USE OF LOW ALTITUDE AVIRIS DATA FOR IDENTIFYING SALT AFFECTED SOIL SURFACES IN WESTERN FRESNO COUNTY, CALIFORNIA

Michael L. Whiting[1, 2] and Susan L. Ustin[2]

[1]USDA – Natural Resources Conservation Service, 650 Capitol Mall, Rm. 7014, Sacramento CA 95814
[2]Center for Spatial Technology and Remote Sensing, Department of Land, Air, and Water Resources, University of California, 1 Shields Road, Davis, CA 95616

This is a report on a limited evaluation of the low altitude Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data, for identifying soil salinity and organic matter concentrations in soils using specific spectral bands cited in the literature. This study is part of a larger investigation for using AVIRIS as the image data layer in developing terrain models to simulate the content and spatial extent of surface soil organic and inorganic carbon.

Soil Salinity and Organic Matter as a Global Issue

California, and most of the Southwest, is exceptionally vulnerable to agricultural production losses due to degrading soil quality by rapid loss of soil organic matter and accumulation of salt. Temperate, moist winters encourage microbial breakdown of soil organic matter (SOM). This is accelerated with aeration from tillage. The soils on the western side of the great Central Valley of California are derived from Cretaceous marine sediments in the California Coast Range. Contribution of salts from the parent material and capillary rise from the high water, continue to concentrate carbonate and chloride salts in soil surfaces. While growers have improved management, adopted salt tolerant crops, and improved reclamation practices, the productivity in California's San Joaquin Valley dropped 10 percent ($32.3 million per year) since 1970 because of high saline water tables (El-Ashry et al., 1985).

Spatially reliable techniques are needed to set base lines and verify changes simulated by soil process models of carbon cycling in the arid West. In the Great Plains, Parton and colleagues (1988) developed the Century Model, when applied using GIS, simulates the spatially distributed impact of management on long-term changes in soil organic carbon (SOC) and macronutrient pools of wheat production. They evaluate the accuracy with intense field sampling. In the arid West, similar carbon models are needed that incorporate parameters for inorganic carbon (SIC) change. In many areas the amount of carbonates is greater than of soil organic carbon. Adding remotely sensed surface SOC and SIC estimates to the GIS database will improve carbon cycling simulation, and reduce the need for intensive field sampling. Identification of salinity types and areas are important elements in capturing the inorganic portion of carbon.

Within the next several years satellite sensors will operate at significantly higher spatial resolutions and over many new regions of the electromagnetic spectrum. This presents an opportunity to couple these new sensor technologies with existing methods and databases to address soil quality problems and greatly improve the quality and resolution of soil maps. In late 1999 NASA will launch two hyperspectral sensors on the EO-1 satellite and in the 2000-2001 period hyperspectral data from 8m-50m spatial resolution will be available from the Australian AIRES sensor and the DOD NEMO and Warfighter sensors (for which NASA has purchase agreements). Current satellites have demonstrated low accuracy in quantifying SOC and SIC due to limited spectral and spatial resolutions. However, the advent of new sensor technologies, particularly imaging spectrometry, multiband thermal sensors, hyperspatial sensors (e.g., Space Imaging's Ikonos), and interferometric SAR suggest that new approaches to this problem would yield positive results.

The use of remote sensing to quantify changes in SOM has been demonstrated by many investigators. Schreier, et al. (1988) in British Columbia, determined the relationship of SOM to moisture, exchangeable Ca and Mg cation exchange capacity, and soil color. Others have established procedures for this estimation and developed reference reflectance libraries from soil samples (Henderson et al., 1992; Henderson et al., 1989; Kimes et al., 1993; Krishnan et al., 1980; Wilcox et al., 1994). Stoner and Baumgardner (1981) determined concentration of organic matter is a multivariate problem as several factors simultaneously affect reflectance, including particle size, sand

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content, iron oxides, and magnesium. Soil organic matter is distinguishable by the characteristic spectral curves between the 700 and 1400 nm, and near 2200 nm (Palacios-Orueta, et al., 1999). Hyperspectral methods developed by Palacios-Orueta and Ustin (1996,1998), and end member separations using Hierarchical Foreground Background Analysis (Palacios-Orueta et al., 1999, derived from Pinzon et al., 1998) may improve SOC and SIC estimates from AVIRIS data.

