts.

Although an attempt was made to acquire AVIRIS data for the forest decline damage sites in the northeastern United States, a lack of cloud-free weather conditions in the New England area during July, 1987 prevented such data acquisition. An AVIRIS overflight on July 30, 1987 did acquire excellent data for the northern end of the Owens Valley, CA, an area characterized as semi-arid, exhibiting extensive vegetation cover dominated by members of the Great Basin sagebrush community and saltbush community. Along river courses a number of tree species form dense canopies, and heavily irrigated areas support either agricultural crops such as alfalfa, or grass-dominated areas such as pastures, lawns, and a golf course. Based on a field visit, vegetated areas were selected from the flightline which represented three basic vegetation types: lush, green vegetation; dry, semi-arid vegetation; and cut, dried, vegetation which had been green prior to cutting. Preliminary analyses of AVIRIS data acquired for these vegetation types are presented.

MATERIALS AND METHODS

AVIRIS data used in this study are from flight line #10, Run #009, Segment 03, and were acquired on July 30th, 1987 at approximately 11:36 AM Pacific Standard Time. The flight line was selected for study because of the diversity of vegetation types occurring near the town of Bishop, CA (37°22'N X 118°20'W) and the surrounding area. In addition, these data were selected because of their high quality. The AVIRIS data presented here are radiometrically corrected and have been flat-field corrected.

The radiometrically-corrected data were obtained from the Jet Propulsion Laboratory in Pasadena, CA. The radiometric correction was accomplished by subtracting the dark current values from the raw data, equalizing the response of the 224 individual detectors and resampling the wavelenghts to a uniform 9.8 nm sampling interval. The radiometrically-corrected data contain 210 spectral bands with band centers ranging from 0.4000 um (band 1) to 2.4482 um (band 210). The response of each detector is such that the same amount of reflected radiance in each of the bands would yield the same DN (digital number) value.

A flat-field correction was applied to the data to remove the effect of solar irradiance. A grus pit (consisting of the weathered products of granitic rocks) was used as the flat field. For each spectral band, pixel values from all vegetated sites were divided by pixel values from the grus pit. Because the grus pit contains no vegetation, all the spectral data from the vegetation at the other sites was preserved while the component of solar irradiance was eliminated. A secondary effect of flat-field correction is the removal of atmospheric absorption features common to both the grus pit and vegetation datasets. The resulting spectral curves, produced by plotting brightness values of the 210 bands for each pixel or group of pixels were comparable to laboratory- or field-acquired spectra of vegetation. The resulting brightness values have not been converted to reflectance as yet, but this would be possible since ground reflectance data have been acquired for the grus pit calibration targets included within the AVIRIS flightline. The curves presented here were plotted on a Macintosh Plus using Cricket Graph software*. All plots are averages of several pixels from the areas cited.

It is difficult to compare red edge and chlorophyll well parameters from spectral curve plots because of variations in the height of the NIR (near infrared) plateau and the depth of the chlorophyll well characteristic of different vegetation types. If the data are normalized, differences in the position of the red edge and the extent of the blue shift can be more easily studied. Therefore, the data were normalized as follows. For each spectral curve, the value corresponding to the lowest spectral band in the chlorophyll well was subtracted from every spectral band in the curve. For all vegetated sites along the flight line, the lowest value occurred at either spectral band 29 (band center = 0.6744 um) or 30 (band center = 0.6842 um). The second step in the normalization involved scaling the curve so that channel 38 (band center = 0.7626 um) on the NIR plateau had a value of two. With these two points on each curve pinioned, the resulting curves clearly show relative red edge positions.

