The Sensitivity of C-Band Polarimetric SAR to Crop Condition

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***Abstract* –The Canada Centre for Remote Sensing conducted an intensive field campaign in 2000 at an agricultural test site at Indian Head, Saskatchewan (Canada). Airborne C-Band fully polarimetric SAR data were acquired over the site. The supporting ground information is being used to establish the sensitivity of several polarimetric parameters to variations in crop condition. Preliminary results suggest that several polarizations are sensitive to variations in crop growth and crop stress, particularly in small grain crops like wheat. Information on crop growth gathered from sensors, like RADARSAT-2, could aid in strategies to better manage nutrient applications on agricultural fields.**

I. Introduction

Applying the right amount of fertilizer at the right location and at the right time can substantially impact farming profits and crop productivity. Also important are the implications for the surrounding ecosystems that occur if fields are over-fertilized or if fertilizers are not applied under optimal conditions. Concern has been mounting across Canada about the impact of farm management practices on both surface and ground sources of drinking water. As an example, public concern has pressured the Government of Ontario to introduce the proposed Nutrient Management Act. The purpose of this legislation is to protect groundwater by minimizing the effects of agricultural practices related to farm land-applied nutrients. This Act will set new standards for all land-applied materials containing nutrients relating to agriculture and will make nutrient management plans mandatory.

Spatial information on both soil and crop conditions will be required to formulate and regulate these nutrient management plans. Gathering this information is challenging because of the variability associated with soil and crop characteristics, both spatially and temporally. Some agricultural service providers are beginning to use simple products from optical sensors on satellite platforms for land management planning, but guaranteed delivery of the imagery is problematic due to cloud cover. Synthetic Aperture Sensors (SARs) like RADARSAT-1 and ERS-1/2 have demonstrated the advantages of microwave sensors for agricultural mapping. But to provide meaningful crop information, multiple images must be acquired over time to build up knowledge about the site. With sensors like RADARSAT-2 and ENVISAT ASAR much more crop information will be provided by a single acquisition.

Information on crop growth gathered from sensors, like RADARSAT-2, could aid in strategies for agricultural land use management. To explore the use of SAR and in particular polarimetric data for crop condition mapping, the Canada Centre for Remote Sensing (CCRS) conducted an intensive field campaign in 2000. The purpose of this experiment was to establish the sensitivity of several polarimetric parameters to variations in crop condition and assess the use of these data for farm management planning.

II. Methods

A. Data Acquisition

The Indian Head Agricultural Research Foundation (IHARF) is a producer-based organization sponsored by 25 different government institutions and private industries (http://paridss.usask.ca/precisionfarm/). In 1997, the Foundation purchased a 124 hectare (307 acre) piece of land to dedicate to precision farming research. This research farm is located in southern Saskatchewan (Canada). On 28 June

2000 in collaboration with IHARF, Agriculture and Agri-food Canada and the Universities of McGill, Ottawa and Manitoba, CCRS acquired airborne C-Band fully polarimetric data over this site. Five flight lines were flown over the site at a range of incidence angles (nominally 25°, 30°, 35°, 40°, 45°), using the SAR-580 operated by Environment Canada. Corner reflectors and Polarimetric Active Radar Calibrators (PARCs) were deployed in the study site during the airborne SAR acquisitions. Data from these instruments were used for radiometric calibration of the airborne data. Polarimetric processing and radiometric calibration of the airborne data was accomplished using the CCRS programs PolGASP and ComplexCAL. Within scene calibration accuracies were less than 1 dB [1]. Geocoding of the image was completed using the CCRS program GEOCOR. Image products were synthesized from the complex data using the CCRS software package POLSIG.