Methods have been established for remotely sensing the surface salinity concentrations, as well (Csillag et al. 1993; Hick and Russell, 1990; Szilagyi and Baumgardner, 1991). Using surfaces samples from San Joaquin Valley, California and the Carpathian Basin, Hungaria, Csillag et al. (1993) analyzed laboratory spectroradiometer data using a modified stepwise principal component band selection algorithm to separate 13 classes of the soil salinity status. They reported the importance of high spectral resolution in recognition accuracy of salinity status decreased from 91, 90, and 88% as band width increased from 10, 20, and 40 nm, respectively, over both locations. They identified 35 - 42 narrow bands, between 500 nm to 2400 nm, that led to recognition accuracy of 100% for San Joaquin Valley. Selecting those bands that represent SPOT, TM, MSS from this analysis yielded 30, 65, and 43 percent accuracy, respectively, to determine "Salinity Status".

Using stepwise regression analysis, Csillag et al. (1993) found high correlation to spectral patterns, coefficients of 0.85, 0.78, 0.60, 0.75, 0.73, and 0.32 for clay content, organic matter, organic carbon, pH, salt content, electrical conductivity (EC), and exchangeable sodium percentage (ESP), respectively. There is no specific band linked to salinity status due to the complexity of the soil characteristics. Further work is needed within the saline and sodic class separation to estimate soil inorganic carbon, $CaCO_3$. It is anticipated that AVIRIS data will provide better spectral resolution for carbonate (CO_3^{2-}). Thus, developing methodology for characterizing the SIC.

Condensation of several literature citations for target soil characteristics demonstrates considerable spectral overlap between targets due to the complexity of the soil reflectance (Table 1). Determining which bands are the most informative is too complex to be reduced to a table form. The reader should refer to the citations for full details. Most of this work was conducted in the laboratory. The spectral response for carbonate minerals is best found in the range from 1,750 nm and 2,250 nm bands, according to lab spectral studies by Bendor and Banin (1990). Free carbonates, also, have a strong absorption in the thermal bands, 11 to 12 nm, (outside the AVIRIS range) because of the internal vibrations of the $CO3^{-2}$ group. Gypsum response in TM band 5, 1500-1730 nm, and can be confused with clay content (Metternicht and Zinck, 1996). Spectra for other commonly associated chemistry are listed. Additional spectral libraries for soils exist (Baumgardner et al., 1970) and geologic materials (Clark et al., 1991) are available for matching spectra. In the future, the laboratory spectroscopy of field samples and field spectra will be collected.

Study Area

The low altitude AVIRIS mission, October 6, 1998, transected the agricultural landscapes from the valley bottom, up the lower fan of the west side of the San Joaquin Valley, Fresno County, California. The flight was southwest from the Fresno Slough towards the California Aqueduct, south and parallel to Panoche Creek, up the Panoche Fan towards the Central Coast Range and Interstate 5. Flight f981006t01p01_r04 was approximately 18 km long, 4-5 km width swath of 3.8 m pixels, of 224 spectral bands, 10 nm spectral resolution. Figure 1 is a Quick Look of this flight from the AVIRIS web page. See Chrien et al. (1999) paper in these proceedings for details on equipment used in these demonstration low altitude flights.

In the images, permanent vegetation is apparent as orchards and some seed alfalfa within the flight line. Annual crops include onions, sugar beets, and cotton. Soil in the bare fields is dry, more than a month since the last rain, though some pre-plant irrigation features, for this winter grain crop, are apparent in the images. Geomorphology within the flight includes basin and low basin rim, rising from the Fresno Slough along a broad pediment, the Panoche Fan. The soils are generally fine textured and very deep, though the water table is shallow or drained, 24 or more inches deep, in the lower fan area. Because of limited time available before the conference, only scene 5 used for this study (Figure 2). In this scene, the dominant soil taxa in the two mapping units are fine loamy, mixed, superactive, thermic, Fluventic Haplocambids (Cerini clay loam, 0-2% slope, mapunit-id 479), and fine loamy, mixed, superactive, thermic, Sodic Haploxerepts (Calflax, clay loam, saline-sodic, wet, 0-2% slope, mapunit-id 482).