The native vegetation occurring in the Bishop, CA area include the following dominant types. In July, lush, green trees and large shrubs occur along stream banks and areas of damp soil, while semi-arid, non-green or partially green sagebrush/saltbush shrubs occupy drier sites. Common tree species are cottonwoods (*Populus*) and willows (*Salix*) and these occur in dense stands where there is enough soil moisture to support their growth. At drier sites, only low desert shrubs are found, consisting of either sagebrush (*Artemisia tridentata*) or rabbit brush (*Chrysothamnus nauseosus*). The rabbit brush characterizes disturbed areas (pasture lands) while the sagebrush is more typical of open range lands that are largely undisturbed. In drier sites characterized by soils high in salt levels, a small desert shrub known as saltbush (*Atriplex* spp.) is common. During the summer months, sagebrush retains its leaves, while rabbit brush and saltbush may lose their leaves.

Along portions of the AVIRIS flightline three major types of

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* Reference to specific products is made for clarity, and does not constitute an endorsement of these products.

cultivated vegetation occurs: large areas of alfalfa (Medicago sativa) grown in rotation (some fields with green, actively growing plants, and other fields with cut, drying plants); a large golf course of green, well-watered grasses and trees (cottonwoods); and irrigated pastures of green grass. The alfalfa fields were of great interest in this study because they provided large, homogeneous areas of either green or dried plants of the same species. Because of their rectangular shape, they could be easily identified in the AVIRIS data. The harvesting of alfalfa results in rows of cut plants alternating with partly green stubble and exposed soil.

RESULTS AND DISCUSSION

Radiometrically-corrected AVIRIS data are strongly influenced by both variation in solar illumination and by atmospheric absorption features. Figure 1 presents such AVIRIS spectral data acquired from the golf course. Note the decreasing brightness with increasing band numbers (wavelength) due to the drop in solar illumination intensity, as well as absorption by atmospheric water, centered at bands 57 (0.9488 um), 76 (1.1350 um), and 102 (1.3898 um). The absorption feature located at band 38 (0.7626 um) is likely due to atmospheric molecular oxygen, while the strong absorption centered at band 29 (0.6744 um) is due to chlorophyll in the vegetation. This feature is referred to herein as the chlorophyll well, and is followed by a sharp rise, the red edge, located between bands 30 and 37. The broad absorption in bands 1-12 (0.4000-0.5078 um) is due to both chlorophyll and carotenoid pigments.

Raw spectral data for the grus pits used for flat-field correction are presented in Figure 2. Many of the same absorption features seen in Figure 1 are also seen in Figure 2 (features at bands 38, 57, 76, and 102), indicating that they are common atmospheric components. A broad absorption seen centered at band 150 (1.8602 um) is due to atmosphereic water, while the strong feature at band 2 (0.4098 um) is likely due to iron oxide found in the grus. Causes of the absorption features at bands 89 (1.2624 um) and 165 (2.0072 um) have not yet been identified.

Flat-field corrected spectral curves are presented in Figure 3 for the golf course, green alfalfa, and an area of low rabbit brush and grass (approximately 20-30% cover). Note that the flat-field correction has removed the effects of variable intensity of solar illumination and of atmospheric absorptions. Artifacts introduced into these curves by the flat-field correction method include a shift of one band in the position of the chlorophyll absorption maximum and the apparent lack of absorption by chlorophylls and carotenoids in the visible blue (bands 1-11), due to the strong iron oxide absorption seen in the grus. The overall results are most encouraging however, since the flat-field corrected curves for the golf course and alfalfa look very much like typical vegetation curves acquired with field and laboratory spectrometers.

A more detailed presentation of flat-field corrected visible and near infrared AVIRIS data is seen in Figure 4. Spectral curves for cottonwoods and green alfalfa show maximum absorption due to chlorophyll (the chlorophyll well) at band 30 (0.6842 um) while the chlorophyll well for drying alfalfa is located at band 29 (0.6744 um). Rock et al. (1988) report a five nanometer blue shift in chlorophyll well position with increased damage in spruce (Picea) forests as measured by the airborne FLI, although a similar blue shift of only two nanometers was measured in situ. Westman and Price (1988) report a similar two nanometer blue shift in chlorophyll well position determined in situ for pines (Pinus) experimentally exposed to drying, acid misting, and ozone.