On the same day, airborne Probe-1 hyperspectral imagery and Ikonos (multispectral and panchromatic) imagery were acquired over the same test site. Extensive supporting ground data on crop status and crop condition were collected coincident with the image acquisitions. Crops grown on the test site included four fields of wheat, two fields of peas and two fields of canola. Variable strip applications of nitrogen were applied to the wheat fields, and variable planting densities to the pea fields. Measurements of various crop and soil indicators were acquired, including Leaf Area Index (LAI), percent ground cover, crop height and surface soil moisture. Across all eight fields, 308 sampling sites were uniformly distributed on an 80 x 50 m grid and each site was located using a GPS. Soil analysis data were acquired at each of these 308 sample sites. Crop condition measurements were taken at 98 of the 308 sites. Yield monitor data and a high resolution DEM were also available for the eight fields. Within 48 hours of acquisition of the SAR imagery, multi-polarization composites were taken into the field for use in validation. During this validation exercise, qualitative observations were made on the test farm as well as on 30 surrounding fields.

B. Data Analysis

Several polarizations were synthesized from the SAR-580 complex data, including two circular polarizations (RR and RL). Linear polarizations were synthesized by choosing an ellipticity angle (χ) of zero and by varying the orientation angle (φ) at 45° increments from 0° to 180°. Incidence angles over the test site, for the flight line analysed in this paper, were between 42-46°. The SAR image was classified into sixteen clusters using seven of these polarizations as input and a K-Means algorithm. The polarizations used in the unsupervised classification included HH, VV, HV, RR, RL and linear polarizations with $\varphi = 45^{o}$ and $\varphi = 135^{o}$. Extensive ground data are available to validate this classified map. However, preliminary results presented here are based on qualitative observations from the Ikonos and hyperspectral imagery, field validation of the SAR imagery immediately following the acquisitions, and soil maps (soil type and soil moisture). A Normalized Difference Vegetation Index (NDVI) map was created from the Ikonos image. Surface soil moisture was derived from 0-5 cm core samples acquired at each of the 98 sample sites, on the day of the SAR overflight. A soil moisture map was generated from the data collected at each sample point, using an inverse distance weighted interpolation algorithm.

III. Results and Discussion

The 16 classes derived from the unsupervised classification could be aggregated into a number of crop condition zones, based on field observations (Fig. 1). For all crops, these zones of productivity were defined by the crop height and density, and were often linked to differences in soil type and thus soil moisture.

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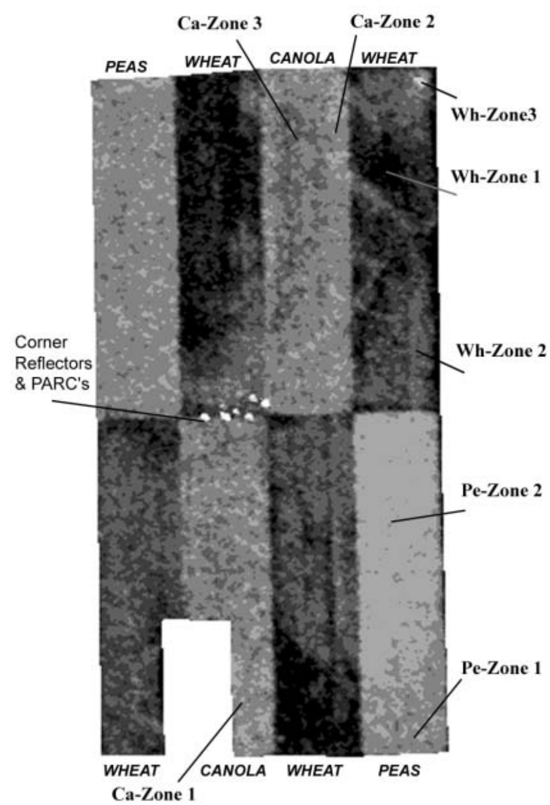

Fig. 1. Crop condition map generated from an unsupervised classification of the SAR image

