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Comparison of in situ LAI retrieval of two instruments of four mature agricultural crops

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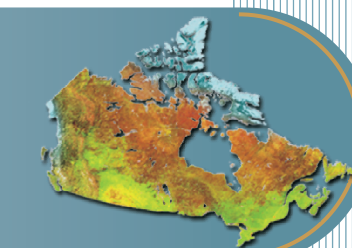
2007

Geomatics Canada

TECHNICAL NOTE 1



Canada

ISSN 1914-4229
Catalogue No. M103-1/1-2007E-PDF
ISBN 978-0-662-46406-8

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Publication approved by Earth Observation and GeoSolutions Division

Correction date:

Comparison of in situ LAI retrieval of two instruments of four mature agricultural crops

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White, H.P. and Young, E.R., 2007: Comparison of in situ retrieval of two instruments of four mature agricultural crops; Geomatics Canada, Technical Note 1, 9 p.

Abstract: In contribution to the land-surface parameter-validation efforts of the Working Group on Calibration and Validation (WGCV) under the Committee on Earth Observation Satellites (CEOS), the Canada Centre for Remote Sensing – Natural Resources Canada participated in a multinational field exercise led by the CEOS Land Product Validation (LPV) subgroup. The purpose of this exercise was to compare existing and commonly used field instruments and methodologies for determining effective leaf-area index (L_e) for the purpose of integrating field Le information to satellite-based Earth Observation (EO) imagery to provide geospatial maps of L_e over a large area. An investigation of integrating these field measurements to satellite imagery will be the focus of a separate report.

This study included (but was not limited to) comparisons between using hemispheric upward and downward photography and using the LICOR LAI-2000 and related methodology as tools for determining L_e during an agricultural field campaign. Where possible, measurements were obtained subject to both direct (near local solar noon) and diffuse (just after sunrise or just before sunset) illumination. Crop types evaluated included corn, sorghum, soybean, and alfalfa, all mature. All sites were located at the Manfredi Instituto Nacional de Tecnología Agropecuaria (INTA) station in the Cordoba province, Argentina. The field exercise was carried out in early March, 2005.

Résumé : À titre de contribution aux efforts de validation des paramètres pour la surface des étendues de terre du *Working Group on Calibration and Validation* (WGCV) du *Committee on Earth Observation Satellites* (CEOS), le Centre canadien de télédétection de Ressources naturelles Canada a participé à un exercice multinational sur le terrain dirigé par le sous-groupe *Land Product Validation* (LPV) du CEOS. Cet exercice avait pour objet la comparaison d'instruments et de méthodes de terrain existants et couramment utilisés pour la détermination de l'indice de surface foliaire efficace (L_e) afin d'intégrer l'information fournie par l'indice L_e à l'imagerie obtenue par satellite d'observation de la Terre (OT) pour obtenir des cartes géospatiales de l'indice L_e couvrant de grandes étendues. Une étude de l'intégration de ces mesures prises sur le terrain à l'imagerie satellitaire fera l'objet d'un rapport distinct.

Cette étude englobait (sans toutefois s'y limiter) des comparaisons de l'utilisation de la photographie hémisphérique vers le haut et vers le bas à l'utilisation du LICOR LAI-2000 et de la méthodologie associée comme outils pour la détermination de l'indice L_e pendant une campagne en terrain agricole. Lorsque cela était possible, les mesures ont été obtenues sous illumination directe (près de midi solaire local) et sous illumination diffuse (juste après le lever ou juste avant le coucher du soleil). Les types de cultures évalués ont été les suivants : maïs, sorgho, soja et luzerne, tous à maturité. Tous les sites étaient situés à la station du *Manfredi Instituto Nacional de Tecnología Agropecuaria* (INTA) dans la province de Cordoba, en Argentine. L'exercice sur le terrain a été mené au début de mars 2005.

INTRODUCTION

Effective Leaf Area Index (L_e) is an important canopy parameter that contributes to monitoring efforts and in modelling such things as carbon balance, ecosystem health, and evapotranspiration. Leaf Area Index (LAI) is determined as one half of the total surface of the foliage (the area of one side of a leaf for flat leaves) to the ground area (United Nations Food and Agriculture Organization, 2002; Chen and Black, 1992). 'Effective' LAI provides an emphasis on the heterogeneity of the leaf distribution and is expressed as the product of LAI and Ω. The parameter Ω is often referred to as the clumping index (Chen, 1996) or 'nonrandomness factor' (Kucharik et al., 1999). The L_e canopy parameter is determined with optical field instruments by observing the canopy gap fraction, $P_{gap}(\theta)$, and applying the relationship as developed by Nilson (1971) of:

$$P_{gap}(\theta) = e^{\frac{-G(\theta)\bullet L_e}{\cos(\theta)}} = e^{\frac{-G(\theta)\bullet \Omega \bullet LAI}{\cos(\theta)}}$$

where θ is the angle of observation and G(θ) is the foliage geometry factor.

Derived L_e values are then applied to remotely sensed georeferenced imagery to develop large geospatial descriptions of foliage density and distribution. Additional information on extracting canopy L_e from field measurements and application to satellite imagery can be obtained from a variety of publications, such as Chen et al. (2002) and Leblanc and Chen (2001). Several hand-held instruments and methodologies exist to determine L_e in the field, and to relate measured L_e to remotely sensed data. Comparisons of hemispherical photography (with a Nikon Coolpix camera) with the LICOR LAI-2000, (a plant canopy analyzer), and their respective methodologies are discussed here.

