# Application of High Resolution Optical Imagery to Precision Agriculture

**R.J. Brown[1], K. Staenz[1], H. McNairn[2], B. Hopp[2] and R. van Acker[3]**

[1] **Canada Centre for Remote Sensing**
588 Booth St., Ottawa, Ontario, Canada K1A 0Y7
(613) 947-1263 (telephone)
ron.brown@ccrs.nrcan.gc.ca

[2] **Noetix Research Inc.**
978 Merivale Road, Ottawa, Ontario, Canada K1Z 6A4

[3] **Department of Plant Science, University of Manitoba**
E319 Agric. Bldg., Winnipeg, Manitoba, Canada R3T 2N2

## Abstract

To evaluate the potential of high resolution satellites such as EarlyBird and QuickBird for use in precision agriculture, a number of datasets were collected over study sites in Manitoba during 1996. These data included *casi* airborne multispectral data and aerial photographs during crop emergence, as well as *casi* data during crop vegetative growth. At the time of image acquisition, ground data were collected in selected fields to characterize weed growth and crop biomass. Preliminary analysis of the 1996 data suggests that the use of high spatial multispectral data for weed and crop vigor detection is promising.

## Background

Significant spatial variations in crop yield often occur across agricultural fields. Much of this variability in yield is attributable to soil nutrient and moisture variability, topography, as well as insect and weed infestations. Precision agriculture combines a number of technologies - Global Positioning Systems (GPS), Geographical Information Systems (GIS), remote sensing and variable rate technology - to site specifically manage this spatial variability. Pilot studies have demonstrated that with this approach, crop production can be optimized with minimum inputs of chemicals, and a corresponding minimum impact on the environment.

Precision agriculture requires immediate and precise knowledge of field locations. GPS is used in creating spatial yield variability maps from continuous yield sensors and to geo-reference field measurements. Variable rate technology (VRT) applies the within field variability information collected from site samples, remote sensing inputs and variable yield monitors. For example, VRT can mix custom fertilizer blends on-the-go and apply the correct combination and amount to a site depending on the site-specific information provided. Flow-rate sprayers can also apply the correct type and rate of herbicide application. GIS technology is used to manage and integrate the geo-referenced data.

The role of remote sensing in precision agriculture is to supply repetitive information on the condition and spatial variability of soil and crop attributes, including crop condition and crop infestations. A number of high spatial visible-infrared satellites, including EarthWatch's QuickBird and EarlyBird, are scheduled for launch over the next few years. Although some information on site-specific farming is now being collected with airborne sensors and cameras, the commercialization of high resolution satellite sensors is creating the opportunity for satellite-derived information inputs.

## Project Objectives

To evaluate the potential of these high resolution satellites sensors for use in precision agriculture, a number of datasets were collected over study sites in Manitoba during 1996. This data included the collection of *casi* airborne multispectral data and aerial photographs during crop emergence, as well as the collection of *casi* data during crop vegetative growth. Within the context of the precision agriculture initiative, two specific questions were addressed.

*(1) What is the potential of high spatial imagery for identifying weed infestations within agricultural fields.*

Site-specific management of herbicide applications is important in reducing environmental impacts and in limiting input costs for producers. Traditionally, farm operators have applied herbicides to a field as a single uniform application. However, weed infestations are extremely variable in terms of location, spatial extent and type of infestation and consequently, there is usually an over application of herbicide across a field.

Some success has already been achieved in mapping weeds from visible-infrared data (Brown and Steckler, 1993). In practice, once the areas of weed infestation are mapped, a geo-referenced map can be input into variable rate sprayers to automatically locate the weed patch and apply the appropriate herbicide.

*(2) Are high spatial data sensitive to crop biomass variability across agricultural fields?*

Biomass, crop vigor and crop yield can vary dramatically across a field, depending on site conditions and management practices. Using site-specific management, more appropriate amounts and types of inputs can be applied to reduce input costs and improve crop yields (Carr *et al.*, 1991). Under some conditions, variable application of inputs may not increase average yields, but may simply hold them constant while reducing input costs.

Within-field information on soil and crop conditions derived from satellite sensors can help determine required site-specific treatments. Numerous studies have related vegetation indices using ratios of red and infrared reflectances to crop vigor, crop condition and biomass (Dusek *et al.,* 1985; Gardner *et al.,* 1985; Jasinski, 1990).