It is difficult to assess the true nature of the blue shift of the chlorophyll well reported here. Westman and Price (1988) attribute the blue shift seen in pine induced by drying to denaturing of chlorophylls. The blue shift seen in spruce has been correlated with decreases in the amount of chlorophyll b relative to chlorophyll a (Rock et al., 1988). The blue shift seen in Figure 4 may also be due to increased amounts of soil and stuble exposed by the cutting of alfalfa.

Note that the variations in amplitude of both red (bands 28-30) and NIR (bands 38-90) reflectance seen in the Figure 4 curves makes evaluation of the red edge position difficult. The red edge of green alfalfa appears shifted to shorter wavelengths when compared with the red edge of the cottonwoods. This apparent shift is due to the greater NIR reflectance seen for the green alfalfa, an effect which can be removed by normalizing the two curves. Figure 5 presents normalized red edge curves for the golf course, cottonwoods, and green alfalfa. This approach demonstrates that the red edge parameters for all three green vegetation types are very similar.

When the red edge data for the cut alfalfa are normalized to those of the green vegetation types (Figure 6) a distinct "shift" is seen such that the red edge curve for the drying vegetation is separated from the others. This blue shift of the red edge of cut alfalfa is very similar to that seen in normalized FLI data acquired from the forest decline sites (Rock et al., 1988). Regardless of the cause of the blue shift (alteration of plant pigments, increased reflectance from soil/stubble, etc.), it is clear that AVIRIS data have been acquired with sufficient spectral resolution to detect such spectral fine features associated with stress in vegetation.

The presence or absence of the red edge feature in spectral curve data may be useful in detecting trace amounts of vegetation in semi-arid regions. Although not presented in detail here, subtle changes in reflectance amplitude across the red edge region are seen in AVIRIS data for the sagebrush and rabbit brush areas of the flightline (see Figure 3). An investigation which relates the occurrence of such amplitude changes with percent ground cover and vegetation type will be needed to establish the value of using red edge data for the purpose of trace vegetation detection and quantification.

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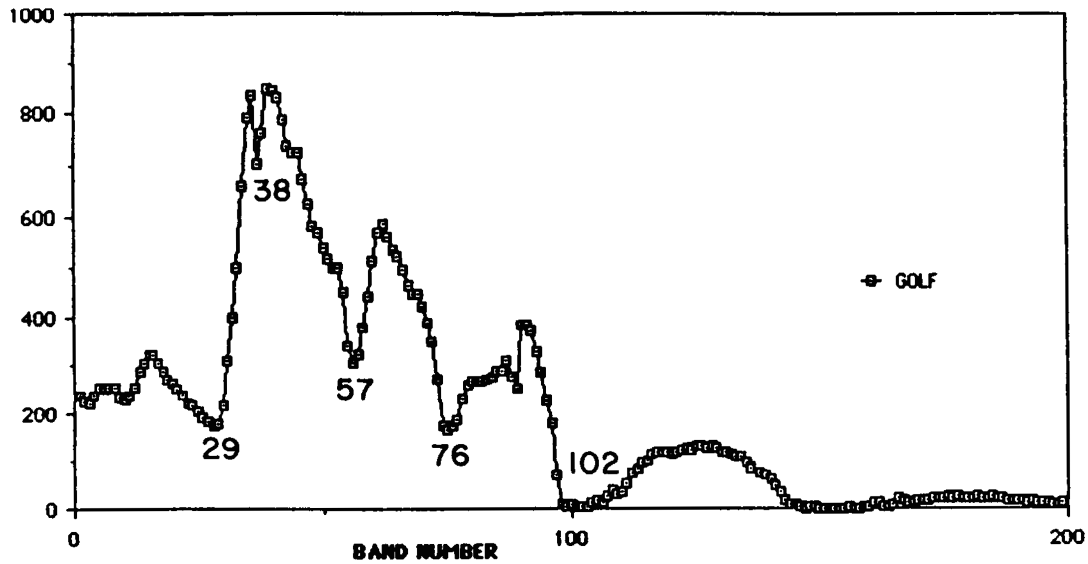

Figure 1. Radiometrically-corrected AVIRIS data plotted as DN vs. band numbers for pixels selected from the golf course. Band numbers discussed in text are labelled.