Table 1. Summary of Salinity and Soil Organic Matter Spectral Bands

Characteristic	Detection Bands (nm)	Confidence	Authors
SOM /1	16 bands, 520 – 2320 nm Spectral Band Selection algorithm	0.96 probability of correct classification	(Henderson et al., 1989)
SOM	550-780; 900-1020; 1270-1520; 1950-2040; 2060-2140; 2270-2400 nm		(Palacios-Orueta and Ustin, 1996)
SOC/1	405-1055, 1075, 1115, 2325, 2375, 2425, 2445-2485 nm	correlation coefficient > 0.8	(Henderson et al., 1992)
Salinity /1	550-770; 900-1030; 1270-1520; 1940-2150; 2150-2310; 2330-2400 nm	91 - 100% class accuracy, Multiple Stepwise PCA	(Csillag et al., 1993)
Salinity	TM bands 1, 2, 4 - 7	33 – 100 % class accuracy	(Metternicht and Zinck, 1996)
Calcite/dolomite /1	2230 – 2270 nm	Std error of prediction = 15% (unheated, 1st deriv. of absorption)	(Bendor and Banin, 1990)
Calcite (fine grain) /1	2310 – 2330 nm		(Mulders, 1987)
Ferric oxide /1	900 nm		
Water /1	1400 and 1900 nm		
Hydroxyl /1	2200 nm		
Structural influence /1	Visible spectrum		
Gypsum /1	1800 and 2300 nm		
/1 Laboratory analysis under control conditions.			

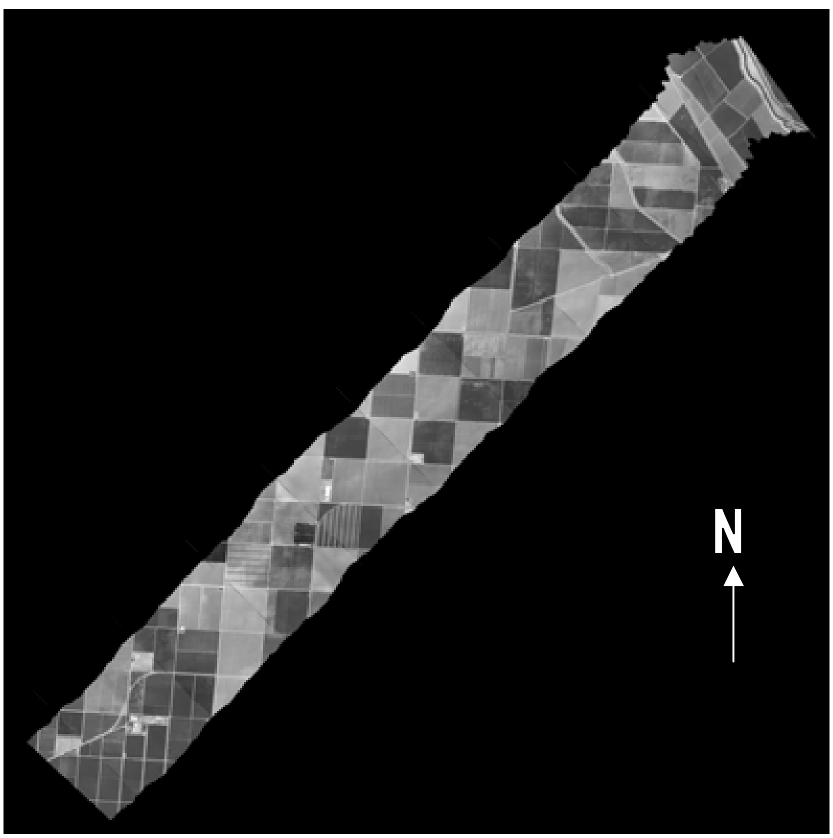

Figure 1. A Quick Look of Flight f981006t01p01_r04. See text for location and description.

The recently completed Natural Resources Conservation Service (USDA – NRCS, formerly Soil Conservation Service) soil survey provides soil chemical and physical characteristics data for soil classification. The modal sites for characterizing the map unit soil series were sampled for analysis by the National Soil Survey Center laboratory. Representative modal sites for soils found within the flight line, contained surface soil organic carbon measurements in three distinctive ranges, 0 to 0.5; 0.7 to 0.85; and 1.4 to 1.7%. Within the flight line, grab samples were collected and $CaCO_3$ in the surface was measured in the soil survey office. $CaCO_3$ ranged from 1 – 3%, weakly to strongly effervescent. Within scene 5, soil boundary lines and mapunit notation are shown on Figure 2. The Cerini (479) surface ranges near 0.75% SOC (modal value) and 3% $CaCO_3$ (average of grab samples). The Calflax (482) surface ranged near 1 % SOC (modal value) and 1 – 2 % $CaCO_3$ (average of grab samples). Calflax contains significantly more sodium (Kerry Arroues, USDA – NRCS, Western Fresno Soil Survey, Supervisor Soil Scientist, personal communication, 1998).

