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[1]Integration of Multi-Polarized SAR Data and High Spatial Optical Imagery For Precision Farming

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Abstract

Monitoring the condition of agricultural crops requires that soils and crop information is readily available throughout the growing season. Visible-infrared wavelengths are sensitive to variations in crop and soil conditions. Although optical imagery can be used to map crop characteristics, cloud cover can impede the use of these data for operational monitoring. RADARSAT-1 can provide crop information, but because imagery is acquired in only one transmit-receive polarization, multi-temporal data sets are required. Radars that acquire imagery in multiple polarizations, like RADARSAT-2, are likely to provide much more information on both crop and soil characteristics.

In 1998 and 1999, airborne C-band polarimetric synthetic aperture radar (SAR) imagery was acquired over two sites in Ontario (Canada). These data are currently being analyzed to assess what crop information polarimetric sensors, like RADARSAT-2, will provide for site specific crop monitoring. In addition to airborne SAR, satellite and airborne optical images were acquired over these test sites. Soil moisture measurements and crop information were collected on corn, soybean and wheat fields during the airborne acquisitions, to support interpretation of the remotely sensed images. Preliminary results indicate that although backscatter from corn fields saturates once crop growth is significant, multi-polarized linear and circular radar configurations do provide some information on grain and soybean crop condition.

Introduction

Monitoring the condition of agricultural crops can be challenging since crop growth is very dynamic. Considerable variability in crop condition often exists not only among fields growing the same crop, but also within individual fields. Frequently, variability in crop growth and condition is linked to variations in soil conditions and topography across the field.

Many agricultural producers hire the services of crop scouts who visit or "scout" their fields, periodically throughout the growing season. These scouts watch for infestations of weeds, insects and fungus, and provide recommendations on treating detected infestations. Scouts also provide recommendations on fertilizer applications. However, because of the huge acreages involved, remotely sensed imagery could be a valuable tool to assist in monitoring crop and soil conditions.

Brown (2000) outlined three barriers to the successful adoption of future remote sensing products and services in agriculture. The timely acquisition and distribution of remote sensing products and services was identified as one of these barriers. Clearly, the value of the information provided by remote sensing significantly diminishes over time, when producers are seeking real time mitigation of infestations and fertility problems. Although visible and infrared wavelengths are sensitive to changes in crop condition, timely acquisition of optical imagery can be problematic. This suggests that if remote sensing technology is to be used in operational site specific crop monitoring, radar must be used to supplement acquisitions of high spatial resolution optical imagery.

The Canada Centre for Remote Sensing (CCRS), in conjunction with Agriculture and Agri-Food Canada, has been involved in assessing the sensitivity of synthetic aperture radar (SAR) to both soils and crop characteristics. Sensors that acquire imagery at a single transmit-receive polarization, like RADARSAT-1, provide one-dimensional data sets. Consequently, more than one date of imagery is usually required to provide meaningful crop information (McNairn *et al*., 2000a). In contrast, similar information can be provided by a single date image, if the sensor acquires information at multiple polarizations (McNairn *et al*., 2000b). This observation suggests that future sensors, like RADARSAT-2, will provide a much richer data set for use in crop monitoring.

In 1998 and 1999, airborne C-band polarimetric SAR imagery was collected over two agricultural test sites. These data are being analyzed to assess what information multi-polarized SAR imagery can provide on site specific crop conditions. Satellite and airborne optical imagery was also acquired over these sites. With this data set, the complementary nature of radar and optical sensors for crop monitoring is being investigated.

Description of Data Sets

During the 1998 growing season, airborne C-band polarimetric SAR data, acquired by Environment Canada's CV-580, was collected over a site just outside of Ottawa, Ontario (Canada). Data were acquired once in June (19^{th}) and twice in July (9^{th} and 29^{th}) at incidence angles of 37º to 67º. Using the same configuration, airborne SAR imagery was also acquired on June 30^{th} 1999 over Clinton, Ontario (Canada). Coincident with the airborne acquisitions, supporting soils and crop information was collected in six (Clinton) to ten (Ottawa) fields of corn, wheat and soybean crops.