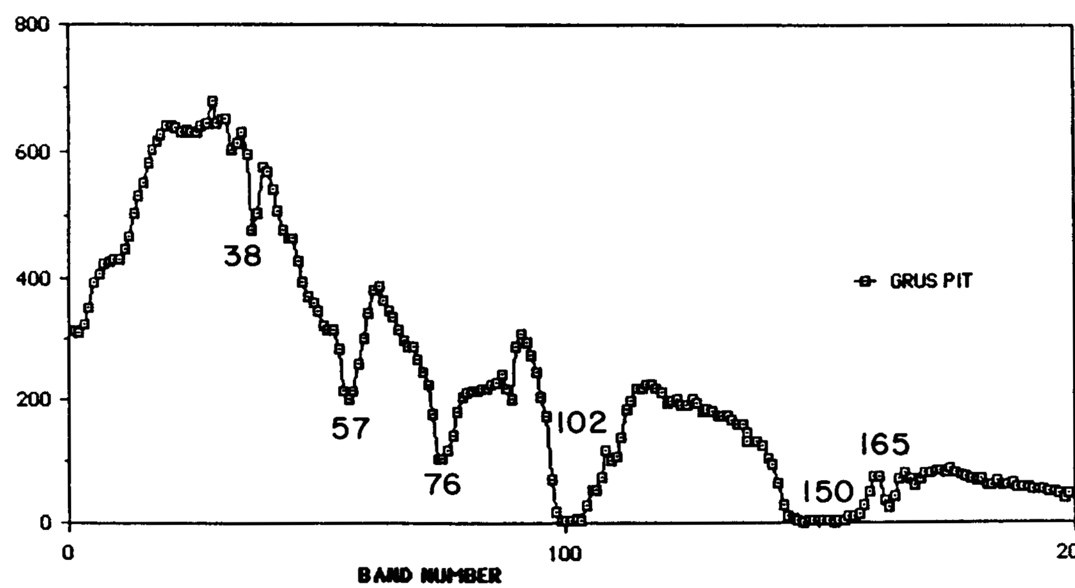

Figure 2. Radiometrically-corrected AVIRIS data plotted as DN vs. band numbers for pixels selected from the grus pits used as calibration targets. Band numbers discussed in text are labelled.