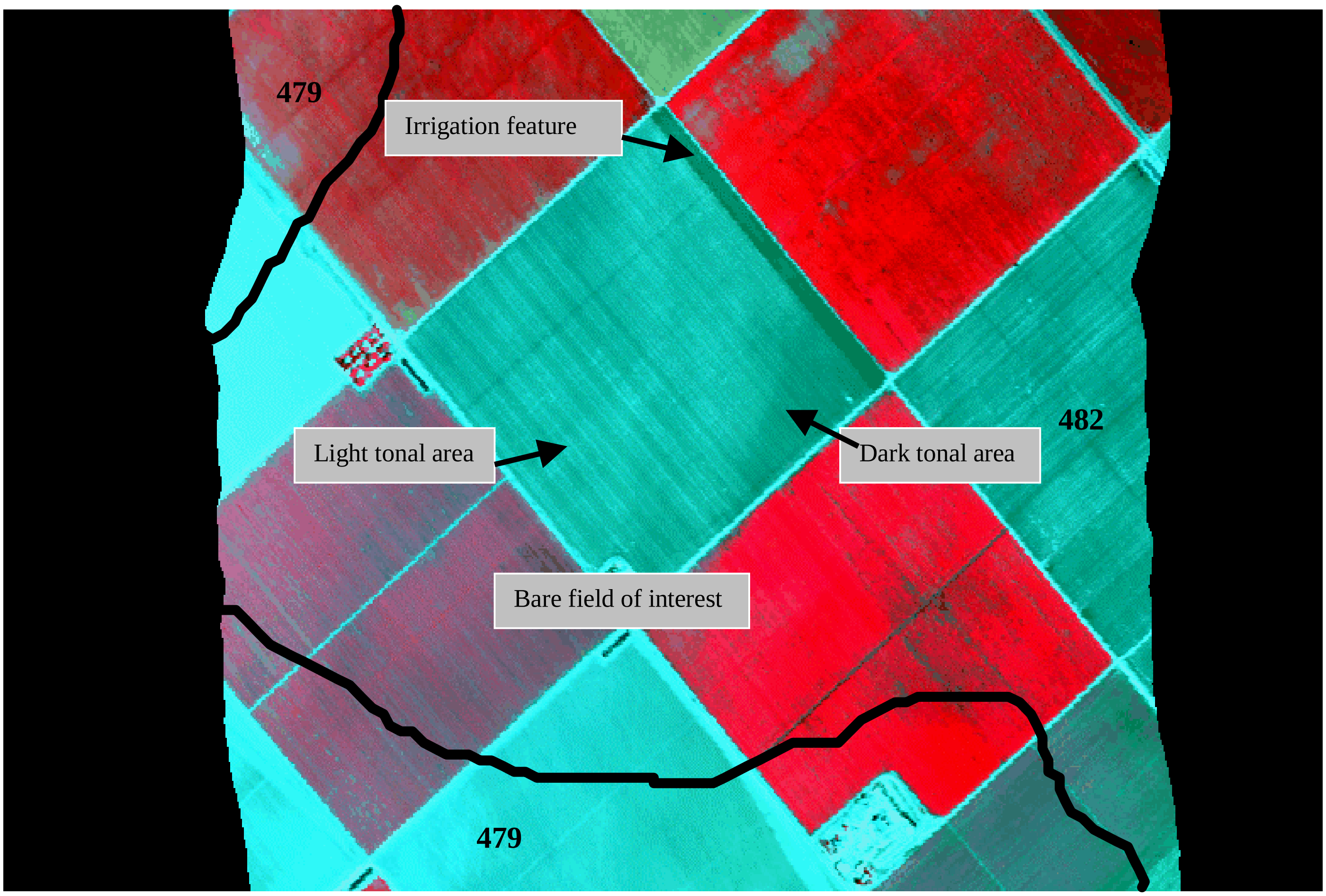

Figure 2. Pseudo-color infrared image, 750, 650, and 550-nm in RGB classes.

