Investigating the Relationship Between Crop Residue Cover and Radar Backscatter

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Abstract

Post-harvest agricultural surfaces have varying amounts of crop residue cover, with the amount and type of cover determining, in part, the erodibility and health of the topsoil. If RADARSAT is to be used to map residue and/or tillage in order to monitor soil conservation practices, an understanding is required of the relationship between residue and radar backscatter.

During the Fall of 1996, an experiment was conducted on agricultural plots at the Agriculture and Agri-Food Canada Central Experimental Farm in Ottawa. The experiment was designed to address the importance of residue type (corn and barley), residue moisture content and residue amount to radar backscatter, and to examine the effect of look direction on radar response. Scatterometer measurements (C- and L-Band with 4 linear polarizations) were made over corn and barley plots with treatments varying by residue amount and moisture level. Soil and residue moisture data were collected during 9 days of scatterometer acquisitions. This paper describes the preliminary results on the relationship between residue characteristics and C-Band radar backscatter, which demonstrated that using RADARSAT and ERS-2 configurations, some information can be provided on residue management practices.

1.0 Background

Attention to the type and timing of tillage operation, as well as maintenance of a protective cover during periods of susceptibility, are important in maintaining the productivity of agricultural soils. Post-harvest agricultural surfaces have varying amounts of crop residue cover depending on the crop type, tillage implement and number of tillage applications. This protective cover, in turn, has a significant impact on the erodibilty and health of the topsoil.

Tracking most agricultural management practices is difficult considering the distributed and dynamic nature of the resource. Consequently, remote sensing provides an ideal data source for mapping management practices. Tillage information extracted from remote sensing data can be used as input into a number of erosion prediction models and in addition, is useful for program evaluation and policy planning.

Although optical remote sensing data have proven to be significantly related to the amount of crop residue cover (McNairn and Protz, 1993; van Deventer *et al*., 1997), the integration of SAR data may help better define some residue categories, would provide a data source during periods of cloud cover and may provide some information on residue conditions under dry snow cover. In previous work, SAR backscatter has been correlated with surface roughness as related to tillage implement (McNairn *et al*., 1995). Results of this study demonstrated that at 40-50^o incidence angles, C-HH backscatter was sensitive to surface roughness and would separate surfaces based on tillage type. Although some research has reported that grain residue following a rainfall or dew event can influence C-HH backscatter (Smith and Major, 1996), many questions still remain regarding the sensitivity of backscatter to various residue parameters.

2.0 Research Objectives and Methodology

Using the Canada Centre for Remote Sensing (CCRS) scatterometer, the response of radar backscatter to crop residue was investigated as a function of residue moisture levels, as well as residue type and amount. The experiment was conducted during the Fall of 1996, on experimental plots on the Agriculture and Agri-Food Canada Central Experimental Farm in Ottawa. Four plots were planted in corn and five in barley with each plot measuring, at a minimum, 50 metres (N-S) by 40 metres (E-W). Scatterometer data were collected at C- and L-bands (HH, VV, VH, HV) and at 10^o incident angle increments from 20^o to 50^o. Measurements were taken along all four sides of the plots providing information at both parallel and perpendicular look directions relative to the residue rows. Thirty independent scatterometer measurements were taken at each plot end. Prior to each data take, scatterometer measurements were made over the same grassed area and the same asphalt area to test that the instrument was operating consistently. In addition, once during the experiment the calibration parameters of the scatterometer were checked using corner reflectors. For further details on the CCRS scatterometer operations, refer to Sofko *et al*. (1989).

During seed bed preparation, the surface across the entire experiment site was prepared consistently, reducing differences in roughness across the individual plots. A control plot which had been cropped in barley, was tilled several weeks prior to the experiment to reduce residue to < 10% cover. With the effects of weathering the surface soil roughness on this bare plot was consistent with roughness on the residue plots. The chain method (Saleh, 1993) was used to verify that differences in roughness among plots were minimal.