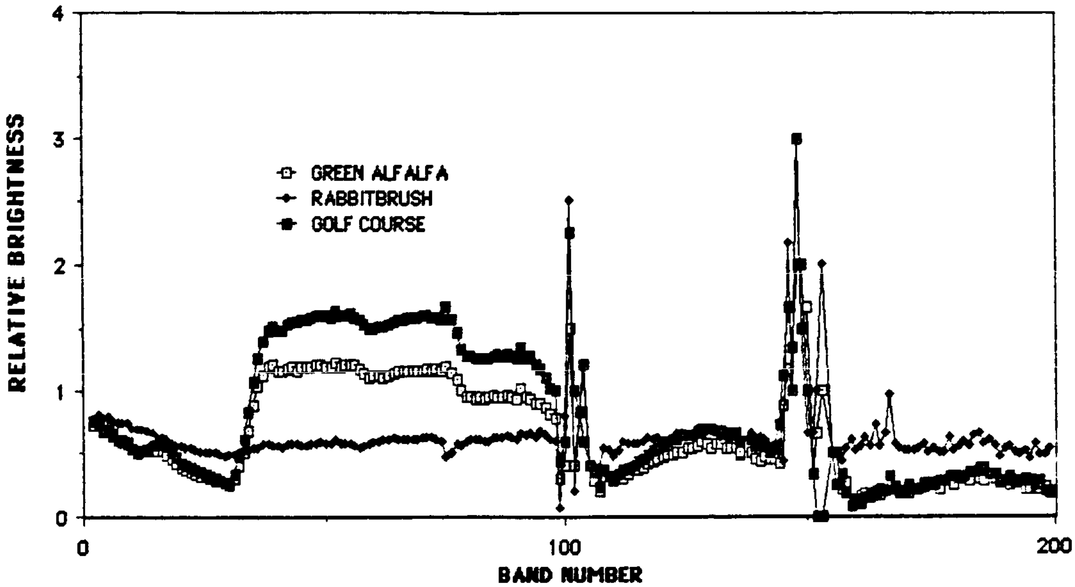

Figure 3. Flat-field corrected AVIRIS data plotted as relative brightness vs. band numbers for pixels selected from fields of green alfalfa, the golf course, and an area of low-density vegetation dominated by rabbit brush.

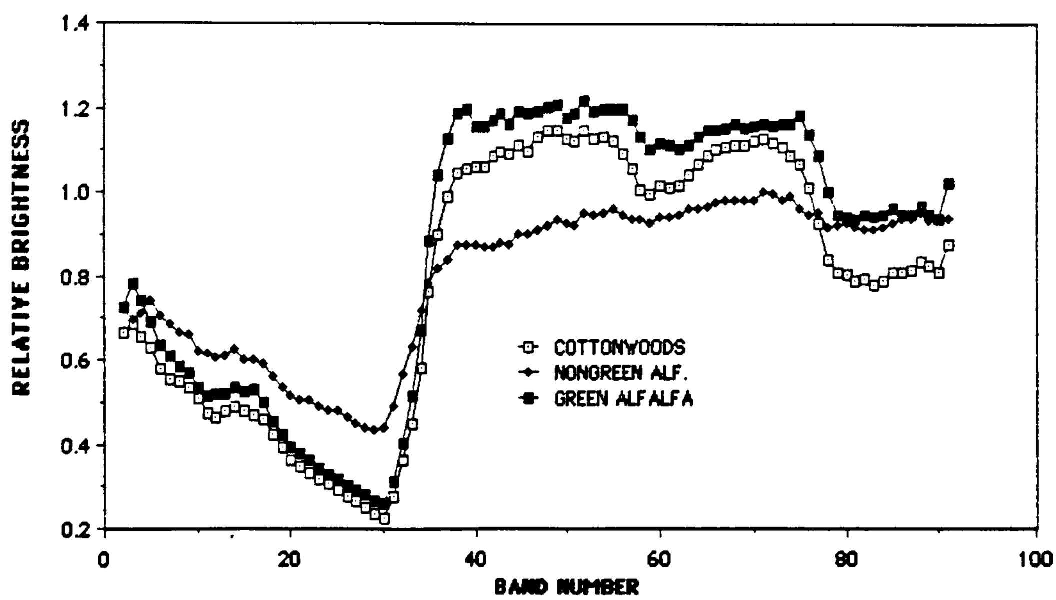

Figure 4. Flat-field corrected visible and near infrared AVIRIS data plotted as brightness values vs. band numbers for pixels selected from stands of cottonwoods and fields of green and cut alfalfa (labelled "nongreen alf."). Note the difference in both shape and position of the chlorophyll wells for green alfalfa and cottonwoods (centered at band 30) and drying alfalfa (centered at band 29).

