EFFECTS OF IMAGE RESOLUTION AND UNCERTAINTIES ON REFLECTANCE-DERIVED CROP STRESS INDICATORS

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1. BACKGROUND

Dozens of private companies across the U.S. are capturing some type of multi-spectral digital imagery (airborne and/or satellite) and deriving some basic assessments of crop health for growers and others involved in the agriculture industry. Although these products are useful, growers need more specific information on the type and cause of the crop stress, at a point before it can be easily detected on the ground. Research in the past decade on various narrow reflectance band stress indices shows promising results, with greater sensitivity than provided by earlier vegetation indices. However, questions certainly remain on the routine application of improved stress indices based on hyperspectral imagery for providing useful products to growers. Under funding by the NASA Hyperspectral EOCAP program, this work is aimed at identifying and addressing both opportunities and technology gaps to commercial application of hyperspectral imagery for agriculture. In this paper we explore some of the impacts of spatial scale and measurement errors (uncertainties in spectral calibration and retrieved reflectance) on some narrow reflectance band stress indicators.

2. NITROGEN STRESS EXPERIMENT AND THE DATA COLLECTED

A two-year research effort was launched to evaluate the utility of hyperspectral imagery for improved spatial characterization of crop stress. This project is part of a NASA Earth Observation Commercial Applications Program to evaluate commercial and scientific applications of hyperspectral imagery. During the summer of 1999, a field experiment was conducted with varying nitrogen applications (0, 40, 80, 100 and 120% of optimal nitrogen) on a production cornfield in eastern Nebraska. Four plots measuring approximately 75 by 90 meters were established for each nitrogen treatment level, which ranged from 0-200 kg/ha Nitrogen. Additionally, eight stress strips of various sizes were developed for a spatial detection study. The field layout for these experiments is outlined in Figure 1.

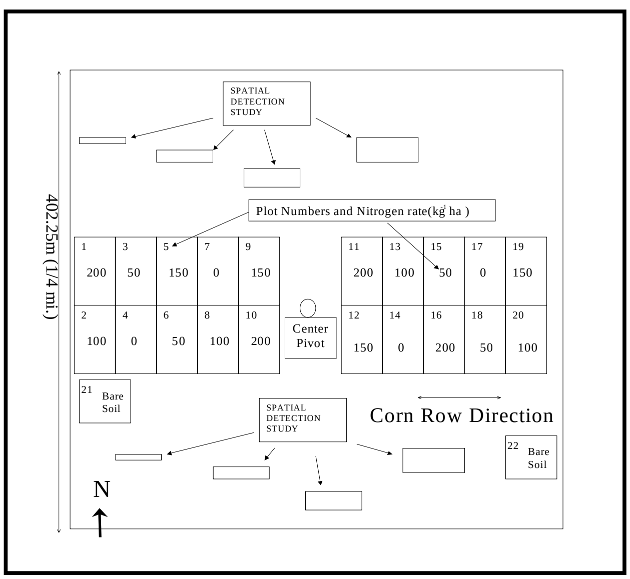

Figure 1. Shelton VRAT Field Layout 1999

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AVIRIS was flown on two dates in July 1999. The first was flown on 990706 at high altitude, resulting in approximately 18 m pixels. The second was flown on 990722 at a lower altitude, resulting in pixels of approximately 3 m resolution. For each of the overpass dates, canopy reflectance measurements for each experimental plot were made using and Analytical Spectral Devices (ASD) full-range spectrometer mounted on a cherry picker. The canopy reflectance measurements were obtained using a field of view of approximately 2.5 m. Bare soil spectra were also collected during each overflight for use in AVIRIS reflectance retrieval. These measurements were collected along bare field transects using a handheld ASD spectrometer. Additional field measurements made throughout study included crop growth stage, height, plant counts, and plant biomass.

3. ANALYSIS OF STRESS INDICES

To determine reflectance from the AVIRIS radiance values, a surface reflectance retrieval code based on the MODTRAN2 radiative transfer code (Kneizys et al. 1988) was used, as described in Roberts et al. (1997). For each pixel in the image (or each measured spectra from the spectroradiometer), the modeled radiance is fit to the measured radiance based on a non-linear, least squares fitting. In addition to surface reflectance, this approach yields both path water vapor and liquid water thickness estimates for each pixel. The model was initialized according to Table 1 for each of the two dates. For both the AVIRIS imagery and the ASD canopy reflectance spectra, various stress indices were computed from the reflectance values for each test plot, as shown in Table 2.

