

Mapping Crop Residue Cover Over Regional Agricultural Landscapes in Canada

A. Pacheco^{a,*} and H. McNairn^a

¹Agriculture and Agri-Food Canada, 960 Carling Avenue, Ottawa, Ontario, Canada K1A 0C6
– (anna.pacheco, heather.mcnairn)@agr.gc.ca

Abstract – Land management practices affect the long term sustainability of agricultural soils. Growing Forward, Agriculture and Agri-Food Canada's (AAFC) agricultural policy framework, has identified promoting environmentally responsible agriculture as one of the department's priorities. Land management information requirements have become increasingly important to a number of programs and policies supporting the Canadian agriculture sector. Earth observing satellites can assist with monitoring tillage activities but to implement an operational monitoring system for a country as large as Canada, large-swath optical satellites are required.

AAFC has developed a spectral unmixing method to estimate crop residue cover, an indicator of land management practices, from the SPOT satellite. However, implementation of this method for monitoring over vast regions would be challenging given this sensor's limited swath (60 km). AWiFS acquires data over a swath of 740 km and at a spectral resolution similar to SPOT. Thus, it is anticipated that monitoring residue cover over large regional landscapes can be accomplished with the AWiFS satellite. AWiFS image data were acquired on October 12 2010 over the Brunkild watershed (near Winnipeg, Manitoba) in the Canadian Prairies. Simultaneous ground data were collected to characterize canola, lentil and small grain residues. Spectral unmixing analysis was applied to the AWiFS data. This approach produced overall crop residue cover estimates with a root mean square error of 20.18%. Errors were lower for lentil fields (17.00%) and comparable for canola (22.19%) and small grains (21.29%).

Keywords: agriculture, land management, tillage, crop residue, AWiFS, spectral unmixing.

1. INTRODUCTION

Land management practices affect the long term sustainability of agricultural soils and the adoption of beneficial management practices can considerably reduce the risk of soil erosion. Growing Forward, Agriculture and Agri-Food Canada's (AAFC) agricultural policy framework, has identified promoting environmentally responsible agriculture as one of the department's priorities. Land management information requirements have become increasingly important to a number of programs and policies within the Growing Forward policy framework. To assess and monitor the success of these programs, rapid, accurate and objective methods are required to map and monitor land management activities. Earth observing satellites can assist with targeting and monitoring tillage activities but to implement such an operational monitoring system, large-swath optical satellites such as AWiFS (Advanced Wide Field Sensor) are required.

Launched in 2003 the AWiFS sensor acquires data over a swath of 740 km, coverage which is well suited to map large regional

landscapes. Given the similarities of its spectral resolution to that of the SPOT (Satellite Pour L'Observation de la Terre) satellites, it is assumed that the AWiFS sensor can estimate residue cover with equivalent accuracies. To further assess this, AWiFS image data were acquired during the 2010 fall tillage season over the Brunkild watershed near Winnipeg (Manitoba, Canada). Simultaneous ground data were collected to characterize residue type, position, direction and percent cover for a variety of crops including canola, lentils and small grains. AAFC developed an endmember extraction and spectral unmixing approach to estimate crop residue cover over agricultural land (Pacheco and McNairn., 2010). In this study, this approach is applied to the AWiFS data to derive percent crop residue cover over an agricultural area in the Canadian Prairies.

2. MATERIALS

2.1 Study Site

Image and ground data were acquired over an AAFC international validation site located in Canada's western prairie region. The validation data was collected in and around the Brunkild watershed (49° 37' N, 97° 58' W) which is located approximately 68 km southwest from the city of Winnipeg in Manitoba, Canada.

The cropping system is dominated by the production of cereals (wheat, barley and oats) along with oilseeds (canola, flaxseed, soybeans and sunflower) and pulse (field peas, soybeans and lentils) crops. The site is characterized by imperfectly drained sandy soils in the west and poorly drained clayey soils in the east. The landscape is flat to gently undulating (0 to 2% slopes). Most producers use a variety of tillage implements including moldboard, chisel and disk ploughs. Direct seeding is also commonly used within the region and some agricultural fields are left in fallow. The 2010 fall tillage activities were delayed due to extremely wet conditions. Environment Canada reported a total of 245.3 mm of rain accumulated over the months of August and September, and agriculture fields were visibly saturated with water.

