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Application of Hyperspectral Remote Sensing for LAI Estimation in Precision Farming

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Abstract

Leaf Area Index (LAI) is a key parameter controlling biophysical processes of the vegetation canopy. LAI helps to estimate productivity of agriculture and forest canopies, which can then serve as input to crop modelling. LAI can be measured using different approaches such as destructive sampling, optical ground-based instruments and optical imagery. Hyperspectral data has the advantage of distinguishing different target types within a pixel using spectral unmixing analysis as a tool to separate such spectral signatures. This paper investigates the relationship between ground-based effective LAI (eLAI) measurements estimated with the LI-COR LAI-2000 and eLAI values derived from Probe-1 hyperspectral surface reflectance data. This data were collected together with ground-based eLAI data during the summer of 1999 in Clinton, an agricultural area in South Western Ontario, Canada. The crops investigated for this study are corn and white beans. Correlations between ground eLAI and eLAI values derived from hyperspectral data produced encouraging results. Correlations were not strong when analysis was done on a single crop type. However, correlation results are good (r = 0.91) when data from all canopies are considered.

1. Introduction

Leaf Area Index (LAI) is a key parameter used to assess biophysical processes of the vegetation canopy. Defined as one half the total green leaf area per unit ground surface area (Chen and Black, 1992), LAI is used to describe the percentage of vegetation cover and to estimate productivity of agriculture and forest canopies. LAI can be estimated using different approaches such as destructive sampling, optical ground-based instruments and optical imagery. The methods associated with multispectral data consider the total amount of the vegetation canopy in a pixel to estimate LAI. However, it is essential in agriculture to distinguish the crop from the other constituents such as residue and weeds in a pixel in order to estimate a more accurate LAI.

Hyperspectral remote sensing has the advantage of distinguishing different target types within a pixel and uses spectral unmixing analysis as a tool to separate spectral signatures. This paper investigates the application of hyperspectral remote sensing to the estimation of LAI in the context of precision farming. The correlations between ground LAI measurements, estimated with the LI-COR LAI-2000 (LI-COR, 1990), and

LAI values derived from Probe-1 hyperspectral surface reflectance data will be analysed.

2. Study Site

The LAI data were acquired from agricultural sites in Clinton, Ontario, Canada (43^o 40' N, 81^o 30' W) (Figure 1). This area is an agricultural region composed mainly of bean, corn and small grain (wheat and barley) fields. The field campaign was carried out from June 24 to July 8, 1999. These dates were chosen to ensure the plants were at a certain growth stage to facilitate LAI measurements.

Figure 1: Study site location: Clinton, Ontario, Canada.

3. Data Acquisition

Two different crops were investigated, corn and white beans. LAI data were acquired from three fields of each crop type. In order to reflect within-field variability, approximately ten sampling sites were selected per field: sampling sites were located in areas of different soil types and elevation. Ground-based LAI measurements and hyperspectral airborne data were acquired within a week to ensure both data sets were analogous for validation purposes.

3.1. Ground Data Collection

Ground LAI measurements were acquired using the LI-COR LAI-2000. The instrument algorithms only measures effective LAI (eLAI) (LI-COR, 1990). It does not take into consideration the clumping index of the crop canopy. The clumping effect assumes that canopy foliage is spatially distributed according to a non-random pattern (Chen and Cilhar, 1995). Using this same data set, previous research reveals that eLAI values acquired with the LAI-2000 have a very good correlation (r = 0.90) with percent ground cover (Pacheco *et al.*, 2001).

Three eLAI measurements were taken at each sampling site in order to minimise errors and, thus, provide a representative eLAI average of the sample site. Measurements were acquired along 2 m diagonal transects between two plant rows within an area of 2 to 3 m surrounding the centre of the sampling site. The LAI-2000 had to be employed during overcast conditions or periods of low sun angles (sunrise and sunset).