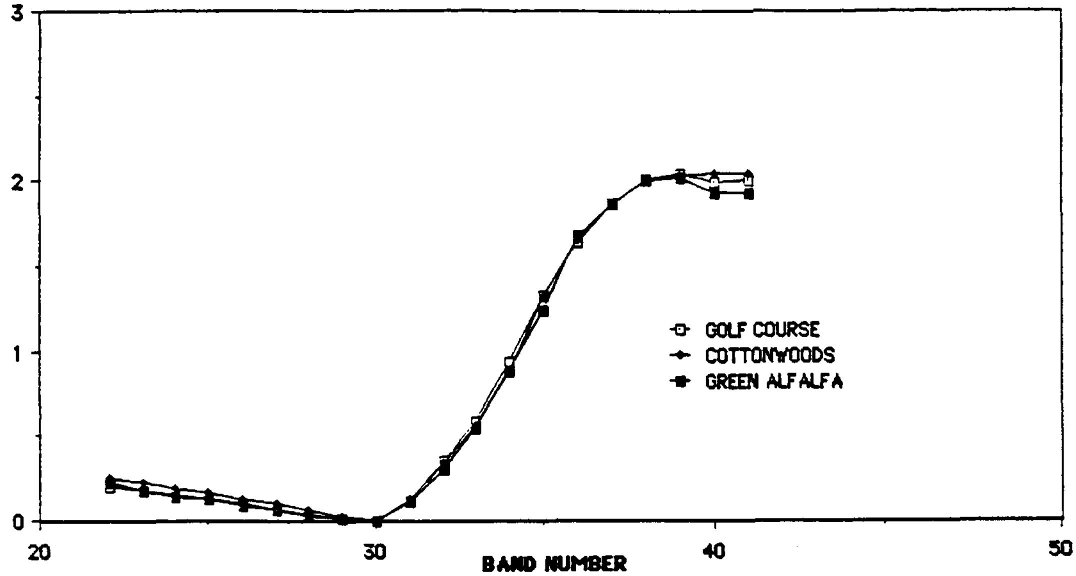

Figure 5. Normalized red edge AVIRIS data for three types of green vegetation: the golf course, cottonwoods, and alfalfa. Note the red edge position is very similar for all three types.

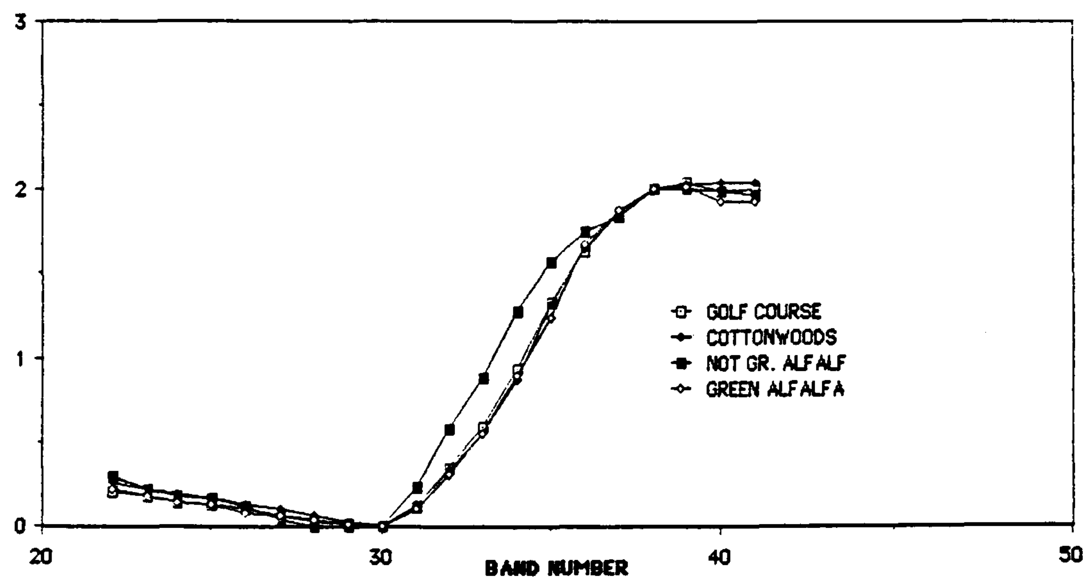

Figure 6. Normalized red edge AVIRIS data for three types of green vegetation (golf course, cottonwoods, and green alfalfa) and cut, drying alfalfa (labelled "not gr. alfalfa"). Note the change in position of the red edge of the cut alfalfa relative to the red edge of the green vegetation.