Table 1. Reflectance Retrieval Model Initialization for 6 July and 22 July 1999 AVIRIS Imagery.

AVIRIS DATE	RUN	PLATFORM HEIGHT (KM)	GROUND HEIGHT (KM)	MODTRAN MODEL	AEROSOL MODEL	VISIBILITY PROCESSED (KM)
990706	10-14	21.7 (run 10), 21.5 (runs 11-13)	.61	Mid-latitude summer	Rural	35 (also 14, 16, 18, 20, 23, 25, 30 for sensitivity tests for run 13)
990722	3,6,7	3.3	.61	Mid-latitude summer	Rural	35 (also 14, 16, 18, 20, 23, 25, 30 for sensitivity tests for run 3)

Table 2. Vegetation Stress Indices Used in Analysis.

INDEX NAME	FORMULA	REFERENCE
For Broad-band Sensors		
Vegetation Index	$VI = R_{830}/R_{660}$	Unknown
Tassled Cap (GVI, SBI)	Orthogonal transformation	Kauth and Thomas (1976)
Normalized Difference Vegetation Index	NDV I= $(R_{830}-R_{660})/ (R_{830}+R_{660})$	Rouse et al. (1973)
Soil Adjusted Vegetation Index	SAVI = $[(R_{830}-R_{660})/(R_{830}+R_{660}+0.5)]*1.5$	Huete et al (1986)
For Hyperspectral Sensors		
Photosynthetic Reflectance Index	PRI = $(R_{531} - R_{570})/ (R\ R_{531} - R_{570})$	Gammon et al (1997)
Red-edge Vegetation Stress Index	RVSI = $(R_{714} + R_{752})/2 - R_{733}$	Merton (1998)
Liquid Water Thickness	Extracted using Retrieval Code	Roberts et al (1997)

The analysis has focused on three issues relative to the utility of hyperspectral imagery for commercial crop stress products;

- *Accuracy of the reflectance-derived stress indices relative to conventional measures of stress.* Compared reflectance-derived indices (both radiometer and AVIRIS) with applied nitrogen, and with leaf level measurements of nitrogen availability and chlorophyll concentrations. This was performed for each of the 20 experimental plots, using the measurements (spectra or AVIRIS pixels) that correspond to a given plot.
- *Ability of the hyperspectral sensors to detect sub-pixel areas under crop stress.* Applied the stress indices to both the 3m and 18m AVIRIS imagery for the entire production corn field, using the sub-pixel areas within the field (as seen in Figure 1) to compare the relative sensitivity of each stress indicator.
- *Influence of measurement uncertainties on the sensitivity of the stress indices.* Calculated some of the stress indices under scenarios of spectral uncertainty (shifting the wavelengths used by 1 and 2 nm), and reflectance uncertainty (computing the resulting indices with varying reflectance retrieval code initialization values).

4. RESULTS TO DATE

To evaluate the accuracy of the reflectance-derived stress indices relative to conventional measures of stress, we compared the indices with applied nitrogen levels and measured nitrogen availability for each experimental plot. The radiometer spectra or AVIRIS pixels were averaged per plot and used to determine several indices including PRI, RVSI, and NDVI Regression models were fit for these data points; we found that 2nd order polynomial models fit the nitrogen treatment, while 1st order linear models fit the regressions of the indices to measured chlorophyll concentration (based on Minolta SPAD™ measurements). Examples of these regression analyses are shown in Figure 2. A summary of regression results for PRI, RVSI and NDVI are shown in Table 3. Viewing these results, we see two general trends. First, PRI and RVSI do show some improvement over NDVI for prediction of nitrogen stress (as indicated by both the treatment level and the leaf chlorophyll concentrations). Second, we see that the AVIRIS 3 m resolution imagery generally estimates both the applied nitrogen and measured leaf chlorophyll amounts better than the 18 m resolution imagery and the radiometric measurements.

