Using RADARSAT to Map Tillage and Residue on Agricultural Fields

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Abstract

Mapping tillage characteristics, and the corresponding crop residue cover, is important for monitoring the adoption of conservation tillage practices and for quantifying wind and water erosion. To investigate the potential of RADARSAT for identifying tillage and residue characteristics, RADARSAT and ground data were gathered over a site in southern Manitoba in October of 1996. From the limited analysis completed to date, results are encouraging for detecting some residue and tillage classes early in the fall using RADARSAT data. Once fields have been tilled several times, differences in surface roughness and residue conditions among fields are reduced and separation into distinct classes is difficult. Consequently, the timeliness of RADARSAT coverage will be important for this application.

Introduction

The frequency of tillage, as well as the type of tillage implement used, can significantly impact the health and erodibility of agricultural soils. Mapping tillage characteristics, and the corresponding crop residue cover, is important for monitoring conservation tillage adoption and for quantifying wind and water erosion. Tillage and the presence of residue cover can also significantly impact the use of radar for other applications such as soil moisture mapping.

Different tillage practices can create varying degrees of surface roughness and previous research has demonstrated that backscatter is tillage dependent (McNairn *et al.*, 1996; Major *et al.*, 1993). However, although research experiments have provided promising results, the range of management practices applied to agricultural fields 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 type and amount of crop residue cover. The objective of this study was to investigate the potential of RADARSAT for identifying tillage and residue characteristics. To address this objective, RADARSAT and ground data were gathered over a site in southern Manitoba in October of 1996.

Methodology

The study site is located in southern Manitoba, centered roughly on the Town of Altona (49^o 4.9’ N, 97^o 39.6’W) and is 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 grown in the site include cereal grains, sunflower, canola, flax, corn, sugarbeets, potatoes and specialty crops such as canary seed, peas, beans and lentils. The topography of the site is characterized by a flat, to very gently sloping lacustrine plain characterized by deep lacustrine, deltaic and fluvial deposits. The dominant soil types of the study area are sandy loams and clays which change in texture throughout the site.

Five RADARSAT scenes, including 3 standard mode and 2 extended high beams, were acquired over the study site during a 3 week period in October 1996 (Table 1). Incidence angles for these acquisitions ranged from approximately 25^o to almost 60^o. During this period, management practices on approximately 200 fields across the study site were characterized. Information gathered included tillage type (chisel, harrow, moldboard, no-till), number of tillage passes and direction of most recent, and if detectable, previous 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.

Table 1. List of RADARSAT Acquisitions for Altona (October 1996)

RADARSAT Mode	Orbit	Incidence Angle	Date
Standard 7	Ascending	$45\text{-}49^o$	October 6
Standard 3	Ascending	$30\text{-}37^o$	October 10
Standard 2	Ascending	$24\text{-}31^o$	October 17
Extended High 1	Ascending	$49\text{-}52^o$	October 23
Extended High 6	Descending	$57\text{-}59^o$	October 25

To date, only 2 datasets have been analyzed (Standard 3 - nominally 30 m resolution; Extended High 1 - nominally 25 m resolution), representing a wide range of incidence angles. Prior to data extraction, the processor applied look up table was removed from each of the scenes. Each scene was then geo-corrected using satellite ephemeris information and field boundaries overlayed on the imagery to aid in data extraction. For selected fields, field average values (in power) were calculated and averages then converted to radar brightness (β^o). Calibration uncertainties are greater with the extended high beams will be a factor in the interpretation of results.

Results and Discussion

Management strategies varied considerably across the study site, with the range of tillage practices increasing over the 3 week period. At the outset of the experiment, many fields had not been tilled and those that were tilled had only a single tillage application. At the time of the last RADARSAT acquisition, the majority of the fields had been tilled at least once. Most surfaces were tilled with a chisel plough, although the number of passes ranged from one to four and in many cases 2 or 3 different tillage directions were visible. Each tillage pass incorporates more of the surface crop residue and for a number of fields across the site, a harrow was subsequently used to spread the remaining residue more evenly.

Results from Extended High Beam (October 23)

Table 2 lists average backscatter values for the extended high beam (October 10) associated with only grain residue fields. These results 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. Also, although there is as much as a 1 dB difference related to tillage and residue row direction, these differences are well within the calibration accuracy of the sensor. The insignificance of these differences may be explained by the fact that for most fields at this point in the season, tillage has occurred in a number of directions, although Table 2 categorizes fields based on the most recent tillage occurrence. Table 2 demonstrates that greater variability in backscatter occurs among fields within a single residue/row direction class (as much as 2-3 dB), relative to variability between the classes (generally < 1 dB). Within category variability was greatest for perpendicular and diagonal row directions.

