Mapping Tillage and Crop Residue Management Practices with RADARSAT

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Abstract

Mapping tillage activities, and the corresponding crop residue cover, is important for monitoring the adoption of conservation tillage practices and for quantifying wind and water erosion. Previous studies have demonstrated that remote sensing data can provide information on residue and tillage management practices. To determine the role of RADARSAT in mapping these practices, SAR imagery and corresponding ground data were gathered over a site in southern Manitoba in October of 1996. No-till surfaces could be identified on imagery collected at shallow incidence angles and radar returns were affected by the type of residue on these surfaces. Using a second data set and a change detection approach, tillage events and harvesting activities were detected using Standard Mode RADARSAT data. Although further investigation into this application is required, this study concludes that RADARSAT can provide some information critical to determining soil erosion risk.

Introduction

The frequency of tillage, as well as the type of tillage implement used, can significantly affect the health and erodibility of agricultural soils (Morgan *et al*., 1979). Residue left on the soil surface after harvest and cultivation provides protection from the impact of rainfall and impedes the movement of soil particles by wind and water. The reduction in the decomposition rate of residue as a result of reduced tillage also increases soil organic matter content. The maintenance of soil structure that occurs in minimally tilled soils also helps decrease erosion potential and these soils also have a greater amount and diversity of soil fauna (Blevins *et al*., 1983). The amount of residue left on the soil surface can be increased by reducing the number of tillage occurrences and/or by using conservation tillage equipment, which are designed to minimize soil disturbance. In addition, the timing of tillage relative to meteorological and soil conditions is important in minimizing erosion potential. Maximum residue cover should be maintained during periods of significant rainfall and runoff.

Mapping tillage characteristics, and the corresponding crop residue cover, is important for monitoring conservation tillage adoption and for identifying areas susceptible to wind and water erosion. However, information regarding agricultural practices is difficult to obtain using conventional field surveys on a timely, cost effective basis and at an acceptable level of accuracy. Although some research has demonstrated the ability to map residue levels using optical remote sensing data (McNairn and Protz, 1993), the acquisition of imagery for this application is time critical and cloud and snow cover can seriously affect the operational use of optical imagery. In contrast, the longer wavelengths associated with microwave energy mean that collection of SAR data is virtually unaffected by atmospheric conditions including cloud cover, suggesting that radar sensors can often be an important data source for time critical agricultural applications.

The management practices applied to agricultural fields during fall and spring activities is both numerous and complex. The surface characteristics are a result of a combination of factors including type of tillage implement, number of tillage passes, timing of tillage, depth of tillage, direction of most recent and previous tillage, as well as the type and amount of crop residue cover. Many of these characteristics have first order effects on the backscatter response from the surface. Crop and tillage row directions relative to the radar look direction can have a significant effect on radar backscatter. Furthermore, different tillage practices often create varying degrees of surface roughness and previous research has demonstrated that backscatter is dependent, to some extent, on the type of tillage implement used (McNairn *et al.*, 1996; Major *et al.*, 1993). Residue can also retain significant amounts of moisture and if present in sufficient quantities, will also affect backscatter (McNairn *et al.*, 1997). Environmental conditions, including rain events and freezing and thawing of the soil surface, can also have significant effects on backscatter and must be considered during the interpretation of SAR imagery.

Most studies related to tillage mapping using SAR data have examined backscatter recorded by ground scatterometers (Brisco *et al.*, 1991; McNairn *et al.*, 1996; Smith and Major, 1996; McNairn *et al.*, 1997) or by ERS-1/2 (Solberg and Weydahl, 1992; Smith *et al.*, 1995). However the flexibility of RADARSAT for data acquisition suggests that this sensor is well suited for monitoring tillage activity, if its sensitivity to these events can be demonstrated. The objective of this study was to investigate whether information on tillage and residue can be derived from RADARSAT imagery. To address this objective, RADARSAT and ground data were gathered over a site in southern Manitoba in October of 1996.