Method and Results

Due to the limited time between the release of the data and the AVIRIS Conference, only a very limited analysis was conducted without ground truth or laboratory chemistry. The images were geo-rectified, but not transformed from radiance values to reflectance. The radiance values are acceptable for relative comparisons within a scene, and not comparable to spectral libraries.

For visual interpretation, a pseudo-color infrared image was created using the 750, 650, and 550-nm bands to RGB classes, Figure 2 (printed in gray for reproduction). The high spatial resolution within the image provided good visual identification of saline-sodic areas within the contrasting vegetated areas. Irrigated moist soil, roads, and other features, also, contain good detail. A bare field in the center of scene 5 was selected to demonstrate the spatial and spectral resolution of the low altitude data.

In this one scene, only two bands were used in the analysis, 1124 and 2139 nm. Literature cited in Table 1 showed strong correlation in the wavelengths between 1940 – 2150 nm to salinity and organic matter (Csillag, et al., 1993; Palacios-Orueta and Ustin, 1996), and just below the 2200-nm band for hydroxyl (Mulders, 1987). These same wavelengths for salinity and organic matter are also noted for gypsum. The modal chemical analysis indicated none to traces of gypsum in these soils.

Two positions in the field, providing contrasting light tone and dark tones, were compared spectrally (Figure 3). In comparing pixels, the change in radiance at 1124 nm appeared to vary with the change observed in the 2139-nm band. The absorption of light by water at the 1124 nm and many of other bands is well documented. To determine if the light versus dark was due to moisture only, the scene was normalizing for water by dividing the radiance at 2139 nm by the radiance at 1124 nm for each pixel. The coefficient was multiplied by 200 to increase the pixel to pixel contrast.

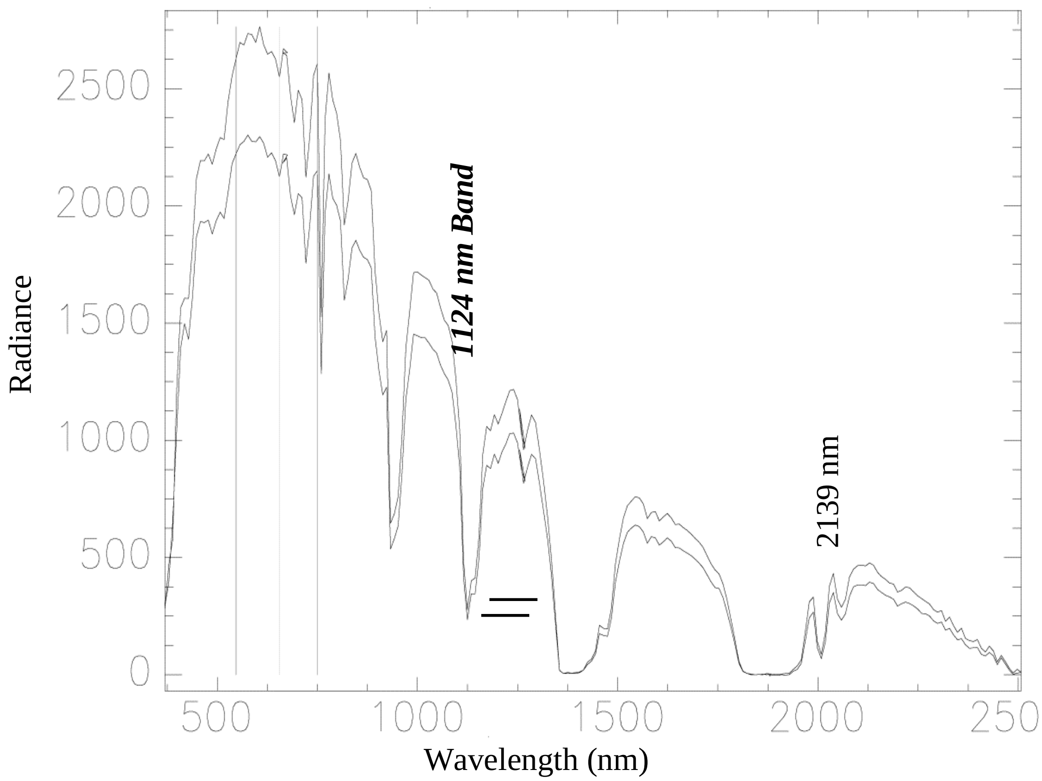

Figure 3. Radiance spectrum of two pixels, the lighter image tone above the darker image tone.

