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REVIEWING THE ROLE OF RADAR IN MAPPING SOIL MANAGEMENT PRACTICES[*]

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ABSTRACT

Information on soil conservation practices, including tillage practices and crop residue management, is required to accurately estimate soil erosion risk, to establish indicators of soil quality and to predict agricultural loadings to surface waterways. A number of recent studies have examined the role of radar in providing information on tillage and crops residue management practices. These studies have concluded that microwaves interact with tillage-induced roughness and as a result, radar imagery may provide useful information on type and timing of tillage. Less is understood about the interaction of microwaves with crop residue cover, but significant correlations between backscatter and residue cover have been observed. This paper briefly summarizes two recent studies which examined the interaction of linearly polarized microwaves (focusing on C-HH) with tilled and residue covered surfaces. The paper then discusses the role of multi-dimensional SAR configurations, including the use of polarimetric SAR parameters, in more completely defining soil management practices. Preliminary results from the 1994 SIR-C data gathered over southern Manitoba suggests that cross-polarized responses and enhanced pedestals associated with multiple scattering may be useful in identifying type and amount of residue.

1.0 INTRODUCTION

Across all agricultural regions of Canada, controlling wind and water erosion continues to be a significant concern related to long-term agricultural productivity. Cropping and tillage practices directly impact the health of the topsoil, but up to date information related to farm management practices is often difficult to acquire. On-site surveys are conducted from time to time but in general, these surveys do not provide information at the spatial coverage or temporal frequency required for evaluating and monitoring these agricultural practices.

Researchers have investigated the use of remote sensing, and in particular, the use of visible-infrared sensors for mapping management practices. Visible-infrared ratios have been correlated with amounts of post-harvest residue (McNairn and Protz, 1993) and work is continuing to further refine these techniques. However,

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within Canada, collecting data on residue management practices is extremely time critical and difficulty often arises in acquiring cloud-free optical imagery in the relative short period between crop harvest and snowfall, and between spring snow-melt and crop emergence.

The all weather capability associated with the longer microwave wavelengths makes the use of this data attractive for mapping cropping and tillage practices. However, microwaves respond to very different target characteristics and in general, it is the moisture content and the geometric characteristics of the target which determine the amount of energy scattered back to the sensor. On a post-harvest agricultural surface, this suggests that the surface soil moisture and the surface roughness are significant contributors to radar backscatter. Several studies have demonstrated that radar responds to the soil surface roughness as created by various tillage implements (Brisco *et al*., 1991; McNairn *et al*., 1996). Some surfaces, in particular no-till and minimum till surfaces, can have significant residue cover, but less is understood about the interaction of microwaves with this post-harvest crop residue.

This paper reviews results from two recent studies which examined the backscatter response to residue using a ground based scatterometer and the response to residue and tillage using RADARSAT data. Both of these studies focused on mapping tillage and residue conditions using linearly-polarized SAR configurations, in particular C-HH. However, the results suggest that multi-dimensional SAR configurations, including the use of polarimetric SAR parameters, may be required to more completely define these management practices. In April and October 1994, SIR-C acquisitions occurred over southern Manitoba. This paper describes the analysis of this data set for residue/tillage mapping and presents some preliminary results.

2.0 PROVIDING TILLAGE INFORMATION FROM RADARSAT

RADARSAT imagery and ground information were gathered over Altona, Manitoba during 3 weeks in October 1996 (see McNairn *et al*., 1998 for details). A RADARSAT Standard Mode beam pair (Standard 3 on October 10 and Standard 2 on October 17) was acquired early in the fall just after harvest and during the period of mostly primary tillage. A single Extended High Mode scene (EH1 on October 23) was acquired later in the season. In general, data collected at shallower incidence angles tend to provide more information on management practices (McNairn *et al*., 1996). During the 3 week field campaign, management practices were characterized on approximately 200 fields across the study site. Information gathered on each field included tillage type (chisel, harrow, moldboard, no-till) and number and direction of tillage passes. Residue type and an estimate of percent residue cover were also recorded for each field. Analysis of the RADARSAT scenes was primarily through visual interpretation, although for the Standard 3 and Extended High images, field average backscatter values were calculated for selected fields. Also, a difference image was created by subtracting the October 17 image from the October 10 image.

Results suggested that residue cover alone accounted for about a quarter of the variation in C-HH backscatter from field to field, although discrimination among grain residue classes was poor. For no-till surfaces on the Extended High image, larger residue such as corn had very high returns (-4.9 dB, on average) relative to finer residues such as beans (-12.7 dB, on average). RADARSAT was also able to detect the occurrence of tillage. When the October 10 and October 17 images were compared, surfaces tilled (primary tillage) during this one week interval showed an average 5 dB increase in backscatter. The study concluded that using only RADARSAT data, it would be possible to map fields into 3 broad classes: fields with low, intermediate and high erosion potential.

It is clear from this analysis that RADARSAT can provide information on tillage and can detect fields which remain in no-till. However, the study concluded that using SAR data alone, particularly with a single configuration or a single date, it would be difficult to map fields into the detailed cropping and management classes required by most erosion models. McNairn *et al*. (1998) proposed a framework to use multi-polarized SAR, along with visible-infrared data in order to better define tillage and residue classes.