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

	Tillage Direction								
	north-south (perpendicular)			**east-west (parallel)**			**diagonal**		
	max	**mean**	*min*	*max*	**mean**	*min*	*max*	**mean**	*min*
low residue	*-9.5*	**-10.8**	*-13.2*	*-11.2*	**-11.4**	*-11.5*	*-9.7*	**-10.8**	*-11.8*
high residue	*-9.7*	**-10.5**	*-11.3*	*-11.2*	**-11.5**	*-11.9*	*-9.9*	**-11.1**	*-12.1*

In spite of these results from grain residue fields, figures 1 and 2 demonstrate that large differences can occur in field average backscatter, even at this late date. Larger residue types (such as corn and sunflowers) on no-till surfaces have very high returns relative to finer residues, such as beans, which have very low returns. These low returns are likely a result of the small amount of residue cover and the very smooth soil surface associated with no-till beans. Figure 2 shows that backscatter differences for no-till corn exist as a function of residue row direction. However, once surfaces are tilled (as in bean residues), residue row direction differences are no longer visible. Although tillage row direction effects might be expected, field observations indicated that the chisel plough did not create large distinct furrows in the fields which is likely a function of the relatively shallow depth of tillage across the site. Too few field observations were available to provide accurate summary statistics on the residue types identified in figures 1 and 2.

The results from the extended high beam suggest that after most of the fall tillage has occurred, separating residue categories or number of tillage passes for fine residues such as grain and beans is difficult. However, backscatter from fine residues is somewhat lower than backscatter from larger residues such as corn and sunflower. Furthermore, row direction effects appear to be significant only for these larger residue types and these effects are primarily a function of residue row direction. It should also be considered that at the time of the extended high acquisition, field observations suggested that residue on all fields was very dry. 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).

Results from Standard 3 Beam (October 10)

In figure 3, backscatter from the standard 3 beam was correlated against percent surface residue for all residue types. 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.

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 row direction, residue type and tillage application.

Figure 4 graphs average backscatter for tillage and residue categories along with mean class variance. Class average differences between no-till canola and no-till grain, and between no-till grain and no-till beans, were > 1 dB. Standing senesced corn had significantly higher backscatter relative to all other fields (> 2 dB difference) although differences in row direction were minimal, likely an effect of volume scattering within the unharvested corn canopy. Residue row direction was however, important for no-till grain and beans with returns from residue perpendicular to radar look direction higher. Large within class variations are still present even for some of these no-till classes.

For grain residue surfaces (figure 5), perpendicular look directions (north-south) had higher backscatter, although average differences associated with row direction were significant only for fields with high residue cover (> 2 dB difference). As with the extended high image, tillage on low residue fields has likely occurred in a range of directions and this may contribute to the small differences in backscatter as a function of tillage direction. Differences between backscatter from surfaces with > 50% (high) and < 50% (low) grain residue cover were approximately 1 dB. In comparison, the larger differences in backscatter as a function of residue amount as presented in figure 3 takes into account backscatter from all residue types.

Implications for Mapping Conservation Practices

Results for both the extended high and standard beam images have specific implications for the use of RADARSAT for conservation adoption mapping. It is clear from this analysis that, on average, backscatter from some residue and tillage classes is different. However, the large variations in backscatter related to some classes suggest that separation of some tillage and residue classes using backscatter coefficients alone may be difficult. These large within class variations are likely a result of the limited number of field observations available for some classes and the complexity associated with management practices, particularly later in the Fall. Results to date suggest 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. 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 and beans. 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.

Conclusions

From the limited analysis completed to date, results are encouraging for detecting some residue and tillage classes early in the fall using RADARSAT data. Results from the Standard 3 acquisition demonstrated that residue amount and residue row orientation significantly affects backscatter response. Once fields have been tilled several times, differences in surface roughness and residue conditions among fields are reduced and separation into distinct classes is more difficult.

The majority of fields examined in this analysis were covered with fine residues such as grain and because of the lack of precipitation during the data acquisition, residue conditions were very dry. Dry fine residues may be more difficult to detect with radar and therefore, separation of residue categories may be easier when RADARSAT acquisitions have occurred at the time of moist surface conditions.