Residue treatments represented differences in residue amounts and were achieved by applying different harvesting techniques. For corn, these treatments included:
(1) harvester (low residue cover);
(2) harvester with crop blown back on plot (intermediate residue cover);
(3) combine (high residue cover, standing residue); and
(4) combine with mower (high residue cover, lying residue).
For barley, the following harvesting treatments were applied:
(1) combine low with straw baled and removed (low residue cover);
(2) combine high. The cut straw was removed and the remaining standing straw was mowed with a bush hogger (intermediate residue cover, lying residue);
(3) the same as 2 above, but residue not mowed (intermediate residue cover; standing residue);
(4) combine low with straw spread on plot (high residue cover);

During scatterometer data collection 0.5 m x 0.5 m samples of above ground residue were collected and processed for gravimetric moisture (wet and dry weights). Five residue samples were collected at each plot end per measurement day. Residue samples were weighed immediately after collection, oven dried for 48-72 hrs and then re-weighed. Five soil moisture measurements were also taken at each plot end. For each measurement day, sixteen residue and soil samples were collected on each plot. Gravimetric sampling was used to estimate surface moisture (0-3 cm) and TDR measurements characterized the 0-5 and 0-10 cm moisture levels. Data were collected for 9 days (5 days for barley and 4 days for corn) with changes in residue moisture driven by rain events and subsequent dry downs.

3.0 Results

3.1 Characteristics of Residue Moisture and the Impact on Surface Soil Moisture

Results from this experiment indicate that crop residue can hold significant amounts of moisture, (as much as 50-60%), although moisture levels strongly depend on meteorological conditions and residue type (Figure 1). Average grain residue moisture was compared to average corn residue moisture for two acquisition dates (September 19 and November 5) for which surface soil moisture levels were equivalent on the bare plot (14% for both dates). From this comparison, corn residue had, on average, 5-10% more moisture than grain residue under similar soil moisture conditions (Table 1). Summary statistics also indicated that moisture content in the residue tended to increase and decrease relatively quickly when compared to changes in surface soil moisture over the same period (Table 2). However, once the grain residue was relatively dry (<20% moisture content), further losses in residue moisture tended to be small.

Table 1. Comparison of Residue and Soil Moisture on Grain and Corn Plots

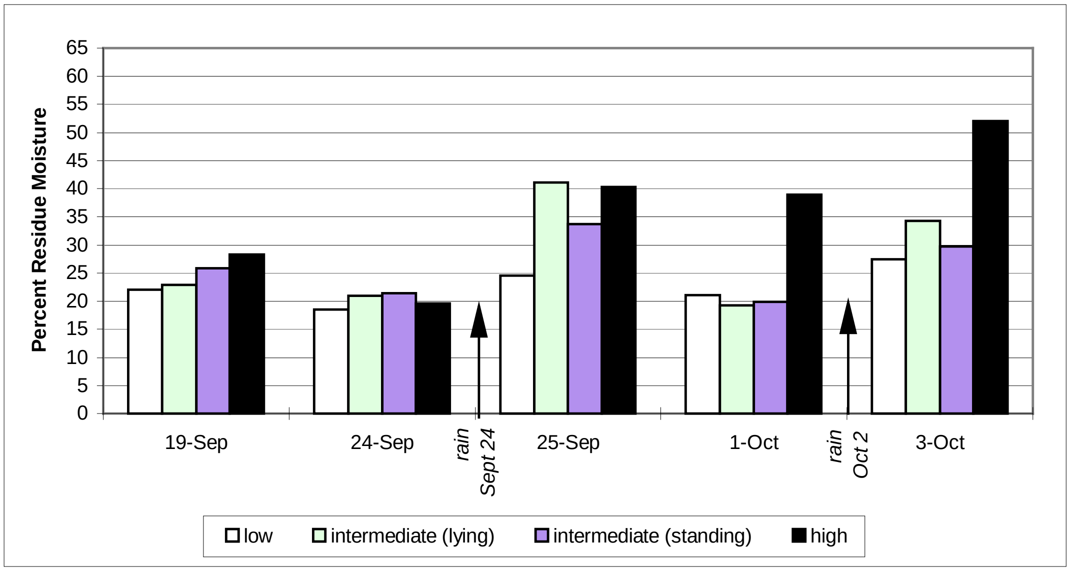
	Volumetric Soil Moisture (0-3 cm)		**Gravimetric Residue Moisture**	
	Grain	*Corn*	*Grain*	*Corn*
lowest residue level	20%	23%	22%	30%
	19%	28%	23%	28%
	19%	23%	26%	41%
highest residue level	21%	25%	28%	33%
bare plot	**14%**	**14%**		

