Estimating Crop Yields from Remote Sensing Data

Joseph M Piwowar

TERRA Lab, Department of Geography, University of Regina
joe.piwowar@uregina.ca

Abstract

Reliable estimates of crop yields are important planning tools, not only for individual farmers, but also for regional and national agronomists. Yield forecasts have been traditionally made at the field level by noting that there is a strong correlation between mid-season green leaf area index (LAI) and harvest production. This paper examines the LAI-yield relationship by estimating LAI from multispectral remote sensing data. Additional relationships between vegetation indices both measured on the ground and estimated from satellite imagery are explored.

Background and Relevance

The production of food, feed, and fibre is fundamental to continued human existence. Remote sensing of croplands can provide important information for crop management decisions to improve water and nutrient use efficiency and enhance crop performance (Hatfield et al. 2004). The application of remote sensing for quantifying crop biomass, leaf area, ground cover, and yield is generally dependent on how they affect the quantity and quality of electromagnetic radiation reflected and/or emitted by the vegetation (Pinter Jr. et al. 2003, Ferencz et al. 2004). However, soil reflectance through an incomplete crop canopy cover complicates the remote sensing of the crop.

Reliable estimates of crop yields are important planning tools (Doraiswamy et al. 2003). The earlier in a growing season that an accurate yield prediction can be made, the more useful the analysis will be. Important crop parameters for yield estimation are the green leaf area index (LAI) and the normalized difference vegetation index (NDVI) (Best and Harlan 1985, Thenkabail 2003).

This paper reports on the application of remote sensing observations to estimate harvest yield for small grain crops near Indian Head, Saskatchewan. The objective was to assess the efficacy of estimating yields from and leaf area index (LAI) measurements derived from multispectral imagery acquired by a spaceborne sensor at some time prior to harvest.

Data

The study site is located near the town of Indian Head, Saskatchewan (50°30'N 103°40'W) and approximately 70 km east of Regina. Canola, spring wheat and field peas are considered the most essential and vital cereal, oilseed, and pulse crops of the region (C. Holzapfel pers. comm. 2009). The area is located in the Aspen Parkland ecoregion and is characterized by a semi-arid continental climate with extreme seasonal temperatures (average daily temperatures are -16°C in January to 18°C in July) and limited precipitation (approximately 250 mm of rain falls throughout the growing season) (Environment Canada 2010).

Field measurements were collected from 16 fields associated with the Agriculture and Agri-Food Canada (AAFC) research centre at Indian Head at approximately 2 week intervals from June 1 through August 31, 2009. The fields were planted in barley, canola, field pea, flax, oat, and spring wheat. Field data included *in situ* NDVI, LAI, crop growth stage, soil moisture, row spacing and orientation, and grain yield at harvest.

Multispectral remote sensing imagery was collected by the RapidEye constellation on June 2, July 17, July 27, August 10, August 25, and September 5. The RapidEye system consists of 5 identical satellites that were launched in 2008. The RapidEye sensors collect reflected radiation in 5 spectral bands from the visible blue (440-510 nm) to the near infrared (760-880 nm), including a unique red-edge band at 690-730 nm). The images are acquired at 12-bit precision with a ground sampling distance of 6.5 m (RapidEye AG 2010).

Analysis Methods

The *in situ* data were averaged to the field level and then divided into 2 groups: one for calibrating the yield model and the other for an independent validation of its effectiveness.

The analyses were completed in 2 parallel procedures: one for NDVI-based estimation and the other for LAI-based estimation. Each procedure followed a 3-step process:

i. Establish the statistical relationship between crop yields and *in situ* measurements.
ii. Establish the statistical relationship between *in situ* and spaceborne measurements.
iii. Establish the statistical relationship between crop yields and spaceborne measurements.

At each step, the coefficient of determination was calculated though linear correlation to estimate the amount of yield variability that could be accounted for with the NDVI or LAI data. The statistical significance of the results was assessed using a *t*-test.

Results and Discussion

A strong correlation ($r^2 = 0.7$; significant at the 95% level) was found between *in situ* LAI and the RapidEye vegetation index. When the calibrated model was applied to the validation data, the results were also found to be statistically significant ($r^2 = 0.7$; significant at the 95% level). However, consistent with other studies (Weiss and Baret 1999), it was found that high levels of pixel heterogeneity affected the LAI estimates. In addition, areas of high LAI values (2–4) had weaker correlations because of high solar attenuation by dense plant canopies (Carlson and Ripley 1997, Asrar et al. 1985). Additional results are still being assessed.

A major challenge to the analysis of the data was the reliability of the RapidEye imagery. No images were available from the critical growth period between June 2 and July 17. In addition the imagery acquired at peak growth stage (July 17 and July 27) had significant cloud contamination.

Conclusions

The methods presented here address the potential of multispectral satellite imagery for estimating crop yield. Future work will include an assessment of non-linear modeling. The analyses will be further extended to calculate net primary productivity.

References

Asrar, G., Kanemasu, E. T., and Yoshida, M. 1985. Estimates of leaf area index from spectral reflectance of wheat under different cultural practices and solar angle. *Remote Sensing of Environment,* 17(1): 1-11.

Best, R. G. and Harlan, J. C. 1985. Spectral estimation of Green leaf area index of oats. *Remote Sensing of Environment,* 17(1): 27-36.

Carlson, T. N. and Ripley, D. A. 1997. On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment,* 62(3): 241-52.

Doraiswamy, P. C., Moulin, S., Cook, P. W., and Stern, A. 2003. Crop Yield Assessment from Remote Sensing. *Photogrammetric Engineering and Remote Sensing,* 69(6): 665-74.

Environment Canada 2010. 'Canadian Climate Normals or Averages 1971-2000', http://www.climate.weatheroffice.gc.ca/climate_normals/index_e.html (last accessed 2010.10.01).

Ferencz, C., Bognar, P., Lichtenberger, J., Hamar, D., Tarcsai, G., Timar, G., Molnar, G., Pasztor, S. Z., Steinbach, P., Szekely, B., Ferencz, O. E., and Ferencz-Arkos, I. 2004. Crop yield estimation by satellite remote sensing. *International Journal of Remote Sensing,* 25(20): 4113-49(37).

Hatfield, J. L., Preuger, J. H., and Kustas, W. P. 2004. 'Remote Sensing of Dryland Crops.' in *Remote Sensing for Natural Resources Management and Environmental Monitoring: Manual of Remote Sensing* ed. S. Ustin, 531-68. Wiley.

Pinter Jr., P. J., Hatfield, J. L., Schepers, J. S., Barnes, E. M., Moran, M. S., Daughtry, C. S. T., and Upchurch, D. R. 2003. Remote Sensing for Crop Management. *Photogrammetric Engineering and Remote Sensing,* 69(6): 647-64.

RapidEye AG 2010. 'RapidEye: Geofacts Turned into Knowledge', http://www.rapideye.de/ (last accessed 2010.10.01).

Thenkabail, P. S. 2003. Biophysical and yield information for precision farming from near-real-time and historical Landsat TM images. *Int. J. Remote Sensing,* 24(14): 2879–904.

Weiss, M. and Baret, F. 1999. Evaluation of Canopy Biophysical Variable Retrieval Performances from the Accumulation of Large Swath Satellite Data. *Remote Sensing of Environment,* 70(3): 293-306.