

A Prototype Sensor for Estimating Light Interception by Plants in a Greenhouse

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Abstract

Light interception is one of the most important factors for plant growth. The intercepted amount depends on the incoming radiation in the greenhouse and the percentage of interception by the crop and is directly related to the leaf area. Proper crop management requires the measurement of the most important growing factors. In case of application of crop growing models the simulation of the leaf area is one of the major uncertainties in the results of the models. Automatic calibration of the model based on radiation interception increases the accuracy of the model results. For the determination of the crop's light interception in a greenhouse, a radiation sensor was used which determines the ratio of the incoming radiation from the upper side and the reflection at a specific wavelength from the lower side. The ratio of reflected radiation versus intercepted radiation can be used to estimate light interception as well as leaf area. However, the measurement of this fraction can only be used after filtering out erroneous data due to technical errors, insufficient diffuseness, insufficient solar height, etc. This paper describes the boundary conditions to be taken into account for proper measurement of reflected radiation. Time series measurements of incoming, reflected and global radiation are used, to filter the data acquired by the sensor. The sensor functioned well during tests on a cucumber crop in a commercial greenhouse.

INTRODUCTION

The interception of photosynthetically active radiation by a canopy is a fundamental requirement for crop growth. Light interception and the relationship to crop growth have been important concepts applicable to virtually all crops (Monteith, 1977). Most of the mechanistic crop models simulate leaf area, in order to calculate light interception. Subsequently photosynthesis and transpiration of leaves can be calculated. Accurate estimation of leaf area is of utmost importance for accurate simulation of crop growth. However, the simulation of leaf area is still one of the weakest features of crop models (e.g. Marcelis et al., 1998).

Optical remote sensing data has been used for the online monitoring of parameters of the plants in the field. Remote sensing is based on radiation measurements and especially in the light reflected from the canopies. Attempts to measure LAI and light interception with the use of remote sensing have been successfully applied in arable crops in recent years (Clevers et al., 1997; Jongschaap, 2004). The relative reflection of incoming radiation by a crop in greenhouse can be used to estimate leaf area index and light interception (Marcelis et al., 2000). These techniques of estimating light interception are yet to be tested further in the greenhouse environment. The reflection properties of the crop in a specific area of the spectrum and the white plastic on the floor have to be taken into account and can be a base for the development of a sensor that monitors on-line the light interception by plants in the greenhouse.

In this paper such a radiation sensor that determines the ratio of the incoming radiation from the upper side (Φ_{incoming}) and the reflection from lower side ($\Phi_{\text{reflecting}}$) ($\text{W}\cdot\text{m}^{-2}$) in a specific spectral region is evaluated as part of the research project

Hydrionline III (Marcelis et al., 2000; Gieling et al., 2004; Van Straten et al., 2005). The appropriate techniques for the sensor's data filtering are part of the investigations in this project.

MATERIAL AND METHODS

For this paper a prototype sensor, positioned in a commercial greenhouse (Jakom Company, Huissen The Netherlands), was used. The sensor was mounted just below the screen and was connected to a standard Priva Integro Climate Controller (Priva, the Netherlands). The position of the sensor in the greenhouse is shown in Figure 1. The greenhouse is cultivated with cucumbers throughout the year. The data that are presented here are measured during the growing period June until September 2006.

General meteorological data (i.e. Global radiation, outdoor climate) were taken from the greenhouses meteorological station as well as from the Meteorological Station at Haarweg, Wageningen (ISO certified).

Measurements from a sensor for global radiation outside the greenhouse were used for estimating the diffuseness.

Sensor Description

From the amount of the radiation that enters a greenhouse a part is absorbed by the plants and other materials and another part is reflected. The fraction of the light that is reflected is not the same for all the wavelengths. In practice the reflection percentage of a full grown crop is affected by the crop with an average reflection of about 5% at the specific wavelength of the sensor while at the same wavelength the floor (covered with white plastic) reflects more than 60%. The specific wavelength is in the blue part of the spectrum.

The sensor consists of two identical sub-sensors, one measuring the incoming light and the other the reflected light. The reflection ratio, $R_{\text{reflection}}$, determines the ratio between the reflection from the floor and crop with the incoming light, which decreases with the increase of the leaf area.

$$R_{\text{reflection}} = \Phi_{\text{incoming}} / \Phi_{\text{reflecting}}$$

Assuming that all the light that is not reflected is absorbed this ratio can be related to the light interception by the crop with:

$$LI = (1 - R_{\text{reflection}}) * 100\% \quad \text{Eq. 1}$$

A proper functioning of the sensor requires diffuse radiation conditions. Measuring in diffuse radiation conditions prevents measuring errors, which could occur in direct sun radiation, e.g. shadow stripes caused by the construction parts of the greenhouse, light spots on the glass, low azimuth of the sun and insufficient cosine correction of the sensor's diffuser.