SITE

This field exercise was co-ordinated and lead by the Land Parameter Validation (LPV) subgroup of the Working Group on Calibration and Validation (WGCV) under the Committee on Earth Observation Satellites (CEOS) (For more information on CEOS and associated working groups and subgroups, *see* http://www.ceos.org). The LPV field exercise was held at the Instituto Nacional de Tecnología Agropecuaria (INTA) Experimental Station at Manfredi, in the Cordoba province, Argentina during the first week of March, 2005 (located at approximately 31.8°S, 63.7°W). This provided a local maximum sun elevation of 52.3° (or zenith angle at local noon of 37.7°) during the field study. The site consisted of mature fields of corn, sorghum, soybean, and alfalfa which were uniformly planted and maintained. The terrain at the site is flat, removing topographical influences on the comparisons.

FIELD EQUIPMENT, L_e EXTRACTION METHODOLOGY, AND STRATEGY

In this field exercise, two commonly used instruments were used to obtain L_e: the Nikon Coolpix 9000 digital camera with hemispherical lens ('fisheye lens'), and the LICOR LAI-2000 (LiCor, 1991) with its 'fisheye' optical sensor, which can be used to azimuthally integrate the light transmission through a canopy at 5 viewing angles (with the 6° ring: 0°–12.3°; 22° ring: 16.7°–28.6°; 38° ring: 32.4°–43.4°; 53° ring: 47.3°–58.1°; and the 68° ring: 62.3°–74.1°). Observations were performed with each instrument by the LPV field exercise team following a set sampling protocol that provided for between 9 and 13 measurements being acquired per 30 m × 30 m site. The L_e of a site is then determined using the complete measurement set. This sampling strategy highlights the fact that L_e is a measure of a canopy parameter, and not a parameter of a subgrouping of plants, or of an individual plant in the canopy.

Measurements were performed at various times of day to provide diffuse (near dawn or twilight) and direct (near local solar noon) conditions for comparison. Unfortunately there was no destructive sampling performed to act as a baseline for the derived Le values.

Imagery taken with the Nikon camera included upward views (taken with the camera positioned below the canopy, pointing at zenith) and downward views (taken with the camera positioned above the canopy at approximately chest height, pointing at nadir) When the canopy was taller than chest height (i.e. corn) only upward views were acquired. Example images are provided in Figure 1.

The upward images were processed with two software packages, CAN_EYE Version 3.6 (Baret and Weiss, 2004) and DHP Version 2.0.2 with TRAC_Win (Leblanc, 2004). The downward images were only processed with CAN_EYE Version 3.6, as the DHP/TRAC_Win software package was not designed for this orientation. Descriptions of the theories applied by the processing software packages have been discussed in Jonckheere et al. (2004) and in Leblanc et al. (2005) for the CAN_EYE and DHP/TRAC_Win packages, respectively.

Data files from the LAI-2000 were downloaded and were also processed using the provided software as described in the LAI-2000 manual (LiCor, 1991). The processing theory has also been coded in a Microsoft Office Excel 2003 Worksheet to allow for interpolation of the clear sky observations to the time mark of each within-canopy observation (observations were taken such that a clear sky observation was performed every third measurement). This Excel code also allows for the determination of L_e from the 53° ring only, as it has been suggested that for some canopies, using all five rings may violate Miller's theorem on which the processing algorithm is based (for example, *see* Hall et al. (2003) and Leblanc and Chen (2001)).