The influence of soil moisture was eliminated as shown in Figure 4. The visible irrigation feature in upper right of the test field was removed; compare the pseudo-color infrared image (Figure 2) to the normalized image (Figure 4). The tone uniformity over the field is also apparent in the gray scale image. An x–x' transect across the gray scale image was used to sample the variation of radiance in field pixels.

The x-x' transect provided a Gaussian frequency distribution of radiance values. Three classes, within these values for the normalized radiance at 2139 nm, were created using the area one standard deviation below the mean, area about the mean, and the area beyond one standard deviation above the mean. The resulting class map is shown as Figure 5. Without field sampled laboratory chemistry, the relationship of the classes to salinity or organic matter content and accuracy of the determinations was not possible. However, note the naturalness of the classed pattern, and the similarity to that of vegetation adjacent to the field. Normalizing for moisture did reduce the radiance values close to the noise-signal boundary, as shown in some of the pixel speckling in the test field.

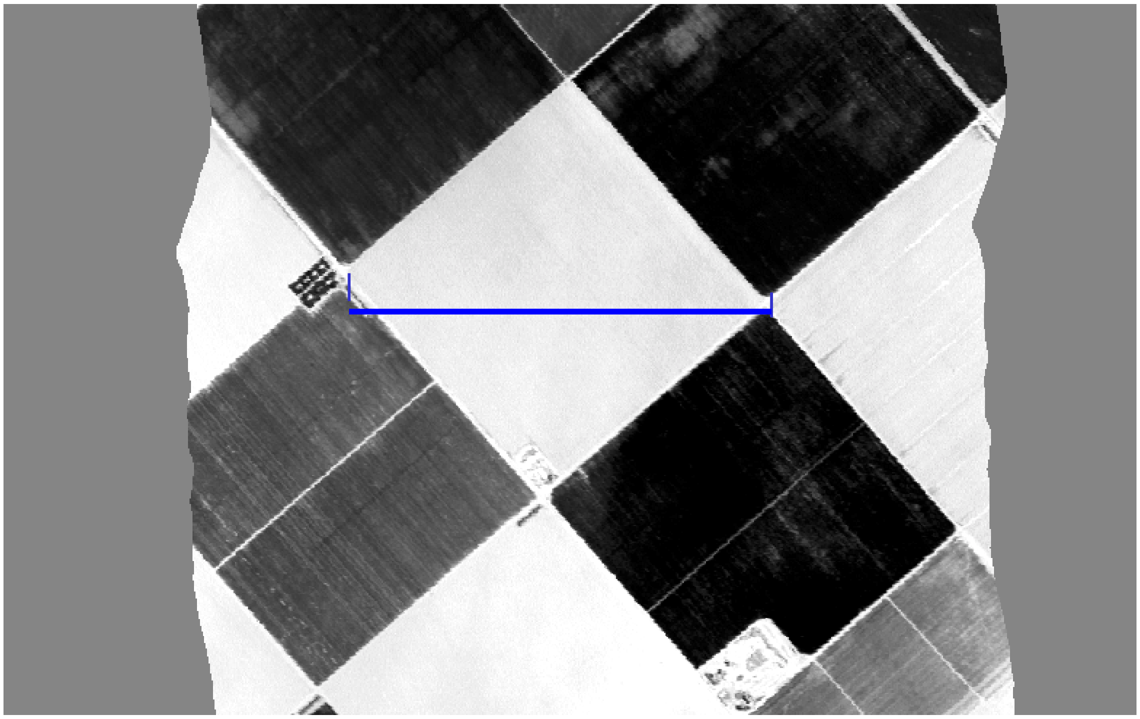

Figure 4. Image display of 2139-nm band after normalizing by the 1134-nm band.