Filtering of the Input Data

For the data filtering and calculations the dedicated software routines were developed in Matlab. The data (per minute) are filtered on a daily basis. The filtering process is following a certain process. First step is to remove errors in the signal of the sensor. These errors can happen due to extreme values sampled by the data acquisition system, electrical disturbance, reflections, shadows, electrical disturbances, as well as saturated sensor signals (out of range of the AD converter). These errors are removed with the use of a strong acting non linear filter (median filter). This is performed using a window consisting of an odd number of samples. The values in the window are sorted into numerical order; the median value, the sample in the center of the window, is selected as the output. The calculation is repeated for the next sample of values.

In the past the radiation transmission of the greenhouse is directly related with the

solar height and it depends on the time of the year and the geographic position (latitude, longitude). In order to reduce the influence of low solar elevation, a minimum elevation of 5° is chosen which results in a compensation for summer and winter (Critten, 1985). For mid summer (21 June) this angle is possible from 5:00 till 20:00 while in mid winter (21 Dec) this is from 9:00 to 15:00 in The Netherlands (51° 55' N). Thus is safe to assume a time frame from 10:00-15:00 is safe to use for the data filtering. The data are also filtered with a diffuseness criterion. The diffuseness criterion applied used the following relationship (Spitters, 1986):

$$F_{\text{diffuseness}} = \Phi_{\text{global}} / \Phi_{\text{extra-terrestrial}}$$

Where Φ_{global} is the total radiation reaching the earth surface and $\Phi_{\text{extra-terrestrial}}$ is the extra-terrestrial radiation to the earth surface and depends on the latitude of a place and the time of the year. $F_{\text{diffuseness}}$ indicates the degree of diffuseness of the global radiation and varies between 0.23 and 1, where a very cloudy sky corresponds to 0.23 and a clear sky to 1. For the data filtering a $F_{\text{diffuseness}}$ threshold of 0.5 was chosen.

After selection based on the diffuseness criteria the best 10 daily values are averaged to form a daily reflection ratio. The mean value, the standard deviation and the number of remaining samples are also calculated.

RESULTS AND DISCUSSION

The results of the data filtering acquired from the sensor during the June - September 2006 period, are presented below in the graphs of Figure 3 and Figure 4.

The original data gathered from the sensor showed quite some variation. By applying a non-linear filter the variation was reduced substantially. In Fig. 2 is shown the effect of the non application of the median filter. After the filter is applied most outliers and disturbances are removed from the data (Fig. 3).

Applying a diffuseness threshold of ≤ 0.5 , results in no useful data on some days. Based on calculations made in a representative year in the Netherlands the amount of direct radiation is 5.5% of the total radiation in winter and 24.1% on summer (Hemming et al., 2006). During summer more days with no useful data are expected.

On days with variation in diffuseness the diffuseness criterion works effectively (Fig. 3) while on a complete clear day all data are filtered out (Fig. 4).

The daily Reflection Ratio's after application of the time frame and the diffuseness criteria for a whole cultivation season are shown in the curve of Figure 5. The graph shows that the reflection ratio is decreasing with the days and becomes almost constant after day 25. In Figure 5 there is a shift of the curve in day 4, this is due to the fruit and leaf picking of the plants. Missing points in the period of day 40 till 45 shows that on these days there is no data to produce a daily reflection ratio. This is the case in days with high radiation and a clear sky.

The data filtering may result in absence of data during several days. For application by growers or for fine tuning of crop growth models one or two reliable measurements per week seem to be sufficient.

The reflection ratio can be transformed to light interception using Eq.1. The result is shown in Figure 6. The light interception is underestimated by about 10% probably due to calibration errors.

CONCLUSIONS

After applying the different filters on the data, it is shown that the use of the best 10 values for each day gives a good estimate of reflection ratio for the crop. This estimate can be used to calculate light interception or leaf area index. Further research is needed to improve the relationship between light reflection and interception and establish one with leaf area index.

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Figures

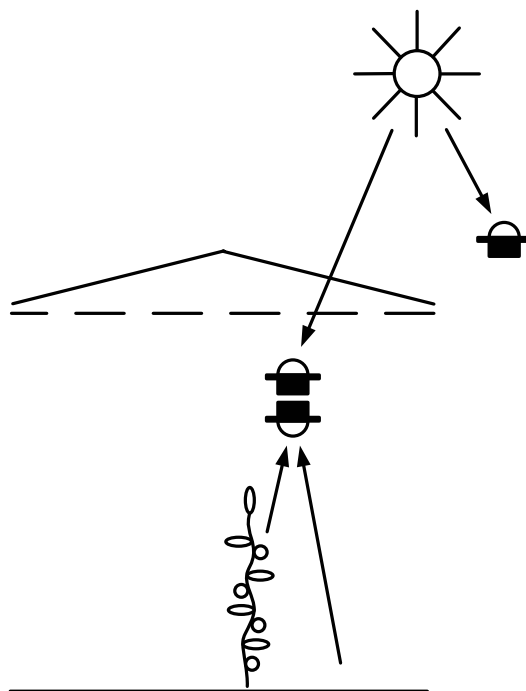


Fig. 1. The position of the three radiation sensors in the greenhouse. The Φ_{global} is a sensor positioned outside the greenhouse measuring global radiation used for the calculation of $F_{\text{diffuseness}}$. Φ_{incoming} and $\Phi_{\text{reflecting}}$ are the two sub sensors of the prototype sensor that gives the reflection ratio.