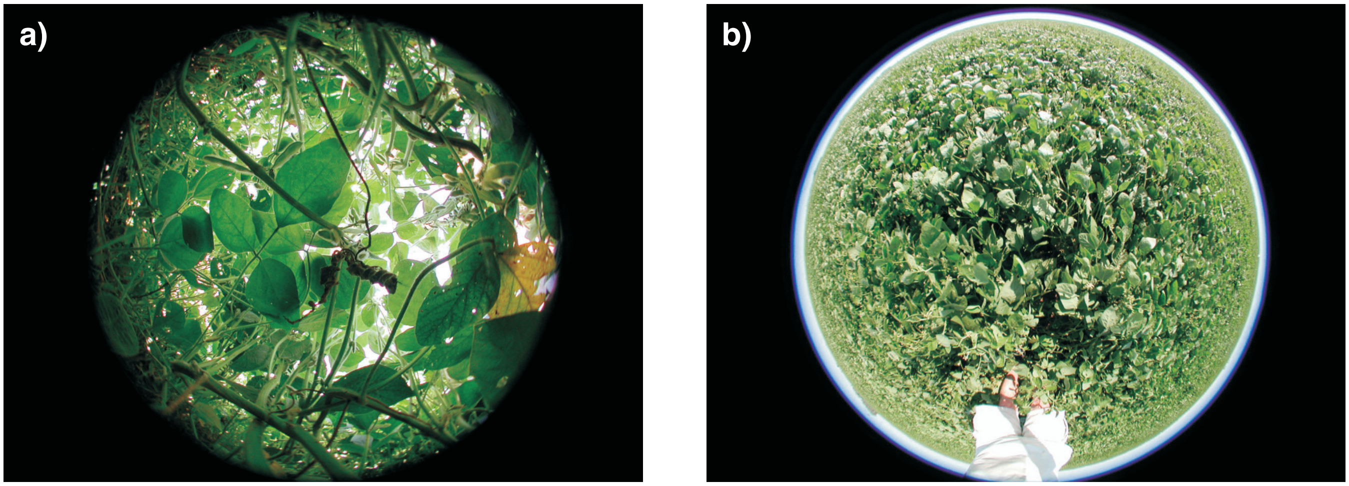

Figure 1: Sample hemispherical images taken with the Nikon Coolpix 9000 digital camera with hemispherical lens. **a)** An upward-pointing camera image taken from ground level within the canopy. **b)** A downward-pointing camera image taken from approximately 1.3 m above ground level. Images were taken with the sun high in the sky (direct conditions) and when the sun was near the horizon (diffuse conditions).

FIELD LAI COMPARISONS

LAI-2000 instrument

Initial comparisons were performed on the results of two processing techniques applied to the LAI-2000 observations. Using this LiCor instrument in one sensor mode with onboard software, L_e is reported while observations are acquired. In this case, L_e was recorded for each measurement location per site (with between 9 and 13 measurement locations per 30 m × 30 m site) and an average was taken to arrive at a mean site L_e. As outlined in the LAI-2000 manual (LiCor, 1991), a value was determined based on the within-canopy observations (B) and the one previous and most recently obtained above-canopy observation (A).

For comparison, the processing algorithm as outlined in the LAI-2000 manual was coded using Excel, where the sensor readings from the above- and within-canopy observations were imported into a spreadsheet. Two above-canopy readings (A), the one closest in time before and the one closest in time after each within-canopy reading (B), were used to interpolate an A for the time stamp of each B. These interpolated values were then used to derive mean L_e for each site. It should be noted that both of these processing methods rely on the assumption that the foliage elements are small relative to the distance between the sensor and the foliage. (To quote the LAI-2000 manual: "the distance from the sensor to the nearest leaf should be at least four times the leaf width" (LiCor, 1991).) For crop canopies used in this study, there was a departure from this assumption as the canopies were in most cases close to the ground. Attempts were made, however, to prevent contact between the foliage and the sensor when making a measurement.

Comparisons between the processing techniques (referred to here as the LiCor and the Excel methods) demonstrates that both methods provide similar results (Fig. 2). The Excel method appears to provide a relatively smaller derived L_e for dense canopies, while the LiCor method results in a slightly larger derived L_e for less dense canopies. It must be noted, however, that this could also be a function of crop type, as the densest canopy structure was observed only with soy crops. No effects of the processing techniques were noted with the diffuse data set relative the direct (sunny) data set.

As previously mentioned, there has been some suggestion in the literature that canopy multiple-scattering may in some cases contaminate the signals measured by the LAI-2000 sensor in forest canopies (Hall et al., 2003; Leblanc and Chen, 2001). To examine for this, the L_e was derived using the Excel method but only using the 53° ring (4th ring) observations (Fig. 3).

For these canopy crop types, no discrepancy appeared between the two Excel methodologies (using all sensor rings in the data processing versus using only the 4th ring centred at 53°), with the exception of one diffuse sky measurement performed in corn. In the case of this agricultural crop study, canopy multiple-scattering contamination is not noted with the LAI-2000 instrument.

An additional assessment that has been commented on in previous studies of forest canopies is that L_e derived from LAI-2000 observations performed under diffuse sky conditions is larger than the value derived subject to direct sunlit conditions (for example, *see* Leblanc and Chen (2001), Kubner and Mosandl (2000) and Chen et al. (1997)). In some cases the direct sunlit-based derived L_e has been noted to underestimate the value determined by using more-direct measurements. In this agricultural crop study, a limited data set exists with which to comment on such a comparison. The