2.2 Image and Ground Data

An AWiFS image was acquired over the Brunkild watershed on October 12, 2010. The AWiFS sensor is on board of the RESOURCESAT-1 (IRS-P6) satellite and collects imagery at a 56-m (at nadir) pixel resolution covering a swath of 740 km. The spectral configuration of the AWiFS sensor is similar to that of SPOT where radiance data is collected in the visible (520-590 nm and 620-680 nm), near-infrared (NIR) (770-860 nm) and shortwave infrared (SWIR) (1550-1770 nm). The image data were received radiometrically corrected and orthorectified. The image was then atmospherically corrected using the ATCOR2 algorithm in PCI Geomatica® (Richter, 2004). This process converted the radiance image data into surface reflectance.

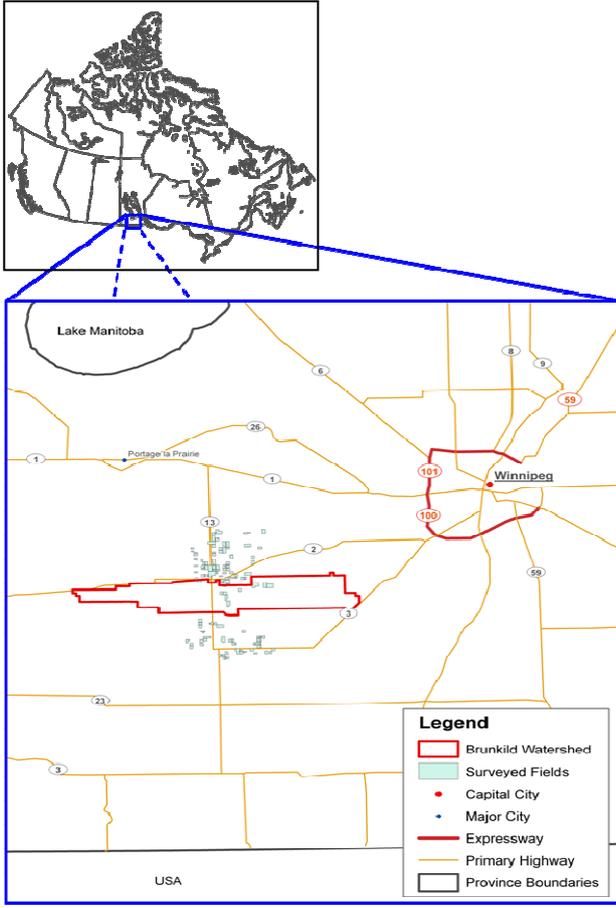


Figure 1. Image and ground data were collected over the Brunkild watershed, an agricultural area southwest of the Provincial capital of Winnipeg.

Ground crop residue data were collected near-coincident to the image acquisition (within 1-3 days) (Table 1). Surveyed fields were closely monitored to ensure no tillage activity occurred between the image acquisition and the ground data collection. For each field, qualitative observations were collected of the harvest condition, tillage type, crop residue type, position, direction and height. The percent residue cover was also visually classified into one of several categories: 0-30% (conventional), 30-60% (conservation) and 60-100% (no-till). These observations were collected using an ArcPad (ESRI) customized data entry form operated from a rugged mobile computer (eXplorist 210) with a built-in GPS device. A quantitative estimate of the percent residue cover was also measured over an area of the field (90m x 90m) using digital ground photographs. A rectangle quadrat (100 x 75 cm) was placed on the ground 30-m from the edge of the field and with its longest side positioned perpendicular to tillage direction. Five vertical photographs were captured within this area of the field following a cross pattern. The location of the sampling sites were recorded using a Garmin GPS device (GPSmap 60Cx) which provides positional accuracies less than or equal to 3 m.

To estimate ground percent residue cover from the vertical photographs, a digital grid (1 x 1 cm) was overlaid on the photographs. For each grid intersection, the presence of crop residue was visually noted and summed. Percent residue cover

was calculated as the ratio of the number of grid intersections where residue was present to the total number of grid intersections. Percent residue cover estimates from the five replicate photos were then averaged to provide a single residue estimate per sampling site. Given that several fields contained a high percent cover of volunteer crop, vegetation cover was also calculated and fields with more than 10% vegetation cover were eliminated from the sample population. The ground data were then collated in a geodatabase using the ArcGIS software.

Table 1. Ground data were collected over canola, lentil and small grain fields coincident (within 1-3 days) with the image acquisition.

Ground Data Collection Date (2010)	Total Fields	Canola	Lentils	Small Grains
October 9	5	3	1	1
October 11	13	4	3	6
October 12	10	2	6	2

3. METHODS

3.1 Endmember Selection and Extraction

Crop residue and soil endmembers were manually extracted from the image data based on the vertical ground photographs. Pacheco and McNairn (2010) developed an endmember extraction approach where agricultural fields with greater than 90% crop residue cover are selected as “pure” residue endmembers, and fields with less than 10% residue cover are selected as “pure” soil endmembers.

