LAI MEASUREMENTS IN WHITE BEANS AND CORN CANOPIES WITH TWO OPTICAL INSTRUMENTS

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ABSTRACT *- Leaf Area Index (LAI) is a parameter used to describe the percentage of vegetation cover and to estimate productivity or yield of agriculture and forest canopies. LAI can be estimated using different techniques such as destructive sampling, vegetation indices and optical instruments. This paper investigates LAI measurements in white beans and corn canopies using two optical instruments, the LI-COR LAI-2000 and the Tracing Radiation and Architecture of Canopies (TRAC), a prototype instrument designed by the Canada Centre for Remote Sensing (CCRS). LAI estimates provided by each instrument are compared and analysed. Also, further investigation is done in regards to the percent crop cover data and LAI values from the LAI-2000 and the TRAC. Preliminary results indicate that LAI measurements with the LAI-2000 and the TRAC do not correlate very well. It was also found that LAI-2000's LAI estimates correlate better with the percent crop cover than the TRAC. Accordingly, the LAI-2000 provides LAI values that are more accurate than those provided with the TRAC.*

1. INTRODUCTION

In the two last decades, there has been extensive developments of functional relations between crop characteristics and remote sensing that have been used in many agricultural studies. Agronomists, crop physiologists and crop modellers often use Leaf Area Index (LAI), a key parameter controlling biophysical processes of the vegetation canopy [Stae 00]. The LAI is defined as one half the total green leaf area per unit ground surface area [Chen 92]. This parameter is used in agricultural or forestry studies to describe the percentage of vegetation cover and to estimate productivity or yield [Mora 95; Boum 92; Wien 91]. The uncertainties in the LAI estimations with vegetation indices such as Normalized Difference Vegetation Index (NDVI) and Simple Ratio are often very large [Chen 95]. Direct measurements are also time consuming, expensive and destructive in their nature whereas indirect methods are more suitable and often used [Lebl 99]. One of these techniques includes optical instruments that are favoured by the speed of the data collection.

These instruments measure the penetrating light in the vegetation canopy where LAI is derived. Several instruments exist on the market such as the LI-COR LAI-2000 and the Tracing Radiation and Architecture of Canopies (TRAC), a prototype designed by the Canada Centre for Remote Sensing (CCRS). There has been numerous studies done in the forest environment with these two optical instruments. Although the LAI-2000 has been utilised before in some agricultural studies, the TRAC instrument has not been used in agricultural research. Both instruments measure LAI but not in the same fashion.

The LAI-2000 only takes gap fraction into account whereas the TRAC takes into consideration two elements of the canopy, the gap fraction and the clumping index. The gap fraction is the percentage of gaps in the canopy at a given solar zenith angle and the clumping index can be quantified by the difference between the measured gap fraction and the gap fraction after the gap removal [Chen 00]. When the clumping effects are not considered, the LAI is underestimated since it is based only on the gap fraction of the vegetation canopy. Therefore, the TRAC measures LAI while the LAI-2000 only measures effective LAI (eLAI). The main objective of this paper is to investigate the relationship between the LAI values from the two optical instruments with the percentage crop cover determined by vertical ground photographs in white beans and corn canopies.

2. MATERIAL AND METHODS

2.1. Study Site

The LAI data were acquired on agricultural sites in Clinton, Ontario, Canada (43^{o} 40' N, 81^{o} 30' W). Clinton is a rural area near Huron Lake, 20 km east of the town Goderich. This area is an agricultural region composed mainly of white beans, corn and grain (wheat and barley) fields. The field campaign was held 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.

2.2. Ground Data Collection

Two different crops were investigated, corn and white beans. LAI data were acquired from three fields of each crop type. Approximately ten sampling sites were selected per field according to within-field variability. Sample sites were located in different soil type, soil moisture, slope angle and aspect. The number of sample sites varied from one field to another in proportion to their surface area.