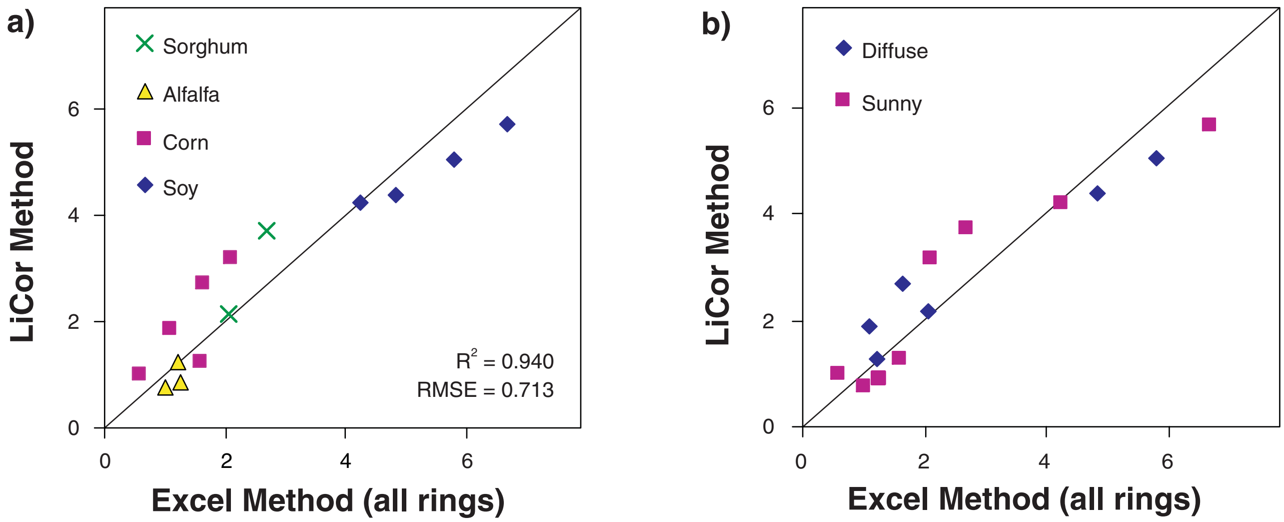

Figure 2: Derivation of the canopy L_e using the onboard LiCor LAI-2000 software (LiCor Method) and the Excel spreadsheet designed to interpolate between sky (above canopy) measurements for each within-canopy time stamp. Information is shown as **a)** a function of crop, and **b)** as a time-of-day measurement (diffuse: sun near horizon; sunny: sun high in sky). Calculations were made using all sensor rings. Correspondence between the two methodologies are ascertained using the two traditional techniques of the correlation coefficient (R^2) and the Root Mean Square Error (RMSE).

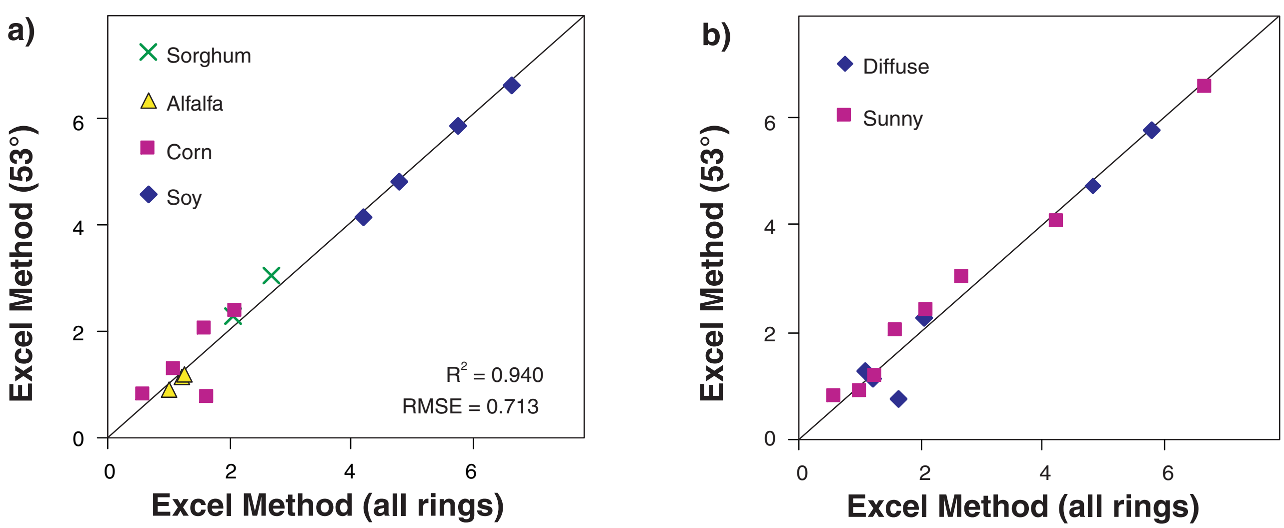

Figure 3: Derivation of the canopy L_e using the Excel spreadsheet algorithm using all sensor rings (all rings), and using only the sensor ring centred at 53°. Information is shown as **a)** a function of crop, and **b)** as a time-of-day measurement (diffuse: sun near horizon; sunny: sun high in sky). Calculations were made using all sensor rings. Correspondence between the two methodologies are ascertained using the two traditional techniques of the correlation coefficient (R^2) and the Root Mean Square Error (RMSE).

available information provided in this study does suggest, however, that L_e values derived (using either methodology) from LAI-2000 measurements performed in the late morning are lower than those derived with diffuse sky conditions, while those derived using early-afternoon measurements provided the largest values, as shown in Figure 4. This suggests that atmospheric conditions, and not solar zenith angle, may have an impact on the derived values acquired using the LAI-2000.

As scheduling (weather conditions) allowed, diffuse observations were sometimes taken in the early morning (corn, sorghum) or early evening (alfalfa, soybean). Insufficient data were obtained to further evaluate variability in the relative temporal effect between these measurements.

Hemispherical photographs

Several hemispherical photographs were taken and used to determine a mean L_e for each site, following a similar sampling technique as was used with the LAI-2000. Photographs taken in the 'upward' direction (with the camera at ground level pointing at zenith) were processed with both the CAN_EYE (Baret and Weiss, 2004) and the DHP with TRAC_Win Package (Leblanc, 2004). Photographs taken in the 'downward' direction (with the camera held at approximately 1.3 m elevation and pointed at nadir) were processed only with CAN_EYE, as the DHP/TRAC_Win software package was not designed for this orientation.