Corner reflectors and PARCs (Polarimetric Active Radar Calibrators) were deployed during all airborne SAR acquisitions. Polarimetric processing and radiometric calibration of the airborne data was accomplished using the CCRS programs POLGASP and COMPLEXCAL (Wind, 1998). Using these data, images were generated for three linear transmit-receive polarizations (HH, HV, VV), as well as two circular polarizations (RR – circular co-polar; RL – circular cross-polar). In addition to the airborne SAR data, several other airborne and satellite images were acquired, including IRS 1-C, colour infrared air photos and Probe-1 hyperspectral images (Table 1). Soil texture and slope information was also available for several of the Ottawa fields.

To date, image interpretation has been completed for one field of each crop type (corn, soybeans and wheat). To aid in this interpretation, each of these fields was also classified using an unsupervised IsoData algorithm. Prior to classification, the SAR imagery was filtered using a 3 x 3 Frost filter.

Results of Image Interpretation

Corn Crops

Both the Ottawa and Clinton data sets suggest that regardless of polarization, very limited within field information related to corn crop condition is contained in the SAR imagery. McNairn *et al.* (2000b) reported that once the corn canopy reaches a height of about one metre, the SAR signal saturates. In Clinton, for example, average corn crop height at the end of June was 113 cm. Signal saturation appears to be a problem for all the linear (HH, VV, HV) and circular (RR, RL)

Table 1. List of Remote Sensing Imagery Acquired

Data Type	Study Site	Date of Acquisition	Data Specifications
Airborne SAR	Ottawa	June 19th (1998) July 9th (1998) July 29th (1998)	C-band fully polarimetric (4 m pixel spacing) (incidence angles of 37° to 67°)
IRS 1-C	Ottawa	July 18th (1998)	4-band multispectral (23 m spatial resolution)
Aerial Photography	Ottawa	July 28th (1998)	Colour-infrared (1:20,000)
Airborne SAR	Clinton	June 30th (1999)	C-band fully polarimetric (4 m pixel spacing) (incidence angles of 37° to 67°)
Airborne Hyperspectral	Clinton	July 7th (1999)	128 bands (400-2400 nm) (5 m spatial resolution)

polarizations synthesized from the airborne data. Although for many of the corn fields variations in reflectance were observed on the airborne optical images, these patterns were not visible on the multi-polarized SAR imagery.

During both the Clinton campaign (June 30th) and the last two Ottawa acquisitions (July 9th and July 29th), in most fields the corn crop height exceeded one metre. However, for the field located on the Agriculture and Agri-Food Canada Experimental Farm, corn growth was well behind that of the other fields, due to a delay in planting. For this particular field, significant within field variability is observed on the June 19th and July 9th imagery (Figure 1). Field average corn height was 23 cm (June 19th) and 92 cm (July 9th). Within field patterns are visible in all polarizations, although the greatest visual contrast is present in the linear cross-polarization (HV) and the circular co-polarization (RR). Both of these polarizations are sensitive to canopy volume scattering.

Soil penetrometer data collected on this field indicate that the variation in radar backscatter may be related to differences in soil compaction across the field (Figure 1e). On the late June image, areas of higher backscatter are clearly associated with areas of higher soil compaction (Figure 1a). Corn grain moisture data collected at harvest also indicate that for these compacted soil zones, grain moisture was higher. This observation suggests that corn development was somewhat delayed in these zones of higher backscatter, and this delay in development resulted in higher grain moisture at harvest. It is also possible to see the same pattern in the elevation data. Higher areas have greater penetration resistance, and are brighter on the SAR image.

Total rainfall was 67 mm in the 7-day period prior to the June acquisition. Higher backscatter in this soil compaction zone may be related to moist soil conditions. Where the soil is less compacted in other areas of the field, the crop is higher and biomass is greater. This more vigorous growth may impede microwave interaction with the underlying soil.

For the July 9th acquisition, within field variations in backscatter are still visible, but contrast among the zones is reduced as the crop approaches one metre in height (Figure 1b). Backscatter appeared lower in areas of the field where the soil is more compacted. This suggests that the SAR is now responding to differences in crop biomass, with higher backscatter in areas with more vigorous crop growth. Later in July the height of the corn was over one metre, with an average height of about 2.2 metres on July 29th. Variability across the field is no longer detectable (Figure 1c).