Table 2. Changes in Residue Moisture Relative to Changes in Soil Moisture

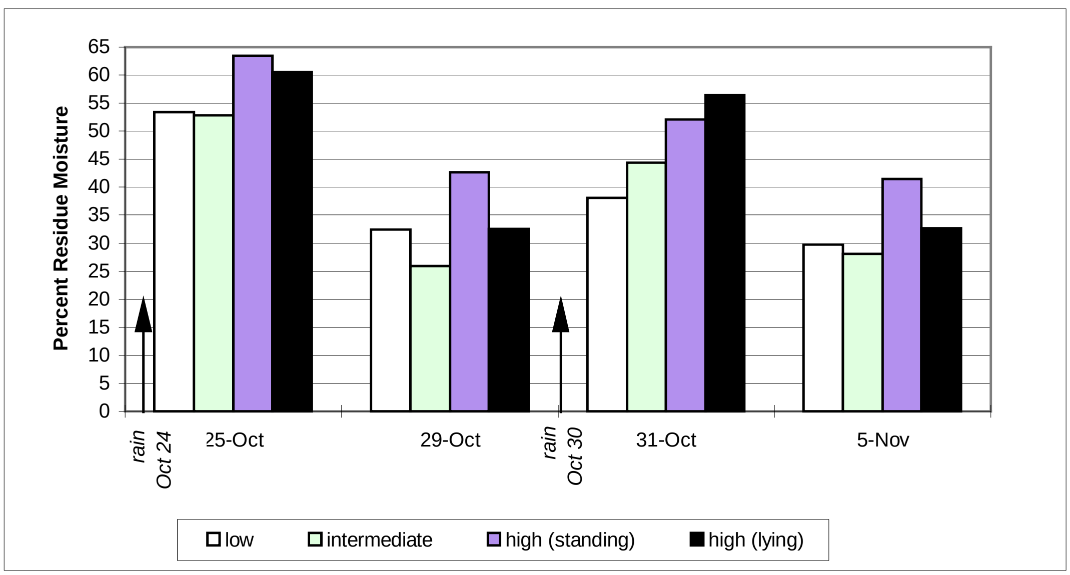
	Grain Residue			
	Day After Rain		*After 5 Day Drying Event*	
	Soil Moisture	***Residue Moisture***	***Soil Moisture***	***Residue Moisture***
lowest residue level	+2%	+7%	-4%	-4%
	+3%	+20%	-4%	-2%
	+5%	+13%	-6%	-4%
highest residue level	+1%	+20%	-2%	-8%
bare plot	+3%		-2%	
	Corn Residue			
	2 Days After Rain		*After 4 Day Drying Event*	
lowest residue level	0%	+5%	-4%	-21%
	+6%	+18%	-9%	-27%
	+5%	+23%	-6%	-28%
highest residue level	0%	+9%	-2%	-21%
bare plot	+3%		-9%	

Figure 1. Residue Moisture Content

(a) Grain Residue



(b) Corn Residue



When examining differences in surface soil moisture values (0-3 cm) across an individual plot, larger variances were associated with soil moisture measurements on the residue covered plots relative to measurements for the bare plot. In contrast over time, plot average surface soil moisture varied little on residue plots. However, over this same time period the bare plot surface experienced greater variability in soil moisture. The type of residue also had an effect on surface soil moisture levels. Comparing two days (September 19 and November 5) for which soil moisture was equivalent for the bare plot, surface soil moisture was consistently higher on all corn plots compared with that on the barley plots (Table 1).

3.2 Correlations Between Soil and Residue Moisture and C-Band Backscatter

Simple and bivariate linear regression models were developed to establish the relationship between C-band backscatter, surface soil moisture and residue moisture (Table 3). Relationships were investigated for normality and linearity.