TABLE 1
FIELD OBSERVATIONS ASSOCIATED WITH ZONES CLASSIFIED FOR WHEAT, PEA AND CANOLA CROPS

	Zone Average Backscatter	Crop Conditions	Soil Moisture & Texture
Wheat – Zones			
Wh-Zone 1	HH (-15.1); HV (-23.3); VV (-15.8)	-taller (40-50 cm) and denser (60-90% cover) -healthier growth	-drier (20-40% moisture) -clay loam and clay
Wh-Zone 2	HH (-11.9); HV (-20.5); VV (-12.6)	-medium (20-40 cm) and less dense (40-60% cover) -moderate growth	-drier (20-40% moisture) -clay soils
Wh-Zone 3	HH (-10.2); HV (-17.7); VV (-10.6)	-shorter (15-30 cm) and less dense (40-60% cover) -crop is stressed and appears yellowish (deficient in nitrogen)	-very wet (40-60% moisture) -gleyed and clay soils
Peas – Zones			
Pe-Zone 1	HH (-9.8); HV (-16.2); VV (-10.1)	- taller (55-75 cm) and denser (90% cover) -very good growth	-drier (10-30% moisture) -clay and clay loam
Pe-Zone 2	HH (-7.4); HV (-14.6); VV (-8.8)	-shorter (25-40 cm) and less dense -poor growth (bottom leaves yellow with brown spots)	-wetter (30-50% moisture) -clay soils
Canola – Zones			
Ca-Zone 1	HH (-9.8); HV (-16.2); VV (-10.1)	- taller (60-70 cm) and denser (70%) -better growth	-drier (10-40% moisture) -clay loam and clay
Ca-Zone 2	HH (-7.4); HV (-14.6); VV (-8.8)	-shorter (40-50 cm) and less dense -poorer growth	-wetter (40-50% moisture) -clay soils
Ca-Zone 3	HH (-10.6); HV (-19.2); VV (-11.2)	-50% weeds -good canola growth (70-90 cm)	-30-50% -clay soils

For the four wheat fields, the seven polarizations classified this crop into six classes. These six classes represented three growth zones (Table 1). The NDVI map, as well as the field observations, indicated that the crop condition in Zone 1 was very healthy. These zones were associated with well drained soils on upper slopes and consequently, wheat plants were taller and denser. The unsupervised classification also detected zones of moderate wheat growth. NDVI values were lower in these zones relative to Zone 1. Although wheat plants were shorter and growth was less dense, plants were still characterized as healthy. Saturated soil conditions were evident in pockets of gleyed soils found throughout the farm, and in regions of clayey soils in lower slopes. In these areas (Zone 3) crops were stressed. Bottom leaves were yellow, suggesting nitrogen deficiency, and plants were shorter.

Fewer classes were generated for the two broadleaf crops – peas and canola. Backscatter differences between zones were less for these crops (~ 1-2.5 dB) when compared to differences observed between zones identified for wheat (~2-3 dB). Four classes were identified in the pea crops, associated with two zones of crop condition. These zones were also associated with soil type, drainage and slope position (Table 1). In zones of poor growth, bottom leaves of the pea plants were yellow with noticeable brown spots (Zone 2). Five classes of canola represented two crop growth zones (Zones 1 and 2) with a third zone characterized by significant weed infestations. In Zone 3 the canola crop appeared healthy and vigorous, but approximately 50% of the area was infested with wild oats. Vegetation (crop plus weeds) in this region was dense, with significantly higher NDVI values relative to the other two zones.

For all three crops, backscatter for all seven polarizations was lower for zones of better crop growth. Table 1 lists the zone average backscatter for the linear polarizations. Other polarimetric parameters are being generated from these data including the pedestal heights, phase differences, and decomposition parameters. These parameters will be used to interpret the dominant scattering sources for these zones. Quantitative analysis will relate ground measurements to radar responses. With this data set, the sensitivity to crop condition as a function of incidence angle can also be studied.

Conclusions

SAR-580 fully polarimetric data were acquired over fields of wheat, peas and canola. Preliminary observations indicate that linear and circular polarizations can detect zones of crop condition characterized by variations in crop height and density. Further analysis is planned to quantify this sensitivity as a function of polarization and incidence angle. Other polarimetric parameters will be used to establish the dominant sources of scattering. These preliminary results indicate that SAR sensors like RADARSAT-2 could provide useful soil and crop condition information for use in nitrogen and land management planning.

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References

[1] R.K. Hawkins, R. Touzi, A. Wind, K. Murnaghan, and C.E. Livingstone, “Polarimetric calibration results and error budget for SAR-580 system,” *Proceedings of CEOS Workshop*, Toulouse, France, 26-29 October, 1999.