The LAI-2000 measures the attenuation of diffuse sky radiation at five zenith angles (7^o, 23^o, 38^o, 53^o and 68^o) simultaneously (LI-COR, 1990). At each sampling site, one reference measurement was taken above crop canopy and four measurements were taken below. For each eLAI measurement, five canopy transmittance values are calculated from the five zenith angles of the optical sensor, which are utilised to calculate foliage amount and orientation.

3.2. Hyperspectral Airborne Data

Hyperspectral imagery was acquired over the Clinton area on July 7, 1999 with the Probe-1 hyperspectral airborne sensor (Earth Search Sciences Inc., 2001). The data were collected over the wavelength range from 430 nm to 2500 nm in 128 bands. The bandwidths at full width of half maximum (FWHM) varies from 13 nm to 22 nm with a spectral sampling interval range of 10 nm to 20 nm. The aircraft was flown at an altitude of 2500 m resulting in a pixel size of 5 m by 5 m.

The Probe-1 sensor was mounted on an active 3-axis gyro-stabilized real time motion compensation system. A non-differential GPS was recording the location of the aircraft during the flight but no attitude measurements were made.

4. Analysis Approach

4.1. Data Preprocessing

The raw imagery was radiometrically calibrated using a reflectance-based vicarious calibration method (Secker *et al*., 2001). Reflectance spectra from a uniform bare soil target were acquired using a GER3700 field spectroradiometer and applied with this method to generate a new set of calibrated gains to convert the raw digital numbers (DN) from Probe-1 to at-sensor radiance. Atmospheric correction was then performed on the calibrated radiance data. Surface reflectance was computed on the hyperspectral cubes using the surface reflectance retrieval procedure in Imaging Spectrometer Data Analysis System (ISDAS) (Staenz and Williams, 1997; Staenz *et al*., 1998).

To preserve the spectral integrity of each pixel in the imagery, no geometric correction of the Probe-1 data was attempted. To locate the Probe-1 pixels where ground sampling was done in each field, a reversed image to image registration process was used. All sampling site locations were accurately measured with a differential GPS during the field campaign. The positions of these sites were digitally marked on a series of aerial ortho-photos of the area. These marked ortho-photos were then registered by a polynomial fit to the Probe-1 imagery until the boundaries of each field used in this study fit the boundaries of the same field in the original Probe-1 imagery. The pixel-line locations of the Probe-1 data of the sampling site markers were relocated by this reverse process and used for the correlations between the eLAI derived from the hyperspectral data and the ground eLAI measurements presented in this paper.

4.2. Endmember Extraction and Spectral Unmixing

The first step in this method is to find the endmembers of the crop canopies, which are the basic spectral constituents of the pixels within the corn and white bean fields. Based on ground cover knowledge of these fields, three endmember spectra were manually extracted from the reflectance image cubes: vegetation (crop), soil and residue. Since the availability of pure pixels under natural field conditions is problematic, pure patches of soil, crop and residue were created on the fields (McNairn *et al.*, 2001). Endmember spectras were then extracted from the canopy within these 20 m by 20 m patches. Although these patches were not exactly "pure", the selected endmember spectra were the "purest" spectra available from the data cube. Double crop density patches constitued about 80% crop and the residue patch did contain a small amount of green grass. However, soil patches were 100% soil.

A constrained linear spectral unmixing method was conducted on the hyperspectral data using an algorithm implemented in ISDAS (Staenz *et al*., 1998). Spectral unmixing was done using the full spectral range from 430 nm to 2500 nm. For each field, reflectance cubes were unmixed using the endmembers mentioned previously. As a result, fraction maps were generated for the various endmembers.