Due to time and weather constraints, only two upward and downward concurrent data sets were obtained, one for the alfalfa site taken in the late morning (upward $L_e = 0.7$, downward $L_e = 1.7$), and one for the soybean1 site taken in the early afternoon (upward Le = 2.6, downward Le = 1.9). Insufficient data is available from this study to do a comparison; however, it is interesting to note that a significant difference exists between the two results ($\Delta L_e = -1.0$ for alfalfa and $\Delta L_e = 0.7$ for soybean), suggesting that more investigation is required to evaluate the impact of camera orientation on the processing techniques and derived results.

Values of L_e derived from the upward photographs were similar for the CAN_EYE and DHP/TRAC_Win algorithms. However, when compared to the LAI-2000 processing method (Figure 5), a definite bias is observed.

Compared to the LAI-2000 techniques, the hemispherical photograph techniques both appear to reach a saturation level at L_e values greater than 3.This effect does not appear to be a function of crop type or time of observation, although there is limited information to evaluate such trends. When evaluated relative to each other (Figure 6), the CAN_EYE and the DHP/TRAC_Win methods derive similar values for L_e, with the DHP/TRAC_Win method consistently providing slightly lower results.

Unlike the LiCor LAI-2000, hemispherical photography provides detail at a spatial scale where the gaps within a canopy can be identified. This is considered by some as a significant improvement over the LiCor LAI-2000, where one azimuthally integrated observation is made for each zenith angle range. This allows the investigators to determine a

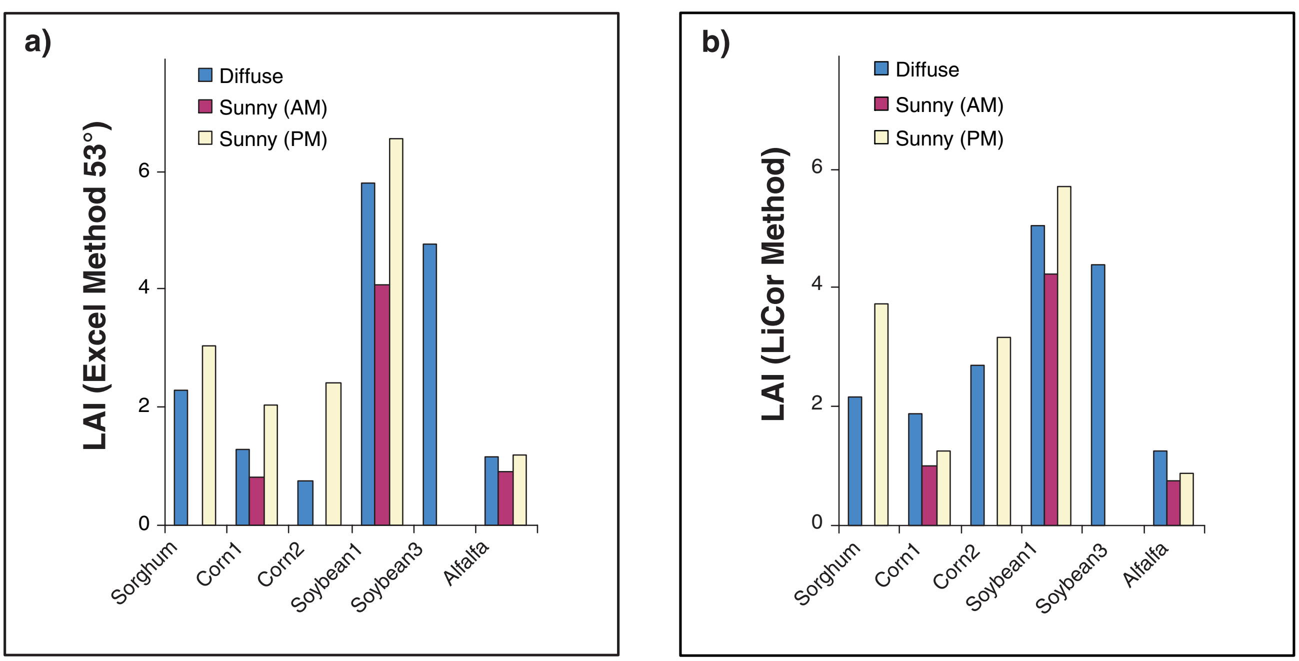

Figure 4: Derivation of the canopy L_e using **a)** the Excel 53° method and **b)** the LiCor method with all sensor rings (all rings) and with only the sensor ring centred at 53°. Information is shown as a function of crop, and as a time of day measurement (diffuse: sun near horizon; sunny: sun high in sky).