3.0 A MULTI-FREQUENCY AND MULTI-POLARIZED APPROACH FOR MAPPING RESIDUE COVER

During the Fall of 1996, an experiment was conducted at the Agriculture and Agri-Food Canada Central Experimental Farm in Ottawa to address the importance of residue type, residue moisture content and residue amount to backscatter (see McNairn *et al*., 1997 for details). During 9 days of data collection, the Canada Centre for Remote Sensing's ground based scatterometer gathered C- and L-band data (all 4 linear polarizations and incidence angles from 20^o to 50^o at 10^o increments) over corn and barley residue plots. Treatments varied by residue amount and residue moisture level. To isolate the effect of residue cover alone, residue levels were varied by applying different harvesting techniques. This approach ensured that roughness conditions were consistent among the plots. Backscatter values were correlated with residue gravimetric moisture, derived from above ground residue samples, and with volumetric soil moisture.

Results from this scatterometer experiment suggested that for grain residue, RADARSAT (at steep incidence angles) and ERS-2 (C-VV at a steep incidence angle) configurations would define residue covered surfaces from bare surfaces. Also, if RADARSAT acquired data at shallow angles, and the residue was wet, some additional information would be provided on grain residue cover. For larger residues such as corn, a C-HH configuration could identify if the surface is covered with residue, and may provide additional information such as harvesting technique, amount of residue and residue position. However, for both residue types, cross-polarizations provided the best discrimination among residue treatments. At an incidence angle of 40^o, C-HV backscatter differentiated 90% of the corn residue treatment comparisons. However, in terms of grain residue, a combination of C-band polarizations were required to separate all classes. When examining separation of residue classes using L-band backscatter, cross-polarizations provided the best results. Using L-HV at shallow angles, backscatter from all grain and corn treatments was statistically different.

4.0 EXAMINING POLARIMETRIC DATA FOR MAPPING RESIDUE AND TILLAGE CHARACTERISTICS

Primarily as a result of sensor constraints, until recently most research has focused on the use of amplitude or polarization diversity radar (in particular the use of HH and VV polarizations) for classifying agricultural scenes or quantifying agricultural target parameters. Polarimetric SARs however, may be useful in more fully characterizing the scattering behaviour of agricultural targets and thus may resolve classes which are confused using RADARSAT or ERS-2 configurations. A fully polarimetric radar records all 4 mutually coherent channels (HH, VV, HV and VH) and more completely defines the scattering properties of the target.

A number of parameters derived from polarimetric SARs may be useful in characterizing agricultural targets. For example, the degree of polarization (Groot *et al*., 1992), polarization ratio, pedestal height (de Matthaies *et al*., 1992) and co- and cross-polarized phase differences (Hoekman *et al*., 1992) may be important in characterizing agricultural targets. Boerner *et al*. (1998, in press) provide a complete discussion of polarimetric parameters. Cross-polarization returns are a result of the depolarization of incident waves, which are primarily due to either multiple scattering from rough surfaces, or volume scattering (Hirosawa *et al*., 1978). The pedestal height indicates the presence of an unpolarized scattering component. As a result of multiple scattering, polarization varies randomly from pixel to pixel, causing a pedestal that increases the minimum power of all polarizations. Van Zyl *et al*. (1987) observed an increase in the pedestal height with increasing surface roughness.

The SIR-C dataset collected over Altona, Manitoba was used to explore the use of polarimetric parameters for identifying tillage operations, including the amount and type of residue cover. The characteristics of the quad-pol datasets used in this analysis are listed in Table 1 and the radiometric calibration of the SIR-C data is summarized in Freeman *et al*. (1995). The data were pre-processed after acquisition as single look complex and were delivered to the Canada Centre for Remote Sensing fully calibrated.

During both the April and October field campaigns, information on surface conditions was collected coincident with SIR-C acquisitions. Quantitative data were gathered on surface soil moisture and surface roughness on 13 fields across the site. Qualitative information on percent residue cover, residue type and residue/tillage direction were recorded on approximately 100 fields. A complete description of the study site and details about the data collection are described in Pultz *et al*. (1997).

Prior to information extraction, the SIR-C data were decompressed and multilooked. Multilooking created relatively square pixels and reduced data volumes. Bitmaps were then drawn over selected fields and field average statistics generated for C- and L-bands included: HH, VV and HV backscatter, total power (span), co-polarized pedestal height, maximum backscatter, co- and cross-circularly polarized backscatter and co- and cross-polarized phase differences. C- and L-band polarization plots were also generated for each field.

When completed, this study will address the use of linearly polarized and polarimetric statistics for discriminating residue type and residue amount. This paper specifically describes preliminary results for identifying residue type using polarization plots and statistical analysis of polarization parameters. To establish the statistical separability of targets (at a probability level of < 0.05) based on residue type, a multiple range test was applied to the field average statistics. To minimize the influence of residue amount, fields were divided into those with high residue levels (> 50% cover) and low levels (<50% cover) according to field observations. In April, the following residue classes were present: grain (high and low), canola (high and low), lentils (low), peas (low) and corn (high). In October, several crop were senesced, but not yet harvested. The classes present for October included: canola (low), grain (high and low), corn (senesced but not harvested), sunflower (senesced but not harvested), sugarbeets (not harvested) and beans (low).