Soybean Crops

The Ottawa data set also suggests that crop condition information on soybean fields can be provided by radar imagery, when acquired early in the season. Figure 2 presents the classification results for one of the Ottawa soybean fields. Using three polarizations (VV, HV, RL), the field can be classified into three or four zones. These zones are easily detected on the June 19th image with the greatest contrast provided by the HV polarization (Figure 2a). On the early July image, within field backscatter differences are reduced and are now only visible with the HV polarization (Figure 2b). Once the soybean crop has reached maturity in late July, variability in growth across the field is not longer detectable (Figure 2c).

The soils map of this field indicates that the zones visible in the radar imagery are likely related to differences in soil drainage, and perhaps soybean emergence (Figure 2d). Zones of lower backscatter correspond to finer textured soils on very gently sloping land. In these zones, soil drainage is poor relative to other areas of the field. Crop emergence and crop growth is these regions are delayed as a result of the reduced soil drainage. The July 18th IRS multi-spectral image supports this observation. Even in the middle of July, less vigorous growth is observed on these finer textured soils.

Areas of the field where the crop emerges early, have more vigorous crop growth and are associated with areas of better soil drainage. Soils in these regions are moderately coarse textured and topography is gently sloping. More volume scattering from the crop canopy is evident in the higher cross-polarized backscatter. However, once growth in the finer textured zones matches that of the rest of the field, variability across the field is reduced. By late July, backscatter across the field is relatively homogeneous (Figure 2c).

Wheat Crops

For both the Clinton and Ottawa data sets, SAR imagery acquired during the period when grain crops were senescing clearly identified variations in crop condition within many of these fields. An unsupervised classification of one field from the Ottawa July 9th acquisition identified several zones within the field (Figure 3e). Field notes verify that the crop across the entire field was undergoing senescence on this date. The soils map identifies three different soil types across this field. Backscatter is lower on the sandier soils where the slope is greater. On these well drained soils, the wheat crop dries down faster and is thus further along in the process of senescence. With a reduced crop moisture content, backscatter decreases. In the north-west corner, soils are even sandier, the slope increases and this effect is more pronounced. These two zones are in contrast to the southern half of the field. Here soils are heavier and the land slopes more gently. Ground photos from this part of the field indicate that although the grain was starting to senesce some parts of the crop, in particular the stem, were still green.

The difference in backscatter across this particular field is most obvious on the circular polarizations (RL, RR). HV and VV backscatter for the July 9th acquisition appears quite homogeneous across this field. In contrast, within field variability was most obvious on the HV images acquired over the Clinton site.

Within field variations in backscatter were not visible in the Ottawa June 19th image. These data were acquired prior to crop senescence when the grain had headed, and the entire field was at the same developmental stage. In late July the crop was fully senesced and backscatter across the field was uniform. Therefore, no significant within field variability was observed for any polarization. The July 18th IRS image also provided very little within field information.

Conclusions

Both optical and radar imagery can play an important role in monitoring within field crop conditions. Site specific crop conditions can be mapped using optical imagery acquired at large scales. However, reliable and quick data acquisition and delivery is required if remotely sensed imagery is to become an important tool for precision farming.

Early analysis of airborne polarimetric SAR imagery suggests that radar will be able to provide some within field information. However, rather than site specific information, soon-to-be-launched SARs like RADARSAT-2 will likely provide zonal crop and soil condition information. Deriving true site specific crop information will likely require SAR image acquisitions at much higher pixel resolutions.

Linear cross-polarizations and circular polarizations appear to be particularly sensitive to crop and soil conditions. However, for larger biomass crops like corn, saturation of the SAR signal will limit the use of radar imagery for crop condition monitoring to early in the growing season.

