DEVELOPMENT OF REMOTE SENSING IMAGE PRODUCTS FOR USE IN PRECISION FARMING

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ABSTRACT

Crop and soil information products derived from data acquired by airborne and satellite sensors could provide valuable input for precision farming. The Canada Centre for Remote Sensing is actively pursuing the development of information products from both hyperspectral and polarimetric radar sensors. Preliminary results suggest that crop physical parameters including Leaf Area Index, canopy water content, chlorophyll and percent crop cover can be derived from hyperspectral imagery. Patterns related to soil and crop conditions are visible on radar imagery. Ground data collected coincident with hyperspectral and radar acquisitions are currently being used to validate these image products.

BACKGROUND

Data and information inputs are critical components of the precision farming system. However, soil and crop conditions vary significantly, both spatially and temporally, and acquiring this information is a challenge. Thus, information products derived from sensors on airborne and spaceborne platforms could provide valuable input for precision farming.

Since 1996, the Canada Centre for Remote Sensing (CCRS) has been exploring the application of remote sensing imagery within precision farming. With Canada’s commitment to RADARSAT-1 and RADARSAT-2, CCRS is developing radar applications related to both soil and crop conditions. RADARSAT-2 is scheduled for launch in 2003. This fully polarimetric radar will acquire imagery at pixel spacings as small as 3 metres. Radar is sensitive to moisture content in soils and crops, and differences in crop structure. Synthetic Aperture Radars (SARs) transmit and receive microwave pulses and with these longer wavelengths, imagery can be acquired regardless of cloud cover.

NASA successfully launched its EO-1 satellite, carrying the Hyperion hyperspectral sensor, in November of 2000. Data available from this sensor, along with several other proposed hyperspectral sensors, have intensified interest in the exploitation of hyperspectral imagery in applications such as precision farming. Hyperspectral sensors record target radiance in the visible and infrared spectral regions, in a series of narrow contiguous bands. These sensors can thus detect very specific responses to different crop and soil conditions. CCRS is also developing information products from hyperspectral data for use in precision farming.

DATA SETS AND DATA PRE-PROCESSING

CCRS led two research campaigns in 1999 and 2000 in which both airborne hyperspectral and airborne polarimetric radar data were acquired. An airborne radar was also flown over a third test site in 1998.

The hyperspectral sensor used was the (Earth Search Sciences Inc.; ESSI) Probe-1. Probe-1 is an imaging spectrometer that has 128 contiguous spectral bands covering the visible to the short-wave infrared regions of the spectrum (440 nm to 2500 nm). During these two campaigns, imagery was acquired at a 5 x 5 metre pixel spacing. Image pre-processing and information extraction was carried out using the Imaging Spectrometer Data Analysis System (ISDAS) (Staenz *et al*., 1998). The Probe-1 data were converted to at-sensor radiance using a vicarious calibration approach (Secker *et al*., 2001). The MODTRAN3 radiative transfer code, implemented within ISDAS using a look-up table (LUT) approach (Staenz and Willams, 1997), was then used to correct the Probe-1 radiance spectra to surface reflectance.

The airborne C-band polarimetric SAR data was acquired by Environment Canada's CV-580, at incidence angles of 37º to 67º and at a 4 metre pixel spacing. Corner reflectors and PARCs (Polarimetric Active Radar Calibrators) were deployed during all airborne SAR acquisitions and were used for radiometric calibration of the airborne data. From these data, backscatter images were generated for three linear transmit-receive polarizations (HH, HV, VV), as well as two circular polarizations (RR – circular co-polar; RL – circular cross-polar).

Detailed crop and soils information was collected coincident with all airborne flights. These details are provided in Table 1.

DATA PRODUCTS DERIVED FROM HYPERSPECTRAL IMAGERY

Fraction Maps

Reflectance recorded for each pixel within an image is a combination of the reflectances from all "contributors" or "endmembers" in that pixel. In an agricultural context, these endmembers are likely to be crop and soil, along with other contributors such as weeds, crop residue and shadow. The purpose of spectral unmixing is to determine the relative contribution of each of these endmembers to the total reflectance recorded for each pixel. The output of spectral unmixing is a series of fraction maps which indicate the proportion (0 to 1) of each endmember (crop, soil, weed, residue, shadow) present in each pixel.

For the Probe-1 imagery from 1999 and 2000, endmembers were extracted using an automatic technique implemented within ISDAS (Szeredi *et al*., 2000). These endmembers were then used as input to a constrained linear unmixing algorithm (Boardman, 1995; Shimabukuru and Smith, 1991), for which the fractions of each endmember are constrained to be positive and sum to 1.0.