4.2. eLAI Extraction and Validation

eLAI values were extracted from the hyperspectral data using an algorithm implemented in ISDAS (Staenz *et al*., 2001). The crop fraction for each of the fields was used as in input to produce the eLAI map (Figure 2).

eLAI can be calculated according to this formula (Ross, 1981):

$$eLAI = \frac{\cos\alpha}{G}\left(-\ln \mathrm{P}\right) \qquad (1)$$

where P is the probability of a view line or a beam of radiation at an incidence angle α passing

Figure 2: eLAI map of a white bean field derived from Probe-1 hyperspectral reflectance data.

through a horizontally uniform plant canopy with random leaf angular and spatial distribution and G is the mean projection coefficient of unit foliage area on a plane perpendicular to α.

To estimate eLAI from hyperspectral data, G (α) can be determined at 0.5 for plants which have randomly distributed leaf angles such as agricultural crops (Norman, 1979). The incidence angle α corresponds to the sensor viewing zenith angle. Probe-1 is usually flown at a view angle of 0^o (nadir looking). Also, P represents the gap (non-vegetation) fraction, which is determined by spectral unmixing as follows:

$$P = 1 - f_c \qquad (2)$$

where f_c is the fraction of the crop endmember. eLAI is then derived from hyperspectral data according to the following formula:

$$eLAI\,(f_c) = -2 \ln (1 - f_c) \qquad (3)$$

For each sampling site, eLAI values were estimated using a 3 by 3 pixel window average centred on the sampling site markers. Correlations were generated between the eLAI estimates from the hyperspectral data and the ground eLAI measurements acquired with the LI-COR LAI-2000.

5. Results and Discussion

Results from the correlations between ground eLAI measurements using the LAI-2000 and eLAI values derived from the hyperspectral data cubes are presented in Table 1. Correlation coefficients were calculated for each crop type, white beans and corn, and on pooled data from all six fields. Correlations were not computed on a field-by-field basis since the number of sample points was too small and variability in eLAI values within a field was almost non-existent. Only ten sample points were chosen per field and thus, more sample points would be necessary and greater variability is required to generate a good valid relationship between ground eLAI and eLAI values derived from the hyperspectral data on a field-by-field basis.

The correlation coefficients generated for each crop type differ significantly. Indeed, the correlation between the ground eLAI measurements and the hyperspectral eLAI values are much higher for the corn (r = 0.69) than for the white beans (r = 0.16) (Figures 3 and 4). The difference of growth stage between the two crops was important: the three corn fields were much more developed than the white beans. Since the white bean crops were small in size, errors might have occurred when ground eLAI measurements were taken with the LAI-2000. In fact, the LAI-2000 instrument determines eLAI values and estimates simultaneously a standard error for the eLAI determination (SEL). It was noted that SEL values were considerably higher for white beans. Corn fields have an average SEL value of 0.04 in comparison to 0.47 for white beans. The low correlation between ground eLAI and eLAI values derived from the hyperspectral data can also be justified by the limitations in the endmember selection. Most of the fields were using the "purest" pixels of endmembers extracted from other fields of the same crop to perform spectral unmixing. Although selecting endmembers directly from the reflectance cube itself was the best method available for endmember extraction, it could have generated some errors in the output of eLAI values from the hyperspectral data.

Finally, when all corn and white beans canopies are considered, the correlation coefficient (r = 0.91) between ground eLAI and eLAI values derived from the hyperspectral data is quite good (Figure 5). Although correlation results are good between ground eLAI and eLAI derived from hyperspectral data, they do not translate into a perfect linear relationship. The eLAI values derived from the remote sensing data overestimates eLAI in comparison with eLAI values measured from the LAI-2000 instrument. The range of eLAI values is also greater for eLAI estimated from hyperspectral data than from LAI-2000. These problems can be observed on all correlation figures (Figure 3, 4 and 5). Further investigation is necessary in order to improve understanding of eLAI estimation from hyperspectral data. Nevertheless, preliminary results are very encouraging for the estimation of eLAI from hyperspectral remote sensing data.

Crop Canopies	**Correlation Coefficient (r)***
White Bean Fields	0.16
Corn Fields	0.69
All Canopies	0.91

*All correlations were significant at a probability level of <0.05.