Methodology

The Altona study site is located in southern Manitoba (49^{o} 4.9’ N, 97^{o} 39.6’W) and covers an area of approximately 26 km (E-W) by 7 km (N-S). The land use and economy of the area is based on intensive and diversified agricultural production. Agricultural crops include cereal grains, sunflower, canola, flax, corn, sugarbeets, potatoes and specialty crops such as canary seed, peas, beans and lentils. The topography of the region is relatively flat and thus the site is well suited for radar applications research. The dominant soil types of the study area are sandy loam to the west, changing to heavier clayey soils in the east.

RADARSAT imagery and the accompanying ground information were collected over a period of three weeks in October 1996. Prior to the field campaign, all crops had been harvested with the exception of corn and sunflower. Almost exclusively, chisel ploughs are used as a primary or secondary implement by farmers in the region to work post harvest fields, although a moldboard may be used as a primary implement on corn residue fields. However, the number of tillage passes varies and could range from none (in the case of no-till) to as many as four. The type of implement used, and the number of passes, directly determines residue cover. Harrows are often used once or twice following the chisel in order to evenly distribute remaining residue over the soil surface.

A RADARSAT Standard Mode beam pair (October 10 and 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 (October 23) was acquired later in the season (Table 1). 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), as well as number and direction of tillage passes. Residue type and an estimate of percent residue cover (using the knotted rope method) were also recorded for each field. During the course of the experiment, only minimal precipitation occurred and consequently, soil moisture conditions during the period were relatively stable. No precipitation occurred between the October 10 and October 24 acquisitions.

Table 1. List of RADARSAT Acquisitions (October 1996)

RADARSAT Mode	Orbit	Incidence Angle	Nominal Resolution (m) rg x az*	Date
Standard 3	Ascending	30-37^o	27.6 x 27.0	October 10
Standard 2	Ascending	24-31^o	22.0 x 27.0	October 17
Extended High 1	Ascending	49-52^o	19.8 x 27.0	October 23

* Measured resolution is approximately 10% better than specification

Prior to image interpretation, the processor applied look up table was removed from all 3 scenes, creating radar brightness (β^o) images. Radar brightness is the mean radar reflectivity per unit pixel area in the slant range and the calculation of β^o does not require knowledge of the local incidence angle (Raney *et al*., 1994). Analysis of the RADARSAT scenes was accomplished primarily through visual interpretation. In the case of the Standard 3 and Extended High images, for selected fields, field average values (in power) were calculated and these averages were then converted back to radar brightness. The most recent antenna pattern correction and payload parameter file had been applied to the two standard mode scenes and consequently, the data quality and calibration accuracies of these data are consistent with those reported by Srivastava *et al.* (1997). Calibration uncertainties are greater with the extended high beams and these uncertainties were taken into consideration in the interpretation of the results. The Altona study site falls approximately in the centre of the RADARSAT image swath for all 3 acquisitions. The central location of the scenes in the SAR beam avoids the larger positional and radiometric uncertainties associated with the beam edges.

Although a large number of observations were recorded during the campaign, image interpretations were based on field observations only when it was certain that no further activity had occurred on the fields between the date of image acquisition, and the time of the field observation. In addition, a wide range of field conditions (tillage direction, number of passes, residue type) were observed and as a result, actual backscatter values were extracted when a sufficient number of sample fields were available.

The RADARSAT data were geocoded using the satellite ephemeris information and a second order cubic convolution resampling algorithm. Each image was then registered to a field boundary vector map. Root mean square resampling errors were within a pixel. An early season difference image was created by subtracting the October 17 backscatter image from the October 10 backscatter image and a three colour composite was created using October 10 (blue), October 17 (green) and the difference image (red). A 3x3 median filter was applied to the final image composite to reduce the speckle effect and thus to aid in visual interpretation. The difference in incidence angle between the two standard mode scenes was approximately 6^o. Although surface responses are incidence angle dependent, this small incident angle difference is of secondary importance when comparing the two images. Interpretation of the difference image is based on large visual field-by-field tonal differences which cannot be accounted for solely by these relatively small differences in incidence angle.