LAI measurements were carried out with two optical instruments, the LAI-2000 and the TRAC. Three LAI measurements were taken at each sample site in order to minimise errors and, thus, provide a good LAI average of the sample site. For the LAI-2000, 10 m transects were done diagonally between two plant rows whereas the TRAC measurements were done perpendicular to the plant rows. Each transect was 10 m in length in order to represent a surface area of 20 m^2 around the sample site. The LAI-2000 had to be used during overcast conditions or during sunrise or sunset. No measurements could have been made during periods of direct sun because the more sunlit leaves the sensor can view, the larger are the underestimation of LAI. 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-C 90]. One reference measurement was taken above the canopy per sample site and four measurements were taken below the vegetation canopy. At each measurement, five canopy transmittance values are calculated from the five zenith angles of the optical sensor that is used to calculate foliage amount and foliage orientation. The LAI-2000 allows the estimation of eLAI, which does not consider the clumping index parameter. The clumping effect assumes that canopy foliage is spatially distributed according to a certain pattern [Chen 00].

The TRAC instrument also has specific operation conditions. Compared to the LAI-2000, the TRAC measurements have to be collected during a clear day. TRAC measurements are acquired along transects and the user has to walk at a steady pace, about 0.3 meter per second. This instrument measure transmitted direct light at a high frequency giving a time series of solar photosynthetic photon flux density along a certain transect. First, the TRAC has to take a reference measurement above the vegetation canopy and, subsequently the user has to walk along a transect and record measurements below the vegetation. These measurements determine different parameters such as LAI, eLAI, gap size and clumping index [Chen 00].

Finally, the percent crop cover was estimated from vertical photographs taken with a camera mounted on a tripod following specific acquisition parameters. The focal length was 28 mm. The aperture was set at 22 mm while the camera viewed an area of 2.3 m^2. Approximately 80 % of the sample sites were photographed. The photographs were taken within 3 to 4 meters of the sample site locations.

2.3. Methodology

LAI values and other parameters such as effective LAI were extracted from the LAI-2000 and the TRAC instruments. True LAI values will not be compared considering the LAI-2000 does not provide this parameter. Therefore, effective LAI from both instruments will be analysed.

The vertical photographs were digitised in three channels (blue, green and red) and processed with PCI ImageWorks. Unsupervised classification was carried out using ten classes: three classes for soil, three classes for leaf cover, two for residue, one for soil shadow, and one for leaf shadow. These classes were then aggregated to form three major components: leaf cover, residue, and soil. After the classification was done, percentage of leaf cover, soil cover and residue was estimated for each photograph.

Correlation between different variables is done using a Pearson coefficient that reflects the extent of a linear relationship between two data sets. Several correlations are examined in this paper such as eLAI values in regards to the LAI-2000 and the TRAC instrument. Also, the relationship between the percent crop cover from the ground data and eLAI values from the TRAC and the LAI-2000 is investigated. Finally, these different variables are also examined on a crop level. Since eLAI values from biomass sampling are not available, it is important to mention that percent crop cover is used as a reference.

3. RESULTS AND DISCUSSION

The correlation coefficient (r) between eLAI values from the LAI-2000 and the TRAC is presented in Figure 1. This figure demonstrates a positive but weak correlation of 0.38 between the two variables. It is also important to note that white beans have lower eLAI values (from approximately 0.5 to 1.5) while corn crops have higher eLAI values (from approximately 1.6 to 2.9) in both sets of data.

Figures 2 and 3 illustrate the relationship between the same two variables but on a corn and white bean level only. The relationship between the LAI-2000 and the TRAC is stronger in white bean crop ($r = 0.59$) than in corn ($r = -0.39$). The relationship is actually negative with respect to the corn crops. Similar results were obtained by Leblanc [00] when comparing LAI values for both instruments in deciduous forest canopies. LAI-2000's LAI was systematically lower that the TRAC values because the TRAC instrument takes into consideration a lower gap fraction and the foliage clumping. These results indicate that the LAI-2000 and the TRAC do not give the same eLAI values. Although, they are better correlated on the white bean crop than the corn, results still reveal a weak relationship between the two instrument measurements.

Furthermore, in order to examine which of the two instruments gives a more realistic view of ground LAI, eLAI values from the LAI-2000 and the TRAC were compared with the percentage of crop cover as illustrated in Figures 4 and 5. It is important to mention that although percent crop cover is not really an LAI value, it will provide us some indication of the foliage quantity, which is what LAI measure. It is clearly demonstrated in these figures that percent crop cover is better correlated with eLAI values from the LAI-2000 (r = 0.90) than the TRAC (r = 0.49). The two correlation coefficients have a difference of 0.41, which is statistically significant. Qi *et al.* [97] also found a good relationship between plant projected areas determined by destructive sampling and LAI-2000 estimates. These results are encouraging for the use of the LAI-2000 instrument.