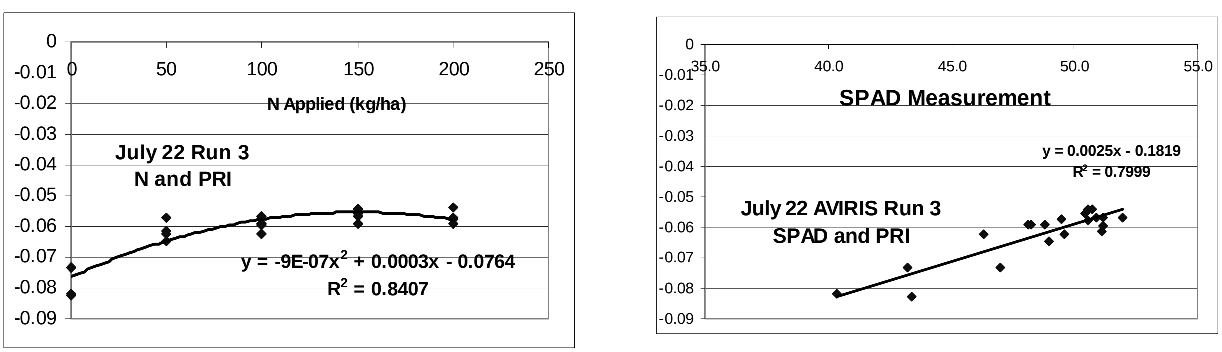

Figure 2. Example graphs and regression equations for comparison of reflectance derived indices (such as PRI) with applied nitrogen and measured leaf chlorophyll.

Table 3. Coefficients of Determination for Derived Stress Indices on Nitrogen Treatment and SPAD (Leaf Chlorophyll Concentration) Measurements.

DATASET	SPAT. RES. (m)	VIEW ANGLE (DEG.)	PRI ON N	PRI ON SPAD	RVSI ON N	RVSI ON SPAD	NDVI ON N	NDVI ON SPAD
			Coefficients of Determination (r^2)					
6 July AVIRIS Run 11	18	nadir	0.5704	0.5937	0.8254	0.718	0.3317	0.6377
22 July AVIRIS, Run 3	18	nadir	0.8407	0.7999	0.8506	0.7833	0.576	0.7469
22 July AVIRIS, Run 6	3	12 (south)	0.8346	0.8193	0.836	0.7834	0.588	0.8077
22 July AVIRIS, Run 7	3	9 (north)	0.8577	0.7996	0.8299	0.7948	0.5492	0.8052
ASD 6-Jul-99	2	nadir	0.568	0.607	0.79	0.7392	0.576	0.5001
ASD 22-July 99	2	nadir	0.1801	0.2729	0.8263	0.6754	0.2384	0.142

Several of the stress indices were applied to the AVIRIS imagery for the entire field. Figure 3 shows NDVI (top), RVSI (middle) and PRI (bottom) applied to both 3m imagery (left-most images) and 18m imagery (right-most). For the 3m imagery, all of these indices detect some differences among the nitrogen treatments (experimental plots) as well as the spatial detection areas. However, both RVSI and PRI show some improvement over NDVI in the sensitivity. For the 18m imagery, we see that RVSI seems most sensitive to differences among the nitrogen treatments, and is able to detect the sub-pixel spatial detection strips better than NDVI. PRI does not seem to provide the same sensitivity at 18m that it does at 3m.

An important evaluation is the impact of measurement uncertainties on the sensitivity of the stress indices. The nitrogen stress experiment provides an excellent opportunity to evaluate the indices in the context of a range of crop stress conditions. Two types of uncertainty were evaluated: spectral uncertainty and reflectance uncertainty. Several factors can influence reflectance retrieval accurac. For this analysis varying levels of visibility were used to initialize the model, and resulting values of the stress indices were determined. An additional test for reflectance uncertainty involved the presence or absence of a field collected spectrum for use in fine-tuning the reflectance retrieval. For the spectral uncertainty, the canopy reflectance (spectroradiometer) data was used. For this analysis, reflectance values were retrieved from the dataset based on the correct wavelengths, and also by retrieving the reflectance values at offsets of 1 and 2 nm, in either direction of the correct wavelength. Figure 4 illustrates graphically how these uncertainties may impact the derived stress index. The uppermost graphs in Figure 4 show the resulting values for RVSI and NDVI, by running the reflectance retrieval code with visibility values from 14-35km. Note that there are four plots per nitrogen treatment. For RVSI, we see that the variability within any given plot (i.e., the error impact of varying visibility) is much less than the variability within treatment or across treatments; the reverse is true for NDVI. The lower graphs in Figure 4 show the impacts of spectral shifts (uncertainty) on RVSI and NDVI. Here, the impact of shifting the central wavelengths up to 2nm has a tremendous impact on RVSI, but little impact on NDVI. These initial results indicate that measurement accuracy has a major impact on the sensitivity of these indices to crop stress, and we feel that a more detailed sensitivity analysis will be useful in defining the necessary data requirements for operational systems.