Similar to the results of the ground based scatterometer experiment, results from the SIR-C data suggest that the cross-polarizations (particularly at L-band) provide important information for residue type separation (Table 2). In both the April and October datasets, L-HV or the L-band pedestal height was able to separate most residue types. This suggests that multiple scattering is likely occurring on some of these residue surfaces and that cross-polarized backscatter and pedestal height may provide similar information. Backscatter from grain and canola residue was not statistically separable and field photographs confirm that these surfaces have similar residue and tillage conditions. Also, scatterplots of the backscatter from grain residue fields demonstrated very large variations in backscatter within this class, suggesting that the residue and tillage characteristics on these surfaces are quite varied. This variation contributes to class confusion.

In Figures 1 and 2, a sample of co-polarization plots are provided. Sample sizes varied depending on field size, but in general, several hundred samples were used to generate each plot. The first group of plots from April compare responses as a function of residue type. The C-band pedestal heights and shape of the plots are very similar for both canola and peas. Maximum returns are at linear polarizations with slightly higher responses at VV. For both the corn and grain no-till fields, C-band pedestal heights are higher, suggesting a greater degree of multiple scattering and VV returns are lower relative to HH. At L-band, canola, grain and peas provide similar plots with a maximum return at VV, a response characteristic of surfaces which appear flat relative to the wavelength (Groot *et al*., 1992). The pedestal height for peas is slightly lower suggesting a smoother surface, although the L-band pedestal for corn residue is significantly increased.

In Figure 2, comparisons are made on the basis of residue amount using the October dataset. Standing senesced corn is similar to no-till corn residue from April. However, as a result of the greater volume of vegetation associated with standing corn, the pedestal height is higher and differences between HH and VV returns are enhanced. Low bean and grain residue, for both C- and L-bands have lower pedestals and similar HH and VV responses. When compared with no-till surfaces, pedestal heights are significantly enhanced, likely due to the increased interaction with standing residue. At L-band, there is a maximum return at VV, similar to that observed in the April dataset.

These plots demonstrate that by examining the complete scattering characteristics of the target, many classes can be differentiated. Residue cover does appear to influence backscatter, with the most obvious effect being an increase in multiple surface scattering producing enhanced pedestals.

5.0 CONCLUSIONS

Both the ground-based scatterometer experiment and the data collected from RADARSAT indicated that linearly polarized backscatter coefficients can be used to provide some information on cropping and tillage practices. However, using a single SAR configuration, it would be difficult to map surfaces into the detailed categories required by most erosion prediction models. Preliminary results from polarimetric SIR-C data gathered over Altona, Manitoba suggests that significant multiple scattering is occurring from surfaces with greater residue amounts. Sample co-polarization plots presented indicate that the scattering mechanisms are different depending on the type and amount of residue. Further investigation is planned into the separability of these surfaces using a number of polarimetric parameters.

6.0 REFERENCES

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Table 1. Quad-Pol SIR-C Acquisitions over Altona, Manitoba

Date	Frequency	Orbit	Incidence Angle
April 10/94	L & C	Asc	33^o
April 11/94	L & C	Asc	38^o
April 12/94	L & C	Asc	44^o
Oct 2/94	L & C	Asc	38^o
Oct 3/94	L & C	Asc	43^o
Oct 5/94	L & C	Asc	51^o

Table 2. Frequency-Polarization Configurations for Separating Surface By Residue Type

April 12, 1994						
	Canola (low)	Grain (low)	Lentils (low)	Grain (high)	Canola (high)	
Grain (low)	▨ all L-Band			---	---	
Lentils (low)	▨ L-HH,L-HV, L-ped	▨ all but C-max		---	---	
Peas (low)	none	▨ all but C-VV & C-max	▨ L-HV	---	---	
Corn (high)	---	---	---	▨ L-HH, L-HV, L-TP, L-ped	▨ L-HH, L-HV, L-TP, L-ped	
Grain (high)	---	---	---		none	
October 5, 1994						
	Canola (low)	Grain (low)	Beans (low)	Corn	Sugarbeets	Sunflowers
Grain (low)	none					
Beans (low)	▨ all L-band	▨ all L-band				
Corn	▨ all	▨ all but C-VV	▨ all			
Sugarbeets	▨ all	▨ C-HV, L-HV, C-ped, L-ped	▨ all	▨ all but C-VV and C-HV		
Sunflowers	▨ all but C-VV	▨ all but C-VV	▨ all	C-HH, C-max, L-HH	▨ all L-band	
Grain (high)	---	---	---	▨ all	▨ all	▨ all

all = separable using C- and L-band: HH, VV, HV, TP (total power), maximum backscatter, pedestal height
none = not separable using any configuration
shaded = separable using either cross-polarizations or pedestal height
--- = not compared