The percent crop cover and the LAI-2000's eLAI relationship was further investigated on a crop level. The results are depicted in Figures 6 and 7. They indicate a relationship with correlation coefficients of around 0.60, which are lower then considering all crops together. Accordingly, there is no particular difference between the white beans and the corn crops. The LAI-2000 instrument estimated both crops with the same accuracy even though the foliage architecture is different for both crops. Indeed, white beans have wider and rounder, but smaller leaves while the corn has leaves that are longer and narrower.

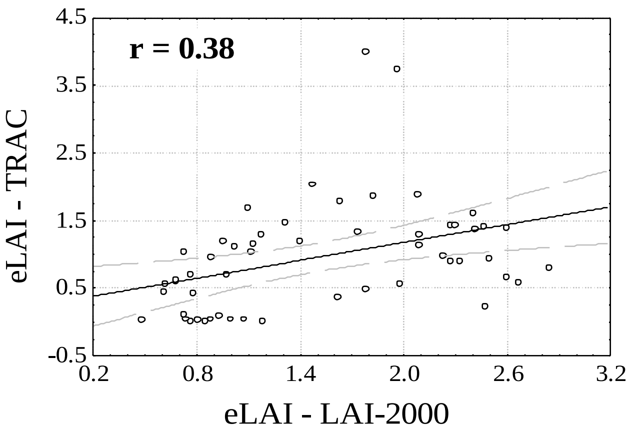

Figure 1. LAI-2000 eLAI versus TRAC eLAI of White Bean and Corn Canopies.

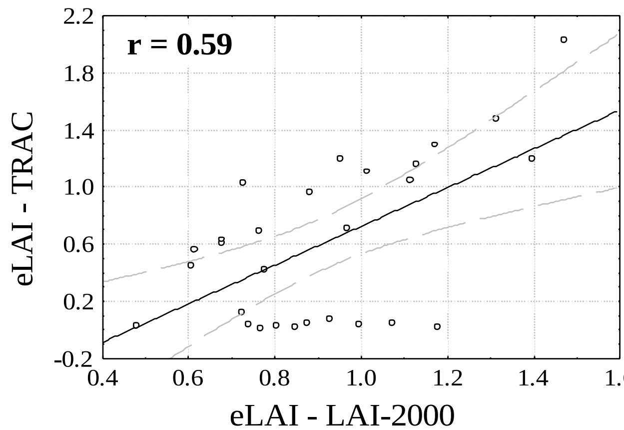

Figure 2. LAI-2000 eLAI versus TRAC eLAI of White Bean Canopies.

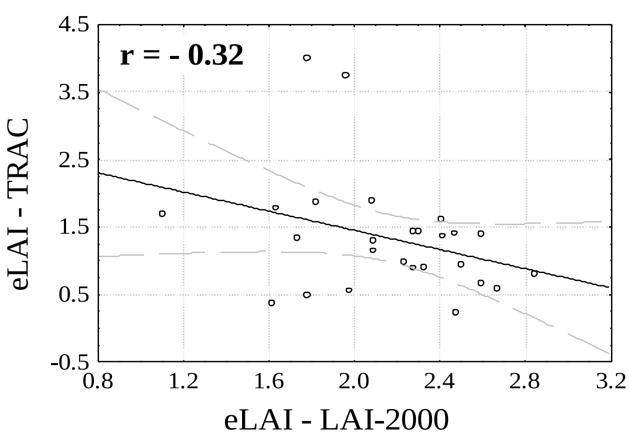

Figure 3. LAI-2000 eLAI versus TRAC eLAI of Corn Canopies.

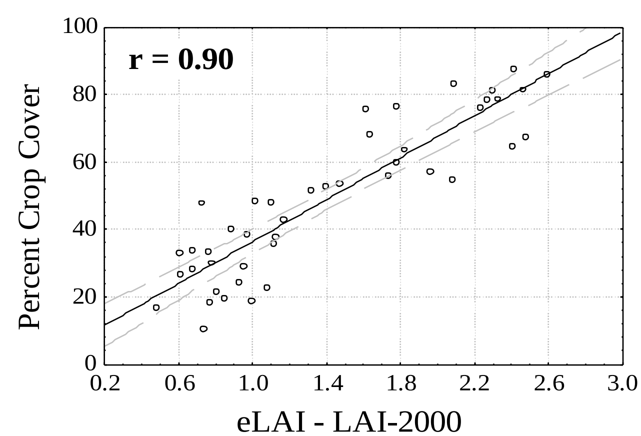

Figure 4. LAI-2000 eLAI versus Percent Crop Cover of White Bean and Corn Canopies.