Table 3. Results for Correlations Between Soil and Residue Moisture and C-Band Backscatter

Results of Simple Linear Regression								
Volumetric Soil Moisture (0-3 cm)					**Gravimetric Residue Moisture**			
Grain	**20°**	**30°**	**40°**	**50°**	**20°**	**30°**	**40°**	**50°**
CHH Parallel	√	√	√	√				√
CHH Perpendicular	√	√						√
CVV Parallel	√	√	√	√				
CVV Perpendicular	√	√	√	√				√
CVH Parallel	√	√	√	√	√	√	√	√
CVH Perpendicular	√				√	√	√	√
Corn	**20°**	**30°**	**40°**	**50°**	**20°**	**30°**	**40°**	**50°**
CHH Parallel						√	√	√
CHH Perpendicular							√	√
CVV Parallel						√	√	√
CVV Perpendicular				√			√	√
CVH Parallel					√	√	√	√
CVH Perpendicular					√	√	√	√
Bivariate Linear Correlation Coefficients*								
Grain					***Corn***			
	20°	**30°**	**40°**	**50°**	**20°**	**30°**	**40°**	**50°**
CHH Parallel	.70	.66	.45	.55	NS	.67	.83	.78
CHH Perpendicular	.73	.47	NS	.53	NS	NS	.66	.68
CVV Parallel	.69	.81	.73	.81	NS	.71	.71	.76
CVV Perpendicular	.67	.66	.59	.72	NS	NS	.52	.52
CVH Parallel	.72	.72	.71	.67	.83	.82	.85	.83
CVH Perpendicular	.72	.67	.64	.61	.68	.61	.85	.82

√ = significant at $p < 0.05$
* X_1 = volumetric soil moisture (0-3 cm); X_2 = gravimetric residue moisture; Y = backscatter
NS = not significant at $p < 0.05$

Barley Residue

C-HH and C-VV backscatter were not significantly correlated with grain residue moisture at incidence angles steeper than 50° and even at $\theta = 50^{o}$, correlations were weak (R=0.360) to moderate (R=0.563). At most angles, backscatter was significantly correlated with surface soil moisture, although R values were lower than might be expected for bare agricultural surfaces, especially at steeper incidence angles. This suggests that eventhough residue moisture is not strongly correlated with backscatter, the residue cover does impede the interaction between the radar and the soil surface. For C-HH, the highest correlation coefficient (0.620) for backscatter versus surface soil moisture was recorded at $\theta = 30^{o}$ (perpendicular look direction).

In almost all cases, correlations were strongest between backscatter and moisture at 0-3 cm when compared to results for moisture measured at depths of 0-5 or 0-10 cm.

Cross-polarized backscatter was significantly correlated with residue moisture at all incidence angles, although the strength of the relationship was only moderate (R = 0.58 to 0.67). The significant correlation between cross-polarized backscatter and residue moisture may indicate the importance of volume scattering to backscatter from these surfaces. Surface soil moisture was significantly related to C-VH backscatter for some angles, although coefficients were weak (< 0.5). Correlation results for C-HV were similar to those for C-VH and therefore, are not reported here. Bivariate regression results were significant in almost all cases.

For RADARSAT and ERS-2 configurations these results suggest that radar backscatter will not be sensitive to moisture in fine residues, particularly at steep incidence angles. For RADARSAT, at incident angles > 40^o, residue moisture may play a significant role in backscatter. Residue cover does, however, appear to have an effect on the correlation between backscatter and surface soil moisture at most angles. In examining the partial correlation coefficients of the bivariate models, residue moisture is a significant contributor to backscatter at $\theta > 30^o$. Cross-polarizations may provide the highest sensitivity to fine residue cover.

Corn Residue

Contrary to results from the barley plots, C-band backscatter was significantly correlated with corn residue moisture beyond $\theta = 30^o$ for C-HH and C-VV configurations, and at all incidence angles for cross-polarizations. The highest R values were at $\theta = 50^o$ and a parallel look direction (0.76 for C-HH; 0.74 for C-VV; and 0.81 for C-VH). In general, coefficients between backscatter and surface soil moisture were not significant. Bivariate regression results tended to follow those of the simple regressions in terms of significance of the model and importance of residue moisture in the model.