Only the major crop types were considered for this study, which include canola, lentils and small grains. For the residue endmembers, nine fields were estimated from the ground data to have greater than 90% residue cover. For each of these residue types, the highest reflectance spectrum was selected as input to the spectral unmixing model. As for the soil endmembers, there were no fields with less than 10% residue cover. Thus, with the help of a soils map classified into coarse soil textures, sandy and clay soil spectra were extracted based on visual interpretation. Fields with low reflectance in the near-infrared, red and green AWiFS bands were selected.

3.2 Spectral Unmixing Analysis

Spectra unmixing analysis was computed using the SPUNMIX algorithm in the PCI Geomatica® software (Shepherd, 2005). Spectral unmixing analysis is a classification technique that can determine the contribution of each material (or endmember) for each pixel within an image. Linear constrained unmixing can be calculated by the following equation:

$$SMA \equiv R_b \equiv \sum_{i=1}^m f_i r_{bi} + e_b, \quad (1)$$

$$\text{in which } \sum_{i=1}^m f_i = 1.0 \quad (2)$$

where R_b is pixel reflectance in band b , f_i is the fractional abundance of endmember i , m is the total number of

endmembers, r_{bi} is the reflectance in band b of endmember i , and e_b is the residual error in band b of the model.

Once the crop residue fractions were derived, these fractions were integrated in a geographical information system for spatial and statistical analysis. The percent crop residue cover values were averaged and extracted over each sampling site. The image percent residue cover was validated against the ground percent residue cover using the square of the Pearson product moment correlation coefficient (R^2) and the Root Mean Square Error ($RMSE$).

4. RESULTS AND DISCUSSION

4.1 Crop Residue and Soil Endmembers

Figure 2 illustrates the spectra that were extracted for input into the spectral unmixing model. It can be noted that the contrast between the crop residue and soil spectra is quite large. Similar to Pacheco and McNairn (2010), sandy soils have greater reflectance than the clay soils especially in the SWIR band. For both the crop residue and the soil spectra, an absorption feature in the red region of the electromagnetic spectrum is found and suggests the presence of vegetation over these fields. The absorption feature is however more amplified on the soil spectra than the crop residue spectra. The various crop residue endmembers are very similar in shape and amplitude. The small grain endmember deviates slightly from the other two residues (lentils and canola) with lower reflectance in the green, red and SWIR regions of the spectrum.

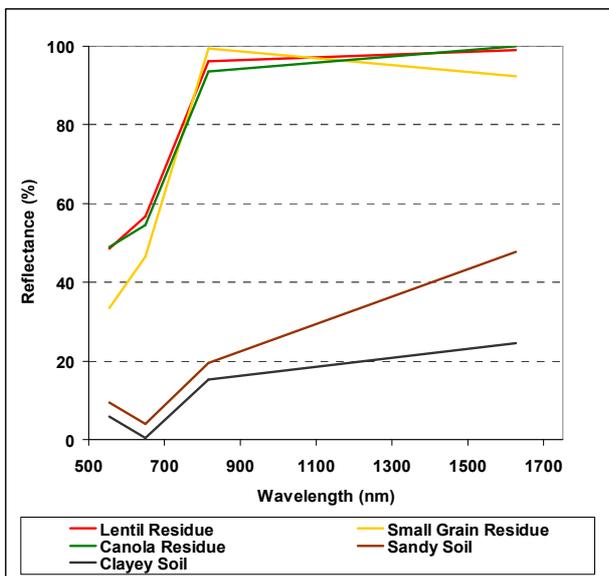


Figure 2. Crop residue and soil endmember spectra extracted directly from the AWiFS imagery.

4.2 Percent Crop Residue Cover Fractions

Crop residue fractions were validated against the percent ground residue cover data. R^2 and $RMSE$ statistics were calculated for all the residue types combined (overall) and for each individual residue type (Table 2). A scatterplot of the

relationship between the image and ground data was also derived (Figure 3).

Table 2. Statistics from the validation of the crop residue fraction derived from the AWiFS imagery.