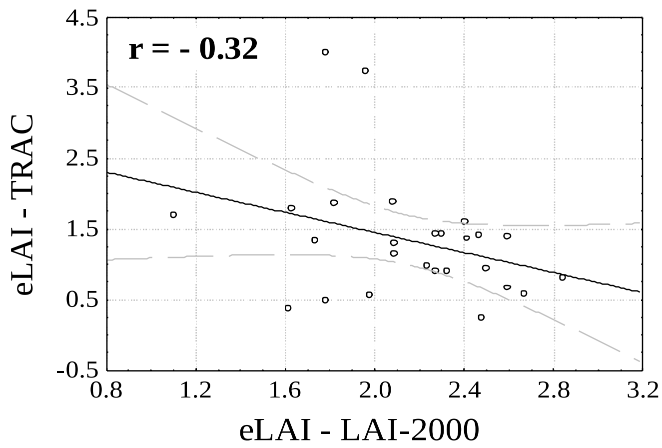

Figure 5. TRAC eLAI versus Percent Crop Cover in White Bean and Corn Canopies.

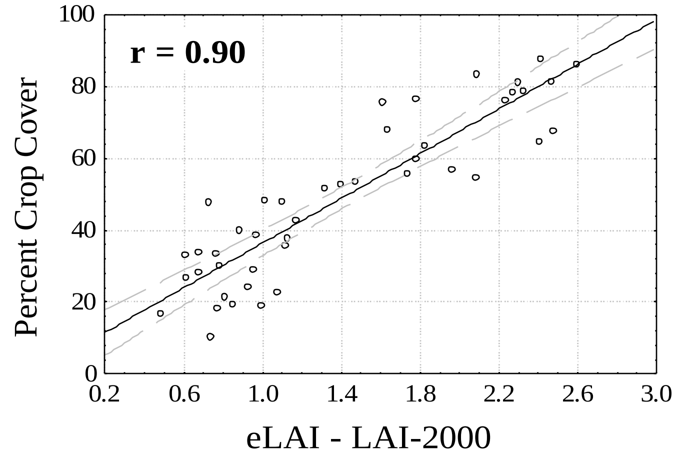

Figure 6. LAI-2000 eLAI versus Percent Crop Cover in White Bean Canopies.

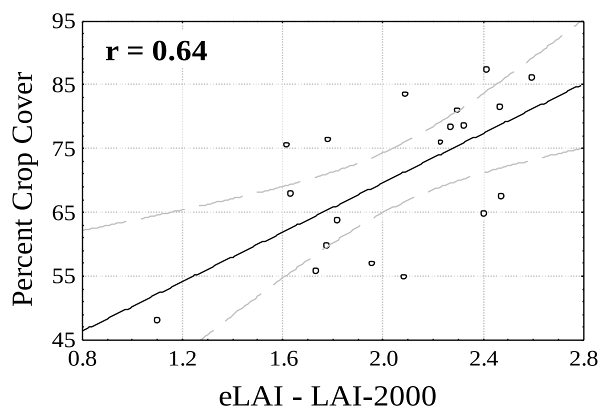

Figure 7. LAI-2000 eLAI versus Percent Crop Cover of Corn Canopies.

3. CONCLUSIONS

In this paper, the relationships between the LAI estimated from two optical instruments, the LAI-2000 and the TRAC, and the percent crop cover have been studied in two different crop canopies, white beans and corn. Preliminary results indicate that eLAI values extracted from the LAI-2000 and the TRAC do not correlate very well. Furthermore, LAI-2000's eLAI has been found to correlate better with the percent crop cover than the TRAC. Accordingly, the LAI-2000 provides eLAI values that are more accurate than those provided with the TRAC.

4. ACKNOWLEDGEMENTS

The authors would like to thank the Natural Sciences and Engineering Research Council of Canada

(NSERC) and CCRS for their financial support. Thanks to Joanne Ellis (Noetix Research Inc.) for her contribution to the data processing and Jean-Claude Deguise and Sylvain Leblanc (CCRS) for their technical support.

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