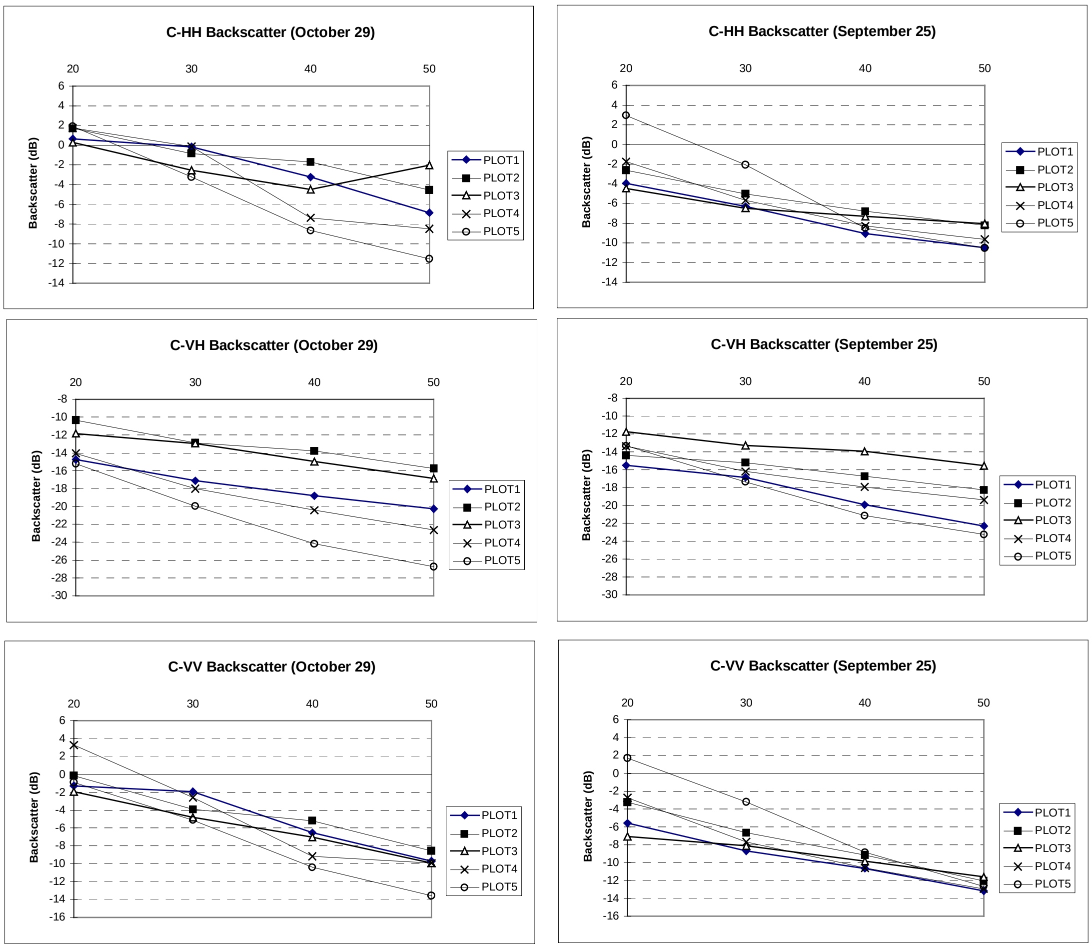
These results suggest that RADARSAT can provide information on larger residues such as corn when shallower angles are used. These shallow angles provide greater interaction with the residue and less contribution to backscatter from the soil surface. ERS-2 would not provide significant information on either residue or surface soil moisture under residue, considering its steep incidence angles. Data collected at cross-polarizations would also be of use in corn residue mapping. Overall, the regression analysis suggests that both the size of the residue relative to the wavelength, as well as the moisture content of the residue, are key considerations in terms of backscatter from residue surfaces.

3.3 Categorizing Residue Covered Surfaces from C-band Backscatter

Multiple range tests were run to determine if, based on backscatter, residue surfaces could be statistically separated from bare surfaces. The statistical separability of backscatter as a function of residue treatment was also investigated. Sample backscatter plots for each polarization and both look directions are provided in Figure 2.