References

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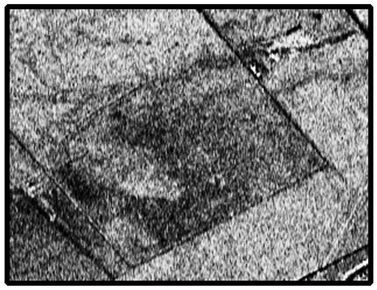
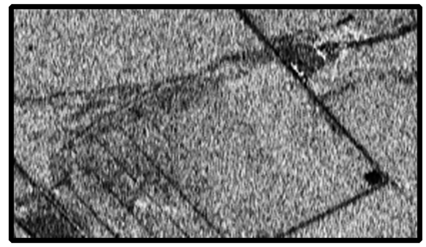
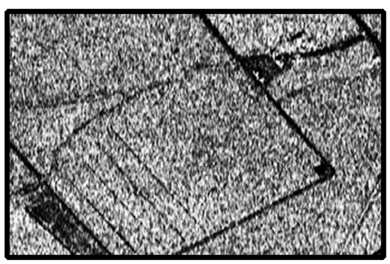
Figure 1. Within field variability associated with a corn crop.



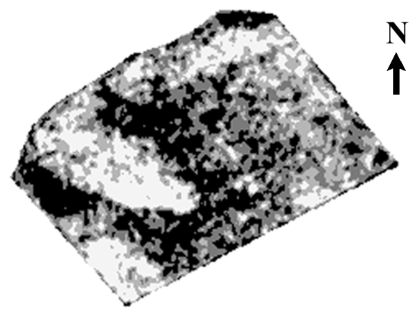
(a) HV Polarized
June 19, 1998



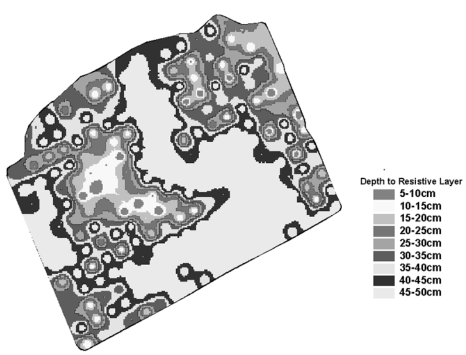
(b) HV Polarized
July 9, 1998



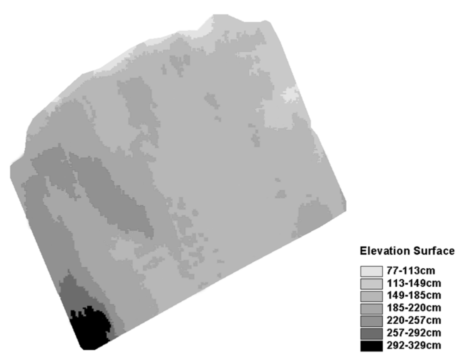
(c) HV Polarized
July 29, 1998



(d) Unsupervised Classification
on VV, HV, and RR Polarizations
for June 19, 1998



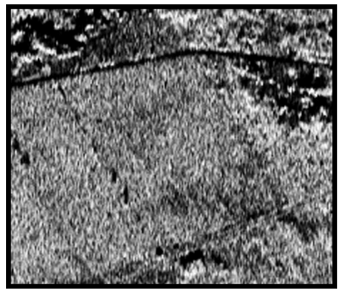
(e) Soil Penetrometer Measurements



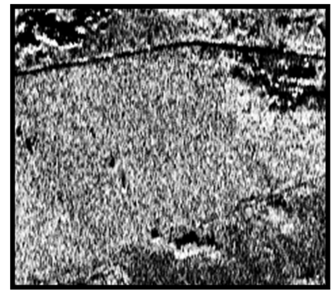
(f) Elevation

Figure 2. Within field variability associated with a soybean crop.