## Experiment Overview

Results from two sites in southern Manitoba are described in this paper. The Altona site is centered on the town of Altona, Manitoba ($49^{o}$ 5’ N, $97^{o}$ 40’ W) and has been used as an agricultural research site by the Canada Centre for Remote Sensing (CCRS) since 1993 (Pultz *et al.*, 1994). The Landmark site is located south of the city of Winnipeg. Both sites are relatively flat and have a mixture of agricultural crops including cereal grains, sunflower, canola, flax, corn, sugarbeets, potatoes and specialty crops such as canary seed, peas, beans and lentils.

Airborne data collected over the sites included natural colour air photos (June 7, Landmark site), colour infrared and black and white air photos (July 9, Landmark and Altona sites) and *casi* (Itres Research Ltd.) multispectral data (June 30 and July 25, Landmark and Altona sites). In spatial mode, *casi* recorded imagery in 20 bands between 463 nm to 995 nm at a 3-metre x 3-metre ground resolution. Actual band locations and associated bandwidths are listed in Table 1 and were chosen to correspond to EarlyBird and QuickBird bands. *Casi* data were geo-corrected using inflight information and GPS ground control points.

**Table 1. *casi* Spatial Mode Band Characteristics**
**(FWHM = Full Width at Half Maximum)**

| Band Number | Wavelength Position (nm) | Bandwidth at FWHM (nm) |
|---|---|---|
| 1 | 462.7 | 16.0 |
| 2 | 483.2 | 27.2 |
| 3 | 508.4 | 25.4 |
| 4 | 532.7 | 25.4 |
| 5 | 555.3 | 21.8 |
| 6 | 582.5 | 35.0 |
| 7 | 620.2 | 20.0 |
| 8 | 641.0 | 23.8 |
| 9 | 663.8 | 23.8 |
| 10 | 680.8 | 12.4 |
| 11 | 765.6 | 10.6 |
| 12 | 775.1 | 10.6 |
| 13 | 792.4 | 26.0 |
| 14 | 817.3 | 26.0 |
| 15 | 845.1 | 31.8 |
| 16 | 870.2 | 20.4 |
| 17 | 884.6 | 10.8 |
| 18 | 938.7 | 10.8 |
| 19 | 969.7 | 10.8 |
| 20 | 994.9 | 10.8 |

Two ground data collection campaigns were carried out in each study site, at the time of the *casi* overflights. To coincide with the overflight of June 30 1996, weed information was gathered on selected fields during the last week of June. In particular, weed information including weed type, location and areal extent was gathered on one canola and one wheat field in Altona, and two sugarbeet fields in Landmark. Weed locations and perimeter of weed patches were recorded using a GPS.

Detailed quantitative data were gathered over a number of fields in each site during the July 15 to 20 time frame (3 bean, 2 canola and 2 sugarbeet fields). On selected fields, a number of site-specific measurements were taken and the location of all within field sample points were recorded using a GPS receiver. Between 8 to 12 sites were located along a transect running diagonally through the field, with each sample site approximately 50 to 60 metres apart.

(1) Biomass: At each site, a 0.5 metre x 0.5 metre sample of above ground crop was cut and placed in a plastic bag. Biomass samples were weighed wet in the field and then transported to the University of Manitoba where they were oven-dried and then weighed dry. Plant water content (PWC) was calculated as follows:

$$PWC\,(\%) = \left[\left(\text{wet biomass (g)} - \text{dry biomass (g)}\right) / \text{wet biomass (g)}\right] * 100\,.$$

(2) Leaf Area: A subsample of plant biomass was used to calculate total leaf area ($cm^2$).

(3) Plant chlorophyll: At each site within a field, 10 chlorophyll measurements were made using a chlorophyll meter. These measurements were taken on upper leaves within the crop canopy. The chlorophyll meter records plant chlorophyll content as a relative value between 0 and 50 with higher chlorophyll contents represented by higher chlorophyll values. The 10 measurements were averaged to provide a mean chlorophyll value per sample site.

(4) Crop height: At each site, crop height was recorded in cm.

(5) Percent ground cover: Vertical photos above the crop canopy recorded percent ground cover.