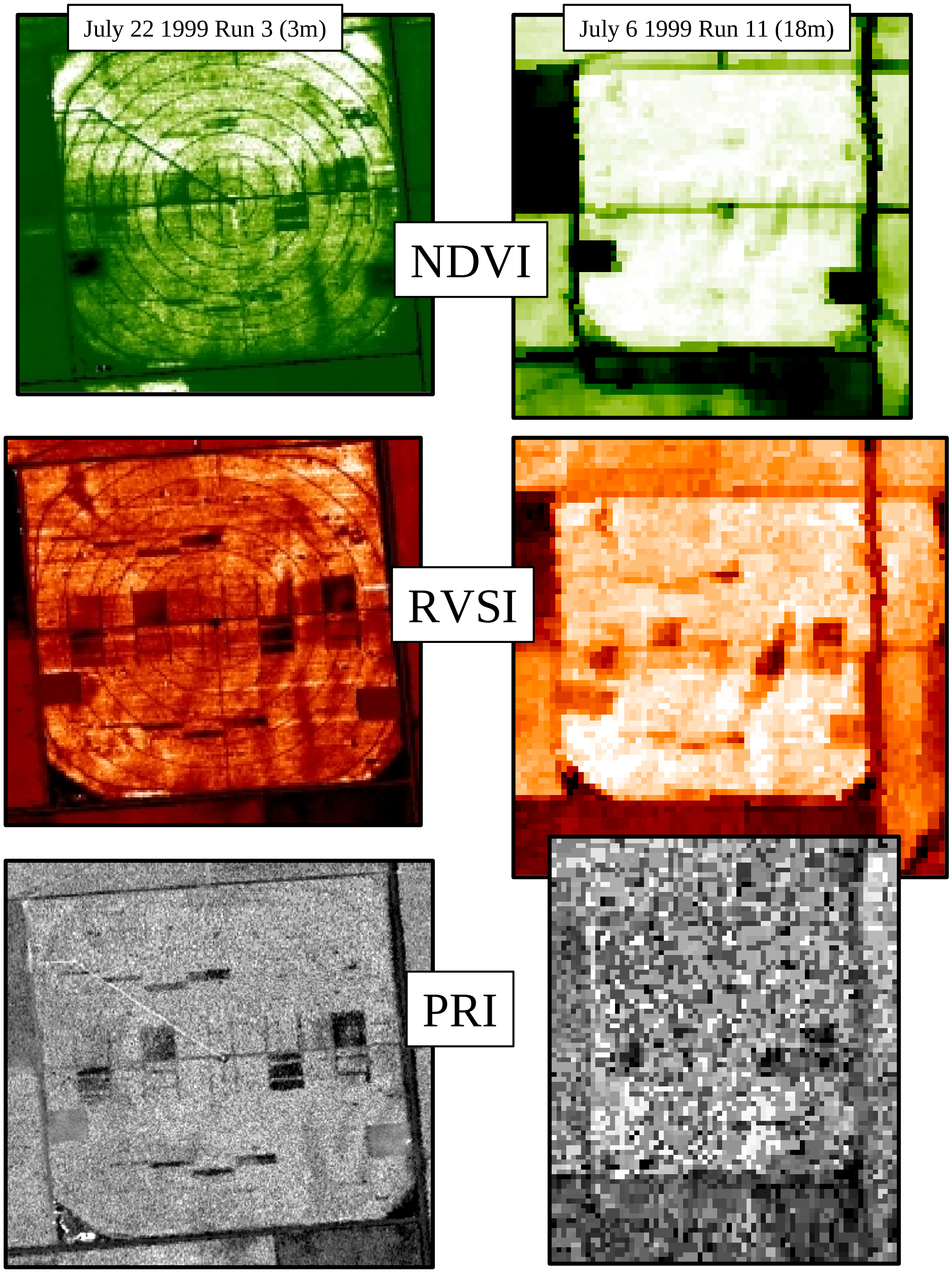

Figure 3. Narrow band stress indices applied to AVIRIS Imagery at 2 scales. The images on the left were derived from July 22 run 3 imagery at 3m spatial resolution, and the right side from July 6 run 11 at 18m resolution. The indices shown are NDVI (top), RVSI (middle) and PRI (bottom).