Since surface conditions changed as a result of tillage activities during the 2 weeks between the standard 3 and extended high 1 acquisitions, the effect of incidence angle on class separability could not be evaluated. This preliminary study, however, effectively demonstrates the complexity associated with tillage and residue management practices. This complexity suggests that in order to reduce within class backscatter variability, surfaces should initially be separated based on residue row direction (easily inferred by shape and orientation of field) and residue type (determined by crop type).

Future work will examine other RADARSAT modes (ie. Standard 7) and will investigate if RADARSAT can identify tillage occurrences using a change detection approach. Further to the work presented here, classes with large backscatter variations will be examined to determine the source of these differences and therefore, to better define class statistics.

Figure 3. Dependence of Radarsat Backscatter on Percent Residue Standard Beam 3

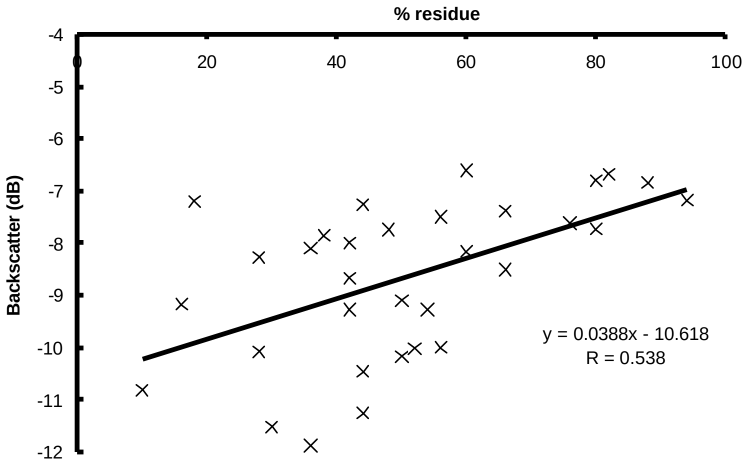


Figure 4. Radarsat Backscatter for No Till Surfaces Standard Beam 3

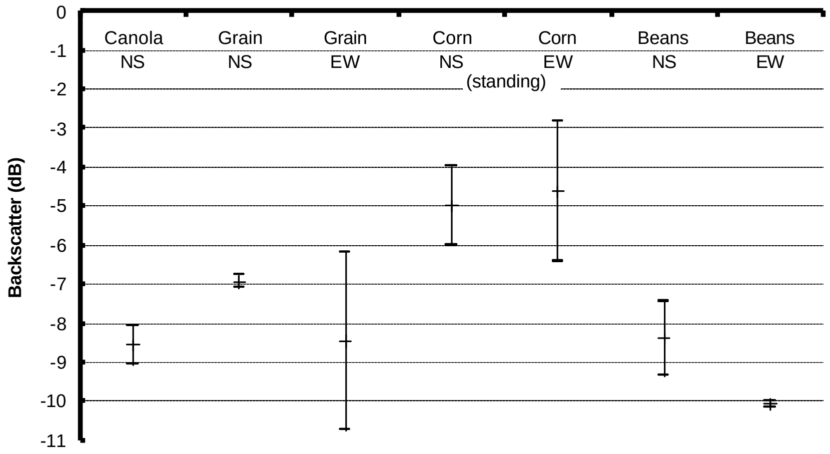
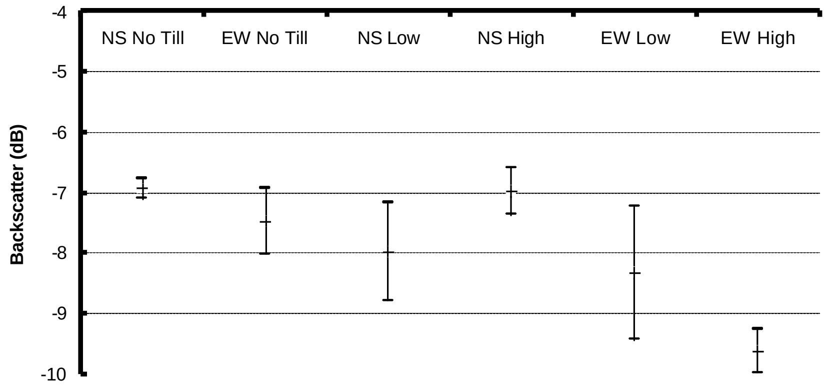


Figure 5. Radarsat Backscatter as a Function of Grain Residue and Tillage - Standard Beam 3



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