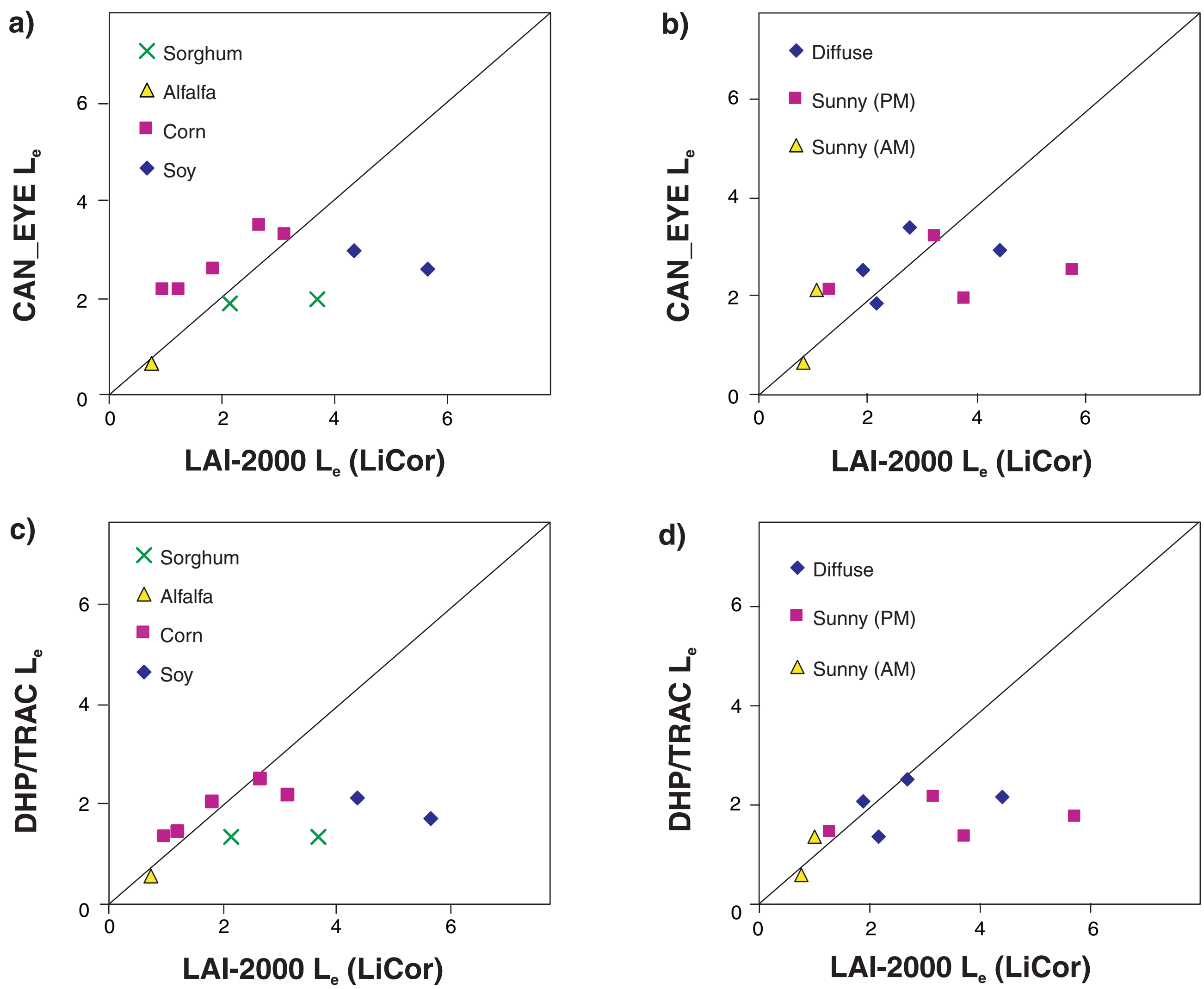

Figure 5: Derivation of the canopy L_e using the CAN_EYE **(a,b)** and the DHP/TRAC_Win **(c,d)** processing packages relative to the LAI-2000 onboard processing results. Similar results would be viewed using either of the Excel methods and thus are not shown here. Information is shown as a function of crop (a,c), and as a time of day measurement (b,d) (diffuse: sun near horizon; sunny: sun high in sky).

clumping index, Ω, based on the size distribution of gaps within the canopy (for example, *see* Chen et al. (1997) and Kucharik et al. (1999)). Evaluation of the clumping index derived with the two processing techniques showed similar results, with values close to, but less than, unity, indicating the closed mature canopies which were investigated here. As the agricultural fields are managed and appear uniform, a consistent value of Ω is suspected per crop type. It can be noted that the DHP/TRAC_Win-derived values were more consistent within a crop type, as shown in Figure 7.

Thus, while the two hemispherical photograph processing techniques result in similar derived values of the effective leaf area index and the clumping index, both techniques appear to underestimate the canopy L_e when it is greater than about 3, based on comparisons with the LAI-2000 processing methods. A similar comparison study for forest canopies did not note this discrepancy between the use of hemispherical photography and the LAI-2000; however, it was noted that the essence of hemispherical photography is to project the hemispherical view onto a plane (Jonckheere et al., 2004). For forest canopies, where the foliage is a significant distance away from the camera, this projection has little effect on the observed zenithal size distribution of foliage surface and gap area. When the foliage is close to the camera, this projection can distort the apparent size of the foliage (*see* Fig. 1). Variations in distance between the top of the canopy to the camera and the bottom of the canopy to the camera also cause a large variation in apparent size of the foliage and gaps when the canopy is close to the ground. Other studies have also noted that foliage located too close to the camera (within approximately 10 times the mean leaf width) can result in an underestimate of LAI of up to 50% (van Gardingen et al., 1999), especially when a nearby leaf blocks a significant