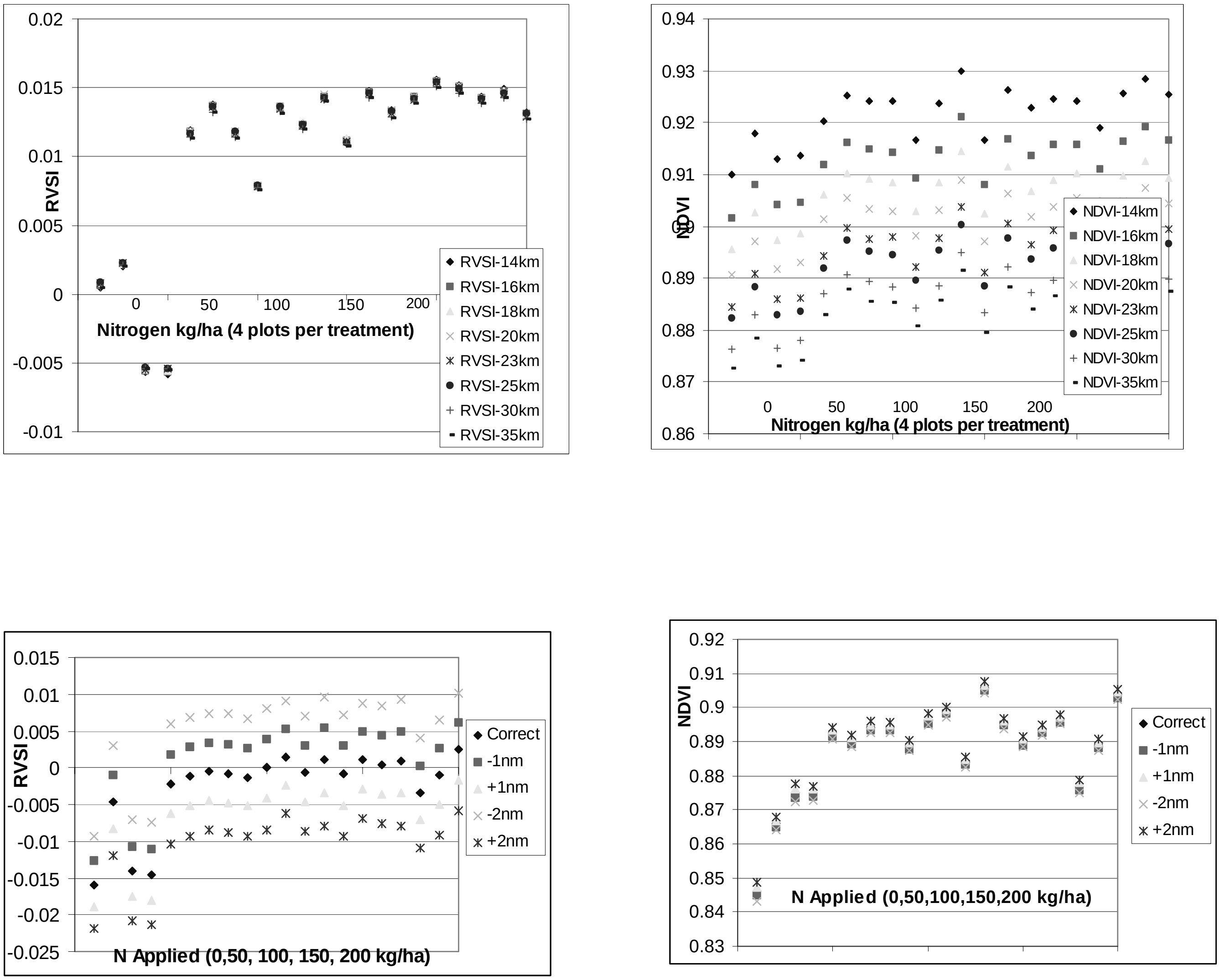

Figure 4. Examples of impact analysis for reflectance uncertainty (top) and spectral calibration (bottom) for two indices, RVSI (left-most) and NDVI (right-most).

5. FUTURE EFFORTS

The goal of our work is to investigate the requirements for both scientific and commercial use of hyperspectral imagery in crop stress detection. In the course of this work we will identify technology gaps and potential mitigations in the paths toward the development of these uses. This future work includes a complete sensitivity analysis for several of the promising stress indices, in order to determine the requirements for operational implementation. Additional spatial crop stress detection experiments are being planned utilizing the NASA Hyperion imagery to be collected during 2000. This work will comprise the first step in a planned three step NASA Hyperspectral Initiative which seeks to fully realize the economic benefits to the nation made possible by Office of Earth Science research and development efforts in remote sensing technology. During the next step we will implement these technology improvements and develop prototype products.

6. REFERENCES

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