Results and Discussion

Tillage activities varied considerably across the study site, with the range of practices increasing over the 3 week period. Early in the experiment, many fields had not been tilled and those that were tilled had only a single tillage application. In contrast, at the time of the last RADARSAT acquisition, the majority of the fields had been tilled at least once. Although most surfaces were tilled with a chisel plough, the number of passes varied and in many cases, 2 or 3 different tillage directions were visible at the time of field characterization. Each tillage pass incorporates more of the surface crop residue. Primary tillage tends to increase surface roughness, while secondary and tertiary tillage smooths the surface created by the primary implement (McNairn *et al*., 1996).

Residue Effects on RADARSAT Backscatter

The October 10 Standard Mode image was used to establish the contribution of residue cover to backscatter by correlating field average backscatter values with percent surface residue, for all residue types and over all fields. The regression was statistically significant (at $p < 0.05$) and produced a moderate correlation coefficient ($R = 0.53$) indicating increasing backscatter with increasing residue cover (Figure 1). Backscatter varied 3 - 4 dB when comparing returns from high residue cover and low residue cover. The scatter of points around the regression line is partially a result of the fact that only one residue measurement was taken on each field and residue cover can vary across the field. In addition, this scatter also indicates that many factors are not accounted for in this simple regression, including residue type and tillage application. As well, some variation may be a function of calibration uncertainties or incidence angle effects, although these effects are minimized since the site covers a relatively small area in range (incidence angle range of approximately 2^o). The variation in backscatter at low residue cover may be related to the influence of surface soil moisture. However, even with this relatively large residual error, residue cover alone accounts for about a quarter of the variation in backscatter from field to field.

Large differences occur in field average backscatter related to residue cover on no-till surfaces, even late in the season (Figure 2). Larger residue types such as corn on no-till surfaces have very high returns relative to finer residues, such as beans, which have very low returns. These low returns are a result of the small amount of residue cover and the very smooth soil surface associated with no-till beans.

To determine if RADARSAT is sensitive to varying amounts of grain residue on tilled surfaces, average backscatter values for grain residue fields on October 23 (Extended High) were calculated (Table 2). Sample numbers for other residue/tillage classes were too few to incorporate in this table. These values suggest that average backscatter does not vary as a function of grain residue amount, when returns from the high (> 50% cover) versus low (< 50% cover) residue categories are compared. Observed differences were well within the calibration accuracy of the sensor. Table 2 also demonstrates that greater variability in backscatter occurs among fields within a single residue/row direction class (as much as 3 - 4 dB), relative to the variability between the classes (< 1 dB). Poorer discrimination among grain residue classes, relative to other residue types, has been reported by McNairn *et al*. (1997) and Smith and Major (1997). However, it is difficult to draw conclusions regarding grain residue class separability from this study, because of the relatively small sample numbers. Confusion among grain residue classes is partially a function of the small size of the residue relative to wavelength, and is also related to the lower amounts of residue (g/cm^2) which are left following grain harvest. Also of importance is the fact that residue was dry during this experiment and some research has reported that, particularly for grain residue, significant moisture (as would occur after a rainfall) must be present in order to detect differences in amount of residue (McNairn *et al.,* 1997). Interpretation of the Extended High image suggests that after most of the fall tillage has occurred, separating residue categories for fine residues such as grain and beans would be difficult. In spite of these quantitative results for grain residue, differences in type of residue cover on no-till surfaces are visually detectable.