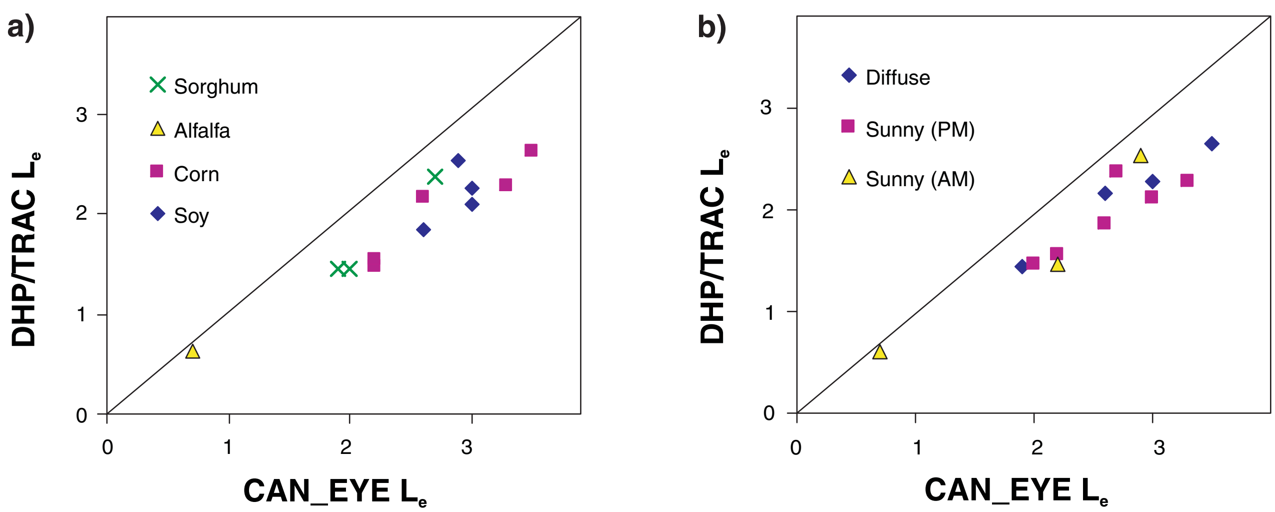

Figure 6: Derivation of the canopy L_e using the CAN_EYE and the DHP/TRAC_Win processing packages. Both methods provide similar results, although the DHP/TRAC_Win method derives values that are consistently lower than those derived with the CAN_EYE method. Information is shown as **a)** a function of crop, and **b)** as a time of day measurement (diffuse: sun near horizon; sunny: sun high in sky).

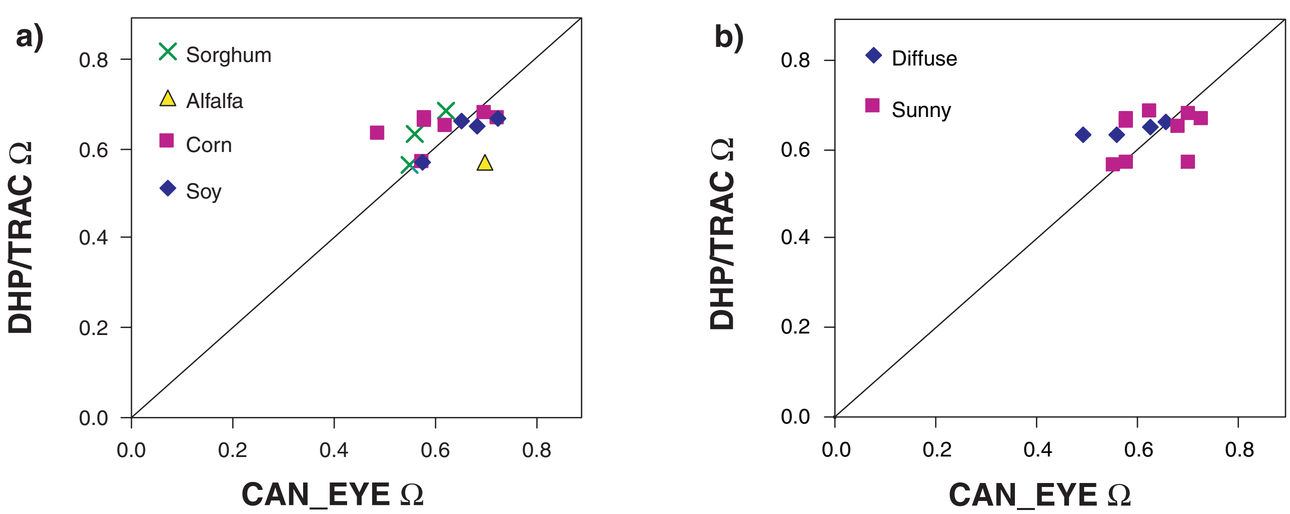

Figure 7: Derivation of the canopy clumping index, Ω, using the CAN_EYE and the DHP/TRAC_Win processing packages. Both methods provide similar results; however, there is some suggestion that the DHP/TRAC_Win method is less sensitive than CAN_EYE when used with observations made using a diffuse sky. Information is shown as **a)** a function of crop, and **b)** as a time of day measurement (b) (diffuse: sun near horizon; sunny: sun high in sky).

proportion of the view. Unfortunately, as previously mentioned, there was no independent sampling performed in this study with which to evaluate these techniques.