Residue	R^2	RMSE (%)
Overall	0.83	20.18
Canola	0.76	22.19
Lentils	0.92	17.00
Small Grain	0.61	21.29

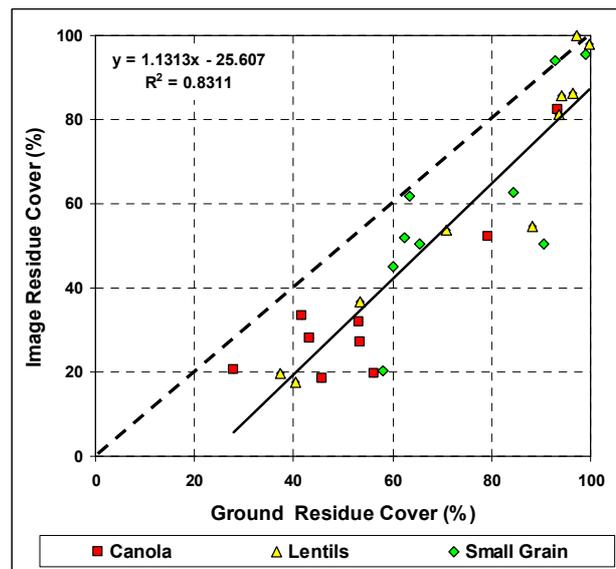


Figure 3. Scatter plots of image residue cover versus ground residue cover.

Overall results show that the spectral unmixing analysis can estimate percent crop residue cover with an R^2 of 0.83 and an $RMSE$ of 20.18%. It is clear from the scatterplot that the spectral unmixing model is underestimating the crop residue cover. Several factors can contribute to this underestimation. Vegetation was present on some of the surveyed fields and although fields with high percent (>10%) vegetation cover were eliminated from the sample population, 10 out of the 28 fields had more than 3% vegetation cover. Given that the soil endmember spectra had an absorption feature in the red, it is likely that any contributing reflectance from vegetation was attributed to the soil fraction. Also, it is possible that the soil endmember selected for spectral unmixing analysis was more representative of the actual soil conditions than the residue endmember was of the crop residue conditions. Finally, although caution was taken to avoid mixed pixels from the field edges, some of the error can be attributed to mixed pixels given the coarse spatial resolution of the AWiFS.

Obtaining good estimates of crop residue cover depends on the reflectance contrast between the crop residue and soil. This contrast can vary based on soil textures as well as crop residue type and condition. For this study, results were fairly consistent between residue types. R^2 showed a positive trend for each of the residue types. Small grain fields had a lower correlation ($R^2 = 0.61$) than the other fields but error was mostly driven by a

single data point. A larger sample size would assist to further validate the error in estimating grain residue cover. RMSE statistics were similar amongst residue types with lentils having the lowest error (RMSE = 17.00%) compared to canola (RMSE = 22.19%) and small grain (RMSE = 21.29%). Upon examining the percent vegetation cover values for the lentil fields, it can be noted that most (8 out of 10) of the fields contained no vegetation cover. Thus these lentil fields were characterized by only crop residue or soil cover, which eliminates errors introduced by even small vegetation contributions.

These results also suggest that the selection and extraction of endmembers may not require the collection of extensive quantitative ground datasets. Indeed, a crop map of the previous growing season along with a soils map may be sufficient to select crop residue and soil endmembers for input into spectral unmixing. The randomly selected soil endmembers had greater “purity” than the ones available from the ground observations. Minimizing the requirement for quantitative ground data will facilitate the migration of these research methods to operational implementation at regional scales.

5. CONCLUSIONS

An AWiFS image was acquired during the 2010 fall tillage season over the Brunkild watershed in the Canadian Prairies. Percent ground crop residue cover was collected during the time of acquisition. Using these ground data, soil and crop residue endmembers were selected directly from the imagery and used as inputs to the spectral unmixing analysis model. Results from this study demonstrated that spectral unmixing analysis applied to AWiFS can produce crop residue cover estimates with room mean square errors between 17.00% and 22.19%. Errors were lower for lentil fields (17.00%). The absence of weeds or volunteer crop on these fields contributed to the lower error statistic. The introduction of a crop endmember into the spectral unmixing model could potentially reduce error on fields with significant vegetation cover and should be investigated in a subsequent study.

REFERENCES

- A. Pacheco, and H. McNairn, “Evaluating multispectral remote sensing and spectral unmixing analysis for crop residue mapping”, *Remote Sensing of Environment*, vol 114 (10), p.p. 2219-2228. October 2010.
- Richter, R. (2004). *Atmospheric/Topographic Correction for Satellite Imagery: Atcor 2/3 Users Guide Version 6.0*, DLR German Aerospace Centre: Wessling, Germany, 71 pages.
- Shepherd (2005). SPUNMIX algorithm, PCI Geomatica 9.1. Earth Observations Lab, Institute for Space and Terrestrial Science. North York, Ontario.

ACKNOWLEDGEMENTS

The authors would like to thank Marc-André Faucher, Andrea Minano, Ian King and Kameron Timms for the processing of the ground data. The research was funded by the Canadian Space Agency under the Government Related Initiatives Program (GRIP).