Figure 2a. Backscatter From Residue Surfaces
(Look Direction Perpendicular to Residue Rows)

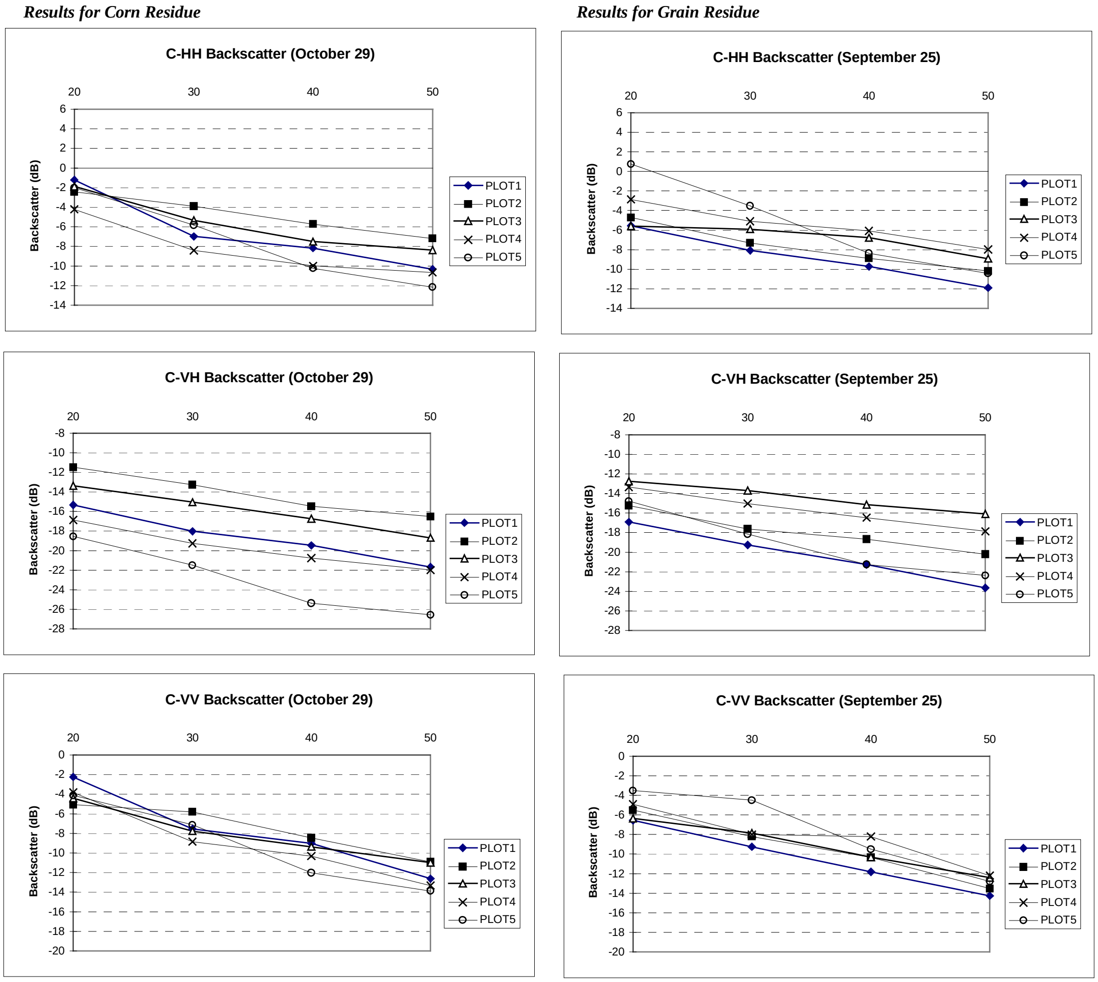
Results for Corn Residue | *Results for Grain Residue*



Corn Residue
plot 1 = low residue cover (harvester)
plot 2 = high residue cover (standing) (combine)
plot 3 = high residue cover (lying)(combine and mower)
plot 4 = intermediate residue cover (harvester)
plot 5 = bare

Grain Residue
plot 1 = intermediate residue cover (lying)
plot 2 = intermediate residue cover (standing)
plot 3 = high residue cover
plot 4 = low residue cover
plot 5 = bare plot