Table 1: Correlations between ground eLAI measurements and eLAI values derived from the PROBE-1 hyperspectral data.

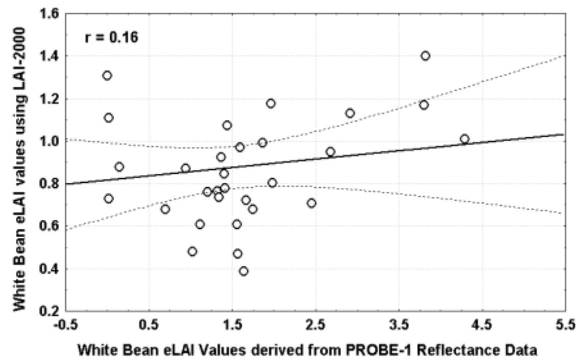

Figure 3: Correlations between ground eLAI measurements and eLAI values derived from the PROBE-1 hyperspectral data for white bean canopies.

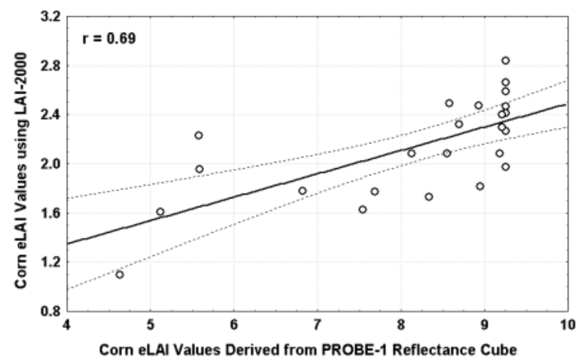

Figure 4: Correlations between ground eLAI measurements and eLAI values derived from the PROBE-1 hyperspectral data for corn canopies.

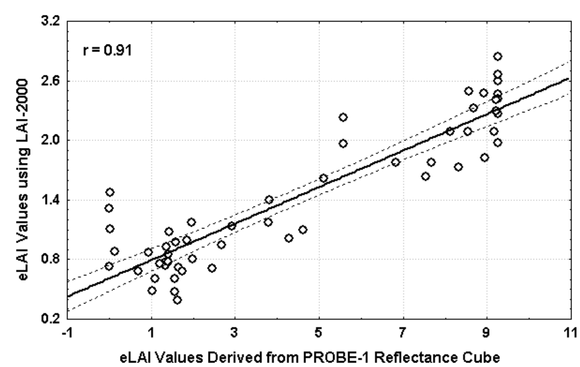

Figure 5: Correlations between ground eLAI measurements and eLAI values derived from the PROBE-1 hyperspectral data for white bean and corn canopies.

6. Conclusions

Probe-1 hyperspectral data were acquired over the Clinton, Ontario area in 1999. Study site includes three white bean and three corn canopies. Simultaneous with the Probe-1 acquisition, ground eLAI measurements were taken using the LI-COR LAI-2000. eLAI values were estimated from the crop fraction once spectral unmixing was conducted. Preliminary results indicate a good relationship between ground-based eLAI and eLAI derived from hyperspectral data. For each individual field, correlations were not calculated since within-field variability was almost non-existent. Results demonstrate a very low correlation between ground eLAI and eLAI derived from hyperspectral data in white bean canopies. Plants from this crop type were not very developed at the time of the measurements and consequently, a greater error is present in the eLAI values. Also, limitations with the endmembers selection may introduce an error in the eLAI estimates from hyperspectral data. In regards to corn canopies, correlation coefficient indicates an interesting relationship. Thus, hyperspectral data was sensitive to variability in ground eLAI values from different canopies. However, this method should be tested on a multi-temporal data set where greater variability is either existent or induced. Nevertheless, correlation between ground eLAI values and eLAI estimates derived from the hyperspectral data reveals a good relationship and demonstrates encouraging results for future analysis.

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