Table 2. Average Backscatter From Grain Residue Fields (Extended High Beam 1)

	north-south (perpendicular) tillage direction			**diagonal tillage direction**		
	max	**mean**	*min*	*max*	**mean**	*min*
low residue	*-9.5*	**-10.8** (N=11)	*-13.2*	*-9.7*	**-10.8** (N=4)	*-11.8*
high residue	*-9.7*	**-10.5** (N=4)	*-11.3*	*-9.9*	**-11.1** (N=6)	*-12.1*

Detection of Tillage and Harvesting Activities

Large field-by-field differences are clearly visible when comparing the two Standard Mode images (Figure 3). Based on field data, these differences are related to tillage and harvesting activities which occurred during the one week interval between image acquisitions.

Very dark fields in the October 10 image correspond to smooth fine residue fields (beans and small grains) which were either in no-till or had only minimal tillage applied (a single tillage pass) (Figure 3). The RGB composite (Figure 3) shows that when no further tillage had occurred on these fields, backscatter remained low for October 17 and these fields appear as dark brown (average difference in backscatter was 0.7 dB). Conversely, for a number of the fields, tillage occurred during the one week interval between acquisition of the images, resulting in an increase in surface roughness and a corresponding increase in backscatter (on average, 5.6 dB increase in backscatter). Bright orange fields on the colour composite represent fields on which some tillage had occurred. Bright blue fields indicate standing senesced corn which remained unharvested on October 17. Dark blue fields had a reduction in backscatter from October 10 to October 17 and according to field observations, had been harvested between image acquisitions. These dark blue fields are no-till corn on October 17. Small changes in backscatter between the two dates may represent incidence angle effects. For some of these fields however, small changes may also indicate the occurrence of secondary or tertiary tillage applications

Implications for Mapping Conservation Practices with RADARSAT

Results from both the Extended High and Standard beam images have specific implications for the use of RADARSAT for tillage and residue mapping. It is clear from the analysis that, backscatter from some residue and tillage classes is different. However, the variations in backscatter related to some classes, such as small grains, suggest that separation of some tillage and residue classes using backscatter coefficients alone may be difficult. These within class variations are likely a result of the limited number of field observations available for some classes and the complexity resulting from management practices, particularly later in the fall. However, the results show that particularly for larger residues such as corn and sunflower, RADARSAT can define no-till surfaces and may be able to identify timing of primary tillage, both of which are important in conservation monitoring. Larger residues which provide better protection from wind and water erosion can also be separated from finer residues. Fields which are tilled in the spring as opposed to the fall experience significantly less soil loss (Moore *et al*., 1986).

To further define residue and tillage classes is more difficult and therefore, the timing of RADARSAT acquisitions is critical, especially for fine residues such as grains. Acquisitions during periods of high residue moisture, for example just after spring snowmelt, will likely provide the best class separation. Further analysis is required to determine if larger residues such as corn, canola and sunflower can be separated beyond tilled versus no-till using RADARSAT imagery.

A Framework to Map Tillage and Residue Characteristics

Although tillage and residue combinations create complex surface conditions, it is critical that these conditions be identified in order to determine the amount of erosion that is likely to occur. This study, as well as previous studies, have demonstrated that SAR is sensitive to the occurrence of tillage, tillage and residue row direction, type of residue, amount of residue and tillage implement used. However, mapping of any of these individual characteristics is difficult due to the confounding effects of these surface conditions and other factors on the SAR signal returned to the sensor.

By 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. However in practice, erosion risk modelling exercises use extremely limited input information related to cropping and management applications. In many operational cases, no information on practices is available and as a result, erosion estimates are based only on site physical characteristics - soils, slopes and rainfall. Without information on management practices, erosion models can grossly overestimate soil loss since, for example, soil loss can be reduced by as much as 75% if adequate amounts of residue are retained on soil surfaces (Ketcheson and Stonehouse, 1983). When management information is gathered, it may be collected only sporadically, on a limited number of fields, and is often reported as a county average (as an example, refer to Coleman and Roberts, 1987). Furthermore, information regarding the timing of tillage is usually not available.