Processing considerations

As scheduling restraints caused by weather and other considerations are part of any field campaign, a comment on the time required to acquire and process the data is relevant. In all cases, once a sampling strategy has been designed, use of both of these instruments in the field is quick, with an observation set from the 9 to 13 sample sub-sites within the 30 m × 30 m target area easily acquired within 10 to 15 minutes.

Data processing associated with the LAI-2000 instrument is very quick, with results provided at the time of acquisition. The processing methodology is also easily coded (in this case as an Excel Worksheet) and results can be evaluated within minutes of downloading the data. As mentioned above, however, this instrument does not provide sufficient information to determine the gap-fraction characteristic of the canopy, and thus the nonrandomness of the canopy can not be derived.

With hemispherical photography, CAN_EYE Version 3.6 (Baret and Weiss, 2004) and DHP Version 2.0.2 with TRAC_Win (4, 2003) require significantly more time and processing capability. In the case of CAN_EYE, the software required a significant amount of computer processing power and was found to crash for systems with less than 1 Gigabyte of RAM available, or when multiple processes were running. This package does allow the investigator to process all images for a site at once, and it was found that one site could be processed in approximately 30 to 60 minutes. With the DHP/TRAC_Win package, each image had to be processed individually, and preprocessing was required (blue channel extraction was required before using the DHP/TRAC_Win package). Computer processing power was not an issue and the package was easy to implement and run. With practice, a site with 9 to 12 images to process could be completed within 1 hour. With both packages the canopy L_e and Ω were derived.

The time (and in the case of the CAN_EYE package, the processing power) required to process the hemispherical photographs to allow the investigator to assess the results was found to be prohibitive in allowing an operational evaluation of the results during the campaign. Post-campaign processing would be required. The LAI-2000, on the other hand, allowed on-site assessments, which provided benefits to the study to identify potential areas of difficulty, or allowed re--assessment of the sampling strategy during the field campaign. It is noted by the authors, however, that both the CAN_EYE and DHP/TRAC_Win packages have been recently updated and may address some of the processing concerns mentioned here.

DISCUSSION

This investigation attempted to examine the impacts of several factors on the retrieval of effective leaf area index from a field campaign. Three basic considerations were looked at, time of day (direct sunlight or diffuse sky conditions), instrumentation, and data processing.

With regard to the time-of-day assessment, insufficient observations with the hemispherical camera were obtained (in either the upward or downward orientation) to allow for an evaluation of sun elevation impact on L_e retrieval. With the LAI-2000, however, a limited data set suggests that variations do occur with time of day, with a trend observed that late-morning conditions result in lower L_e retrievals than early- afternoon conditions, and that diffuse sky conditions appear to provide L_e retrievals within the range of values determined with a high sun elevation. Crop type appears to have no impact on this trend given the available data. This suggests that other potential factors, such as atmospheric conditions of humidity or aerosol abundance have a greater influence, which would require a significantly larger data set for evaluation.

The impact of processing methodology on the retrieval of L_e is also demonstrated to be minor. With the LAI-2000, results determined by the LiCor software and the Excel algorithm were similar. For circumstances of cloudless skies, the need to interpolate sky conditions for each within-canopy observation does not appear to greatly influence the result, provided that observations are made within a 10 to 15 minute period. Using the Excel method, the impact of scattered light in the instrument was evaluated by comparing the derived L_e using the 53° ring only to that derived using all rings. No impact was observed.

The two processing methodologies used to retrieve L_e from upward pointing hemispheric digital pictures have provided relatively similar results, with values of L_e determined with the CAN_EYE package being consistently slightly larger than those determined with DHP/TRAC_Win. The DHP_TRAC_Win package did produce values of canopy clumping, Ω, which were more consistent as a function of crop type. Only two sets of upward- and downward-pointing hemispherical observations were performed during this study, one with alfalfa and one with soybean. When processed with the CAN_EYE software package, a significant difference is noted in the retrieved L_e. A more intensive field study would be required to compare the impact of camera orientation on the CAN_EYE retrieval methodology.

It is when comparing instruments that the largest relative discrepancy in L_e retrieval is noted. For lower values of L_e (less than 3) the retrieved values using hemispherical photograph or the LAI-2000 appear to loosely follow a linear 1:1 trend. When the LAI-2000 determined higher values of L_e, however, the hemispherical photography appears to saturate. This study only reports that an inconsistency appears to exist at conditions of high L_e, a more detailed study of dense vegetation conditions for situations when the foliage is close to the instrument would be required to determine the cause of this discrepancy.

CONCLUDING REMARKS

This LPV Campaign has provided some interesting comparisons between methods of retrieving L_e in the field. By comparing algorithms used to extract information from the observations for each instrument, the theory incorporated with the LAI-2000 and the hemispherical photography appear to be understood. It is when the instruments are compared operationally that the largest discrepancies are noted. To evaluate the differences between the two instruments will require a more extensive field campaign that focuses on this aspect, comparing these instruments for a wide range of L_e and the processing theory behind information extraction when the foliage is relatively close to the sensing instrument. Additional influences on L_e retrieval (time of day, processing software) while important, do not appear to be as significant.

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