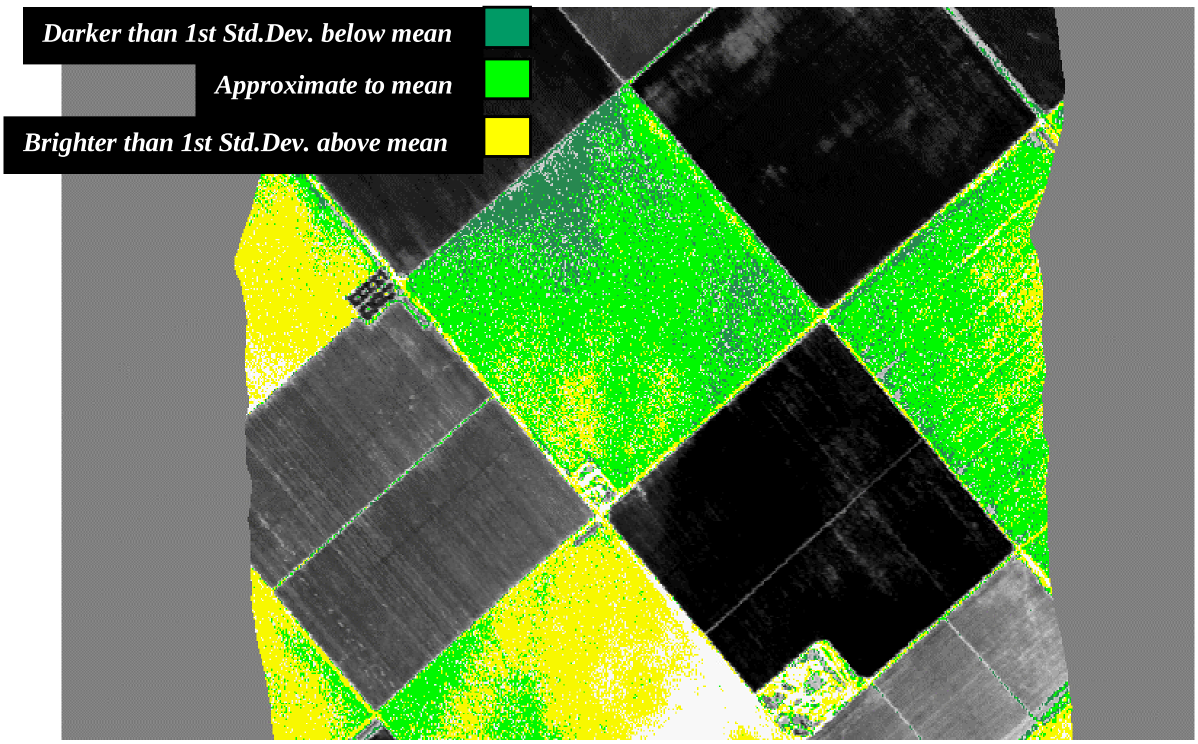

Figure 5. Classed normalized radiance values for band 2139-nm.

Future Work

During the soil survey in 1987-89, modal profiles were described and sampled for laboratory analysis. These points will be included in future GPS located surface sampling for chemical and spectroscopy laboratory analysis. At selected sites, additional ground data will be collected for SOC and SIC spatial variability, calibration of the images to surface reflectance, and classification error estimation. Rhoades and Corwin (1984) demonstrated a consistent, repeatable field method for collecting salinity concentrations using an electro-magnetic induction instrument (EM). Using this instrument, EM readings will compliment the spectrometer grid measurements, also, georeferenced using GPS. Ground spectrometer measurements will be collected for image classification of this low altitude and, hopefully, other AVIRIS data, statistical accuracy and errors evaluation.

Conclusions

Visual interpretation verified that the higher spatial resolution of low altitude flights provides important detail for identifying the small, spotty morphology common to saline-sodic features. Within orchards and other vegetation, the vegetation reflectance would overwhelm the small saline-sodic features within. Greater detail in the bright areas of the bare fields would also have appeared larger than actual area, over estimating salinity. The lighter versus darker patterns in the test field may be due to mixtures of salts and soil organic matter.

Though limited by the time available for a thorough evaluation of the data, normalizing the radiance by the water band at 1124 nm, did eliminate the water effect in the bare field. Further work to eliminate spectral mixing with other chemistry, by combining other bands, is needed. (Bendor and Banin, 1990) described effectiveness of drying soil samples at high temperatures to eliminate hydroxyl groups on the phyllosilicates, as well as, water to improve quantifying calcite. Elimination of moisture also demonstrates the potential for using AVIRIS for measuring soil moisture. Mulders (1987) identifies significant reflectance differences within the same soil at very wide range of soil moistures, from extremely dry (0.8%) to near field capacity (20% soil moisture by volume).

Many authors (Csillag et al., 1993; Henderson et al., 1989; Palacios-Orueta and Ustin, 1996) have shown using several bands, after selecting the most unique for the target, produces higher confidence. The simple evaluation described here would be improved greatly by the use of additional bands, taking advantage of the hyperspectral sensor high spectral resolution.

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