## Preliminary Results and Discussion

### *Weed Detection*

The July 9th black and white air photos covering the Landmark sugarbeet fields were scanned at a resolution of 1 metre. Vectors outlining weed locations in the fields, as recorded using a GPS receiver, were incorporated with the digital black and white photos, as well as with the *casi* data. A *casi* colour infrared 3-metre image was resampled at 1-metre intervals up to a 20 metre spatial resolution, using a cubic convolution algorithm (Figure 1). Also, the 1-metre black and white image was resampled at 1-metre intervals up to a 10 metre resolution (Figure 2). The 1-metre and 3-metre black and white images simulate what might be expected from EarlyBird and QuickBird panchromatic data. These two satellites will also carry a 15-metre and 4-metre multispectral sensor in the visible and infrared, respectively.

To date, only visual interpretation of the weed data has been conducted. However, examining the original *casi* imagery over the Landmark fields suggests that weed patches can be separated from post-emergent sugarbeet crops using a colour-infrared combination, using bands 5, 8 and 15 (Table 1). Vector-defined weed areas in Figures 1 and 2 represent remaining weed patches approximately 2 to 3 weeks after spraying in late June. Some areas reflecting strongly in the infrared as recorded on the imagery were not outlined with the GPS receiver during ground data collection. These larger weed areas were present just after spraying during the *casi* overflight, but as a result of spraying, were reduced in size by the time of ground truthing.

In comparing similar scale colour-infrared *casi* data (Figure 1) with black and white scanned photos (Figure 2), weed patches are not as easily detected on the black and white imagery, suggesting that panchromatic EarlyBird and QuickBird imagery may not be suitable for this application. This panchromatic data does however provide interesting information on soil conditions including subsurface drainage patterns.

Figures 1 and 2 demonstrate the importance of spatial resolution for providing information on within-field characteristics such as location of weed patches. In examining the resampled colour-infrared imagery, visual inspection suggests that resolutions of less than 10 metres are required to accurately delineate even significant weed patches.

### *Crop Vigor*

GPS sample point locations were overlayed on the July 25 *casi* imagery for the Altona site (Figure 3). For the two canola fields, average radiance was extracted for a 3 x 3 pixel area centered on the sample point. Radiance values for the canola crop were normalized for a first-order removal of atmospheric effects using the flat-field approach (Roberts *et al.*, 1986 ). Each pixel value in each band was divided by the corresponding radiance of the road's asphalt surface (spectrally flat target). The resulting values, pseudo-reflectances, were then multiplied by 100. In Figures 4 and 5, near infrared (765.6 nm) pseudo-reflectance values for the canola sites are plotted against wet biomass weights and leaf area values as measured at these sites. Results from a linear regression indicate a strong positive correlation between wet biomass and reflectance (coefficient of determination ($R^2$) = 0.846; significance level (p) < .001), as well as between leaf area and reflectance ($R^2$ = 0.885; p < .001). However, pseudo-reflectance values appear to level off at higher leaf area values (Figure 5). As a result of significant cloud cover over the site, sample numbers were reduced and consequently, regression results should be considered preliminary.

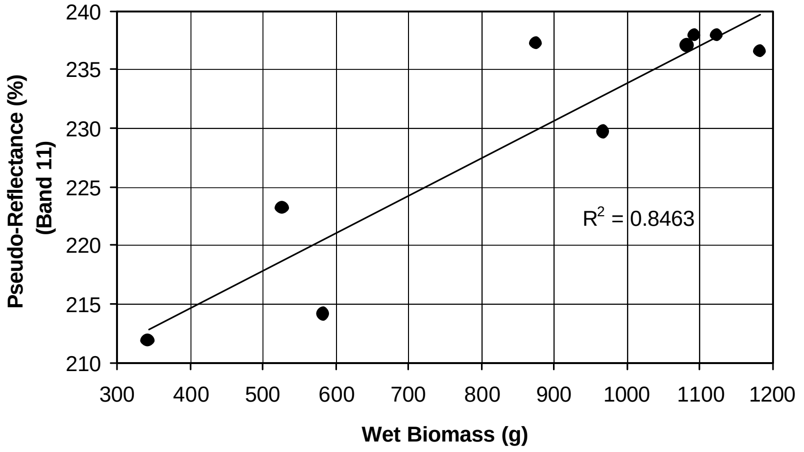
Figure 4. Near-Infrared Response From Canola Crop