The relationship between these fraction maps and crop characteristics is being investigated. Along with measurements of several crop indicators (biomass, height, SPAD, nitrogen), vertical ground photos were taken at each sample site. For each photo, the percent cover of crop, soil and residue will be estimated using an unsupervised classification. Regression analysis between crop fractions and the crop indicators will establish the significance of these fraction maps. Significant variability in crop growth existed within many of the test fields, primarily as a result of variable planting densities, variable nitrogen applications, weed infestations and moisture stress. For these fields, unmixing produced two fraction maps that appear to be related to crop vigor.

Canopy Liquid Water Content

Canopy liquid water content can be estimated from the liquid water absorption features at 980 nm and 1170 nm. Within ISDAS, this is computed as the Equivalent Water Thickness (EWT), which is estimated from the Probe-1 imagery using a curve fitting approach. This approach combines atmospheric correction and non-linear least squares regression modelling for parameter estimation (Staenz *et al*., 1997). For several other data sets, EWT maps have been compared to within field canopy moisture measurements (Staenz *et al*., 1997). The EWT map reflected relative differences in vegetation water status, but further validation with the 1999 and 2000 data sets is planned.

Leaf Area Index

Maps estimating effective Leaf Area Index (LAI_e) can also be generated from hyperspectral data. LAI_e is estimated using the crop fraction maps derived from spectral unmixing (Staenz *et al*., 1999). Unlike other methods, this approach means that only the crop portion of vegetation (excluding weeds or volunteer crops) is taken into account when estimating LAI. As with the EWT maps, preliminary validation of the LAI_e maps has been encouraging (Staenz *et al*., 1999). This technique will be applied to the new data sets for further validation.

Total Chlorophyll Content

Based on the methodology given in Chappell *et al.* (1992) a map of crop chlorophyll can be generated. In this approach, absorptions in the reflectance spectra due to plant chlorophyll content are enhanced using a ratio analysis. A ratio image is calculated from the original reflectance spectra through two steps. First, the reflectance spectrum recorded for each pixel is divided by the reflectance spectrum of a chosen reference pixel. Then, the ratio image is calculated from the standardised image by dividing the reflectance at 675 nm by the reflectance at 700 nm, which Chappell *et al.* (1992) demonstrate has a strong linear relationship to the chlorophyll concentration.

The slope and intercept of the model are derived by regressing chlorophyll measured in the lab with the reflectance ratio. In the 1999 and 2000 experiments, chlorophyll data were not collected.

Thus the coefficients used for this analysis were defaulted to those given in Chappell *et al*. (1992). The map generated from the Probe-1 images, using this approach, detected variations in chlorophyll content across the test fields. The validity of these chlorophyll maps will be tested against SPAD and nitrogen data collected during the campaigns.

SOIL AND CROP CONDITION DETECTED WITH SYNTHETIC APERTURE RADAR

If remote sensing is to provide operational information for precision farming, SAR imagery must be integrated with imagery acquired by optical sensors. Although, useful crop indicators can be derived from hyperspectral data, image acquisition cannot be guaranteed due to cloud cover. Analysis of the airborne SAR imagery has produced encouraging results (McNairn *et al*., 2000). To date, radar response on three fields (one corn, soybean and wheat) has been correlated with soil and crop measurements. For corn, patterns visible in the radar imagery closely match patterns of soil compaction and elevation across the field. Corn grain moisture data collected at harvest is related to zones of soil compaction as detected on the radar image. Differences in soil texture and moisture across the soybean field meant that crop emergence varied across this field. Backscatter differences closely follow these patterns of soybean emergence. The SAR sensor also detects differences in the onset and rate of senescence across the field of wheat.

SAR was also sensitive to within field variations in crop biomass, resulting from moisture stress. For these fields, excess soil moisture and leaching of nitrogen early in the season stressed grain crops in lower lying areas. These zones of stress are visible on the SAR images acquired during the period of peak vegetation growth. For all three data sets, further analysis will focus on statistical correlations between soil, crop and yield data and SAR backscatter.

CONCLUSIONS

The proposed launch of several new radar and hyperspectral sensors suggests that remote sensing could provide valuable data for precision farming. Information products are being developed at the Canada Centre for Remote Sensing based on imagery acquired by airborne SAR and hyperspectral sensors. These products must be carefully validated and future analysis will focus on the correlation of these image products with ground data. As well, evaluation of these products within crop growth and crop yield models is planned.

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Table 1. Crop and Soil Measurements Taken During the 1998, 1999 and 2000 Field Campaigns

	Soil Variables	**Crop Variables**
Airborne SAR *1998 (soybean, wheat and corn)*	volumetric water content; elevation; texture; compaction	biomass; height; plant water content; LAI; yield stem diameter; grain moisture
Airborne Hyperspectral and SAR *1999 (white beans and corn)* *2000 (peas, wheat and canola)*	volumetric water content; elevation; texture; NPK; ground spectra	biomass; height; plant water content; LAI; yield; nitrogen; SPAD; weed counts; ground spectra; vertical photos