Given results from this study, radar data can provide broad conservation classes and can substantially improve many erosion risk estimates. For example, the RGB difference image created with the RADARSAT Standard Mode data suggests three obvious classes:

(Class 1) Fields with low erosion potential: These fields are characterized by significant residue cover and have bright radar returns (no-till corn and no-till sunflower).

(Class 2) Fields with intermediate erosion potential: These fields are relatively smooth, fine residue fields with little or no tillage and have low radar returns. Although residue amounts are less than the above class, with no disruption to the soil from tillage soil loss would be expected to be lower than Class 3.

(Class 3) Fields with higher erosion potential: These fields have had some tillage and reduction in residue and exhibit intermediate gray tones.

The Standard Mode images also demonstrate the ability of radar to provide information on when fields are tilled (and with more images, perhaps number of tillage occurrences). As stated previously, this information is critical in erosion modelling and is very difficult to establish using ground data collection. Above and beyond these gross management categories and mapping of tillage events with SAR, further refinements can be made using additional remote sensing data, or ancillary information and knowledge. Figure 4 provides an example of how this framework might look. A similar approach to agricultural classification using remote sensing is presented by Smith *et al.* (1995).

The framework presented in Figure 4 begins with the segmentation of the study site into agricultural areas, and then into crop type. Using TM images, Bober *et al*. (1996) demonstrated that agricultural crops (particularly corn, soybeans and cereal grains) can be classified with a high level of accuracy (kappa coefficient of 0.89). Alternatively, multitemporal SAR data could provide this classification. Crop type mapped during the growing season then dictates post-harvest residue cover type.

The current study demonstrates that no-till bean, grain and corn fields are detectable using RADARSAT imagery, and that the occurrence of tillage can also be determined. Low amounts of residue are generally left behind after harvesting of beans and consequently, even primary tillage significantly reduces residue cover. The low residue cover and disruption of the soil structure associated with tilled bean surfaces makes these surfaces more susceptible to wind and water erosion. No-till beans have less residue than other post-harvest surfaces, but the maintenance of soil structure reduces erosion risk.

Results from this study indicate that further refinement of tilled grain surfaces is more difficult, especially if residue conditions are dry. One alternative would be to link residue cover reductions to number of tillage events and to use SAR imagery to track the occurrence of these tillage passes. McNairn *et al.* (1997) also suggest that more information on grain residue cover may be available using cross-polarizations.

Using a single date Landsat TM image, McNairn and Protz (1993) easily separated corn residue cover into 2 classes (88% classification accuracy). Unlike SAR imagery however, optical imagery is not as sensitive to changes in surface roughness and thus no-till surfaces can be confused with surfaces which have been tilled, but still maintain a large residue cover. Further separation of surfaces with > 30% residue cover may be possible using SAR imagery (McNairn *et al*., 1996 and 1997). However, these studies suggest that careful attention must be given to acquiring imagery in the optimal SAR configuration (incidence angle, polarization and frequency), as well as to the timing of SAR acquisitions.

Conclusions

Gathering information on tillage and residue conditions is important for soil erosion modelling, but is difficult to collect operationally using ground surveys. In this study, three RADARSAT scenes acquired over Altona, Manitoba were examined and the information content of C-HH SAR data was evaluated for this application.

Analysis of the 3 dates of imagery indicated that particularly for larger residues, RADARSAT can define no-till surfaces and may be able to identify timing of primary tillage, both of which are important in conservation monitoring. Larger residues which provide better protection from wind and water erosion can also be separated from finer residues. When examining the correlation between residue amount and backscatter, the study found 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.

Results from this study demonstrate that RADARSAT could be used to provide broad conservation classes. However, 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 many erosion models. Consequently, a simple framework is proposed which uses multi-polarized SAR, along with visible-infrared data to better define these tillage and residue classes.

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