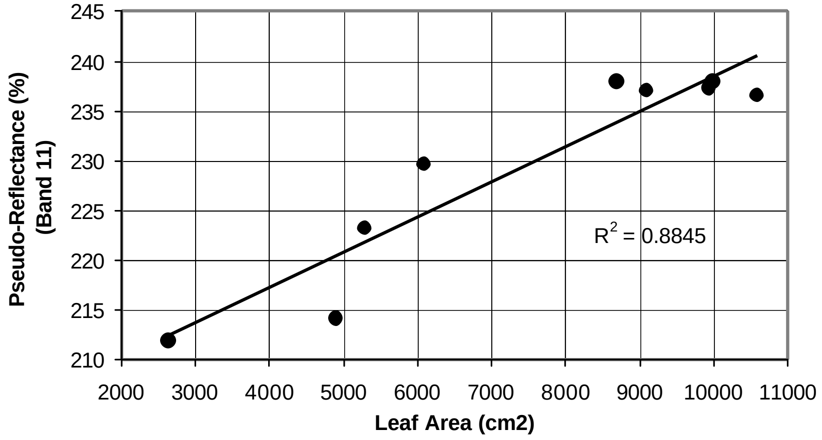
Figure 5. Near-Infrared Response From Canola Crop

## Conclusions

Preliminary analysis of the 1996 data suggests that the use of high spatial multispectral data for weed and crop vigor detection is promising. Weed patches can be visually detected on post-emergent sugarbeet fields using colour-infrared imagery at ground resolutions of less than 10 metres. Preliminary regression results from this limited data set indicate a significant linear correlation between near-infrared reflectance from canola crops and indicators of crop vigor including wet biomass and leaf area. These results suggest that the QuickBird multispectral sensor (4-metre spatial resolution) may be most suitable for weed detection. Both EarlyBird (15-metre resolution) and QuickBird multispectral sensors would provide information on crop vigor.

## Future Work

The 1996 project provides a solid background to the 1997 Manitoba campaign which will further address these study objectives, with a larger number of sample sites and a broader range of soil and crop measurements. The 1997 work will also integrate variable yield data to investigate the ability of remote sensing derived products for determining site-specific yield.

## References

Brown, R.B., and J-P.G.A. Steckler. 1993. “Weed Patch Identification in No-Till Digital Imagery”, *Can. J. Remote Sens*., 19:88-91.

Carr, P.M., G.R. Carlson, J.S. Jacobsen, G.A. Nielsen, and E.O. Skogley. 1991. “Farming Soils, Not Fields: A Strategy for Increasing Fertilizer Profitability”, *J. Prod. Agric*., 4:57-61.

Dusek, D.A., R.D. Jackson, and J.T. Musick. 1985. “Winter Wheat Vegetation Indices Calculated from Combinations of Seven Spectral Bands”, *Remote Sens. Env*., 18:255-267.

Gardner, B.R., B.L. Blad, D.R. Thompson, and K.E. Henderson. 1985. “Evaluation and Interpretation of Thematic Mapper Ratios in Equations for Estimating Corn Growth Parameters”, *Remote Sens. Env.*, 18:225-234.

Jasinski, M.F. 1990. “Sensitivity of the Normalized Difference Vegetation Index to Subpixel Canopy Cover, Soil Albedo, and Pixel Scale”, *Remote Sens. Env*., 32:169-187.

Pultz, T.J., R.J. Brown, J. Boisvert, Y. Crevier, R. Duncan, H. McNairn, D. Mullins, D. Randall, D. Wood, and P. Vincent. 1994. “The CCRS SIR-C/X SAR Soil Moisture Experiment”, *Proceedings of the Second International Workshop, Applications of Remote Sensing in Hydrology*.

Roberts, D.A., Y. Yamaguchi, and R.J.P. Lyon. 1986. "Comparisons of Various Techniques for Calibration of AIS Data”, *Proceedings of the Second Airborne Imaging Spectrometer Data Analysis Workshop*, JPL Publication 86-35, Pasadena, California, pp. 21-30.