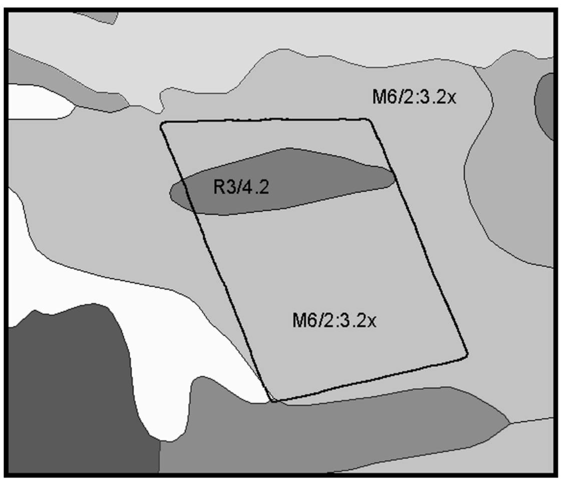
(a) HV Polarized
June 19, 1998



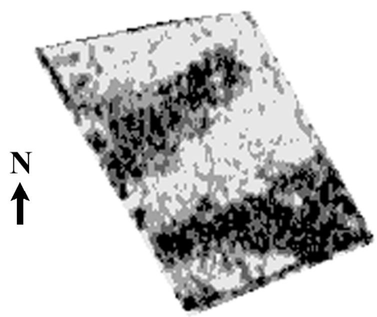
(b) HV Polarized
July 9, 1998



(c) HV Polarized
July 29, 1998

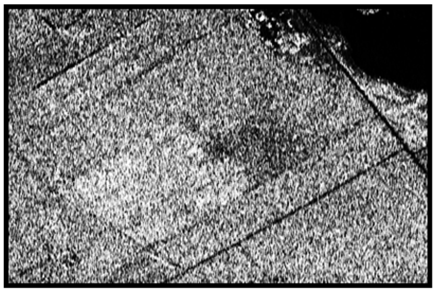


(d) Soils Map



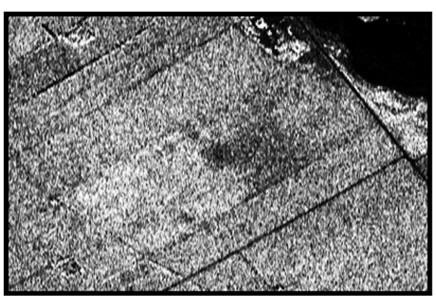
(e) Unsupervised Classification
on VV, HV, and RL Polarizations
for June 19, 1998

Figure 3. Within field variability associated with a wheat crop.

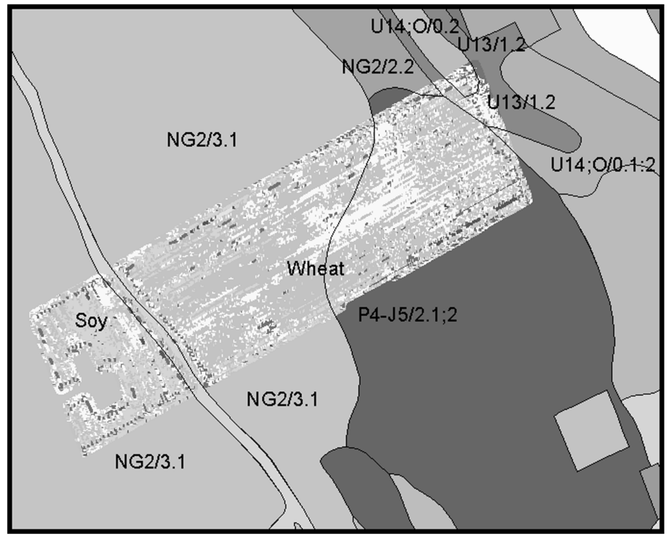


(a) HH Polarization
July 9, 1998

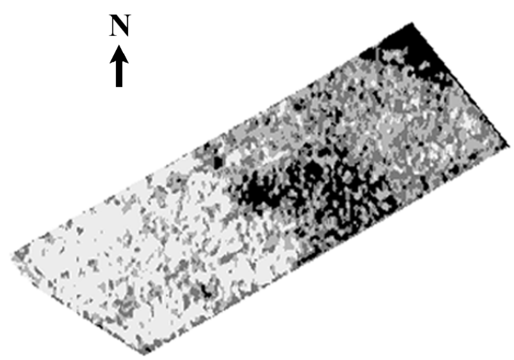
(b) RR Polarization
July 9, 1998



(c) RL Polarization
July 9, 1998



(d) Yield and Soils Map



(e) Unsupervised Classification on HH, RR, and RL Polarizations for July 9, 1998