Figure 2b. Backscatter From Residue Surfaces (Look Direction Parallel to Residue Rows)



Corn Residue
plot 1 = low residue cover (harvester)
plot 2 = high residue cover (standing) (combine)
plot 3 = high residue cover (lying)(combine and mower)
plot 4 = intermediate residue cover (harvester)
plot 5 = bare

Grain Residue
plot 1 = intermediate residue cover (lying)
plot 2 = intermediate residue cover (standing)
plot 3 = high residue cover
plot 4 = low residue cover
plot 5 = bare plot

Grain Residue

For the purpose of the multiple range test, one date was dropped from the analysis of grain residue treatments. In examining backscatter on the driest date, virtually no difference was evident between backscatter from the various plots and in comparing results, separation among residue treatments significantly improved after this date was dropped. This observation suggests the importance of residue moisture for residue class separability. However, in most cases backscatter from the bare plot was significantly different from backscatter from each of the residue plots regardless of whether this dry date was included or not.

Using C-HH and C-VV, grain residue plots were significantly different from the bare plot at steep incidence angles (<30^{o}). Among the residue plots, C-HH backscatter from most plots was significantly different at some angle, with the exception of plot 2 (residue cut high and left standing). Shallow angles provided more residue-backscatter interaction and tended to be better at differentiating residue treatments and in particular, for separating standing versus lying residue. C-VV backscatter at 40^o differentiated half the residue treatments although in some instances steeper angles could separate the remaining treatments. Although residue position (standing versus lying) could not be separated at parallel look directions, C-VV backscatter did differentiate height of residue (combine high versus combine low).

Cross-polarized backscatter ($\theta < 30^o$) was able to separate the bare plot from all residue surfaces, except again plot 2 (residue cut high and left standing), where angles of $> 40^o$ are required. Using $\theta = 20^o - 30^o$, all residue treatments except combine high versus combine low could be distinguished. Residue position (standing versus lying) could be differentiated at all incidence angles. For all polarizations, perpendicular look directions provide more differentiation among plots.

Corn Residue

Relative to grain residue, C-band backscatter could separate more corn residue treatments and at a larger range of angles. Individual corn residue stalks are larger and as well, these surfaces typically have greater volumes of residue per unit area and a higher residue moisture content. For C-HH , backscatter from the bare plot was significantly different from residue plots at both steep and shallow angles. Again, in differentiating among residue treatments, shallower angles ($>40^o$) tended to be better. Backscatter from lying versus standing residue, as well as harvester versus combine were significantly different at $40\text{-}50^o$. When the standing residue was mowed however, differences in backscatter from harvester versus combine were not significant at shallow angles.

Results from C-VV were not as promising as those from C-HH, although in most cases, backscatter from the bare plot was different from that of the residue plots. C-VV did not perform as well in identifying residue treatment, particularly at a parallel look direction. Although most residue treatments were different at some angle, data would be required at a range of angles in order to differentiate all residue treatments.

At $\theta = 40^o$, C-VH backscatter differentiated 90% of the residue treatment comparisons. In addition, an incident angle of $40\text{-}50^o$ C-VH would separate each residue plot from the bare plot, regardless of look direction.

4.0 Conclusions

Data from current SAR satellites will provide some information on residue management practices. For fine residue, RADARSAT (at steep incidence angles) and ERS-2 will define bare surfaces from those with residue cover. If RADARSAT data are acquired at shallower incidence angles, and the residue is wet, some additional information will be provided on residue cover. For larger residues such as corn, a C-HH configuration can identify if the surface is covered with residue, and may provide additional information such as harvesting technique, amount of residue and residue position. For both residue types, cross-polarizations appear promising for this application.

Although the potential of RADARSAT and ERS-2 for grain residue mapping is not as promising as for corn residue, residue cover does contain significant moisture and will impede the use of these sensors for surface soil moisture mapping if residue is present.

If SAR data is to be used for residue mapping, careful attention must be given to the timing of data acquisition as well as the type of SAR configurations used. Separability of residue classes is likely to be better after a rain when residue is wet. In addition, steeper angles can be used to mask out bare surfaces with shallower angles acquired for further residue class separation.

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