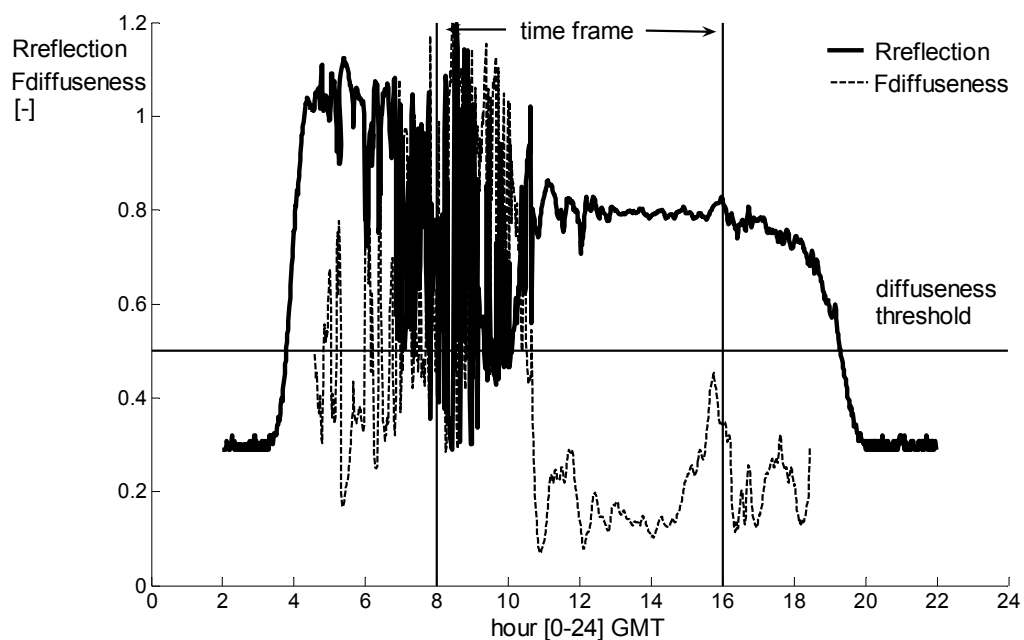


Fig. 2. Data without the application of the median filter on 03-Aug-2006.

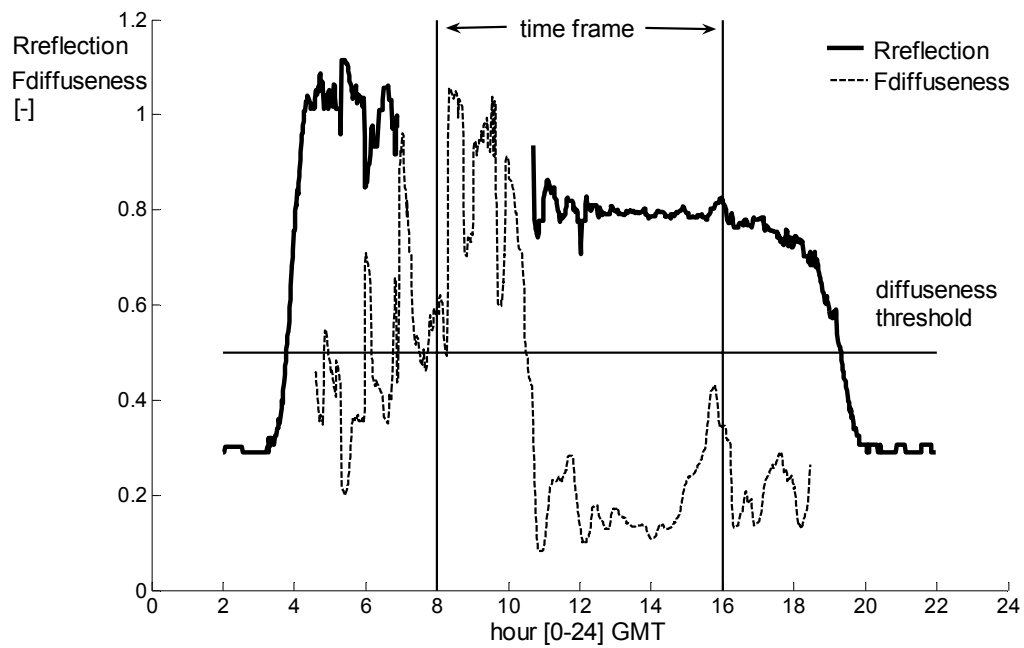


Fig. 3. Data with the application of the median filter where interception can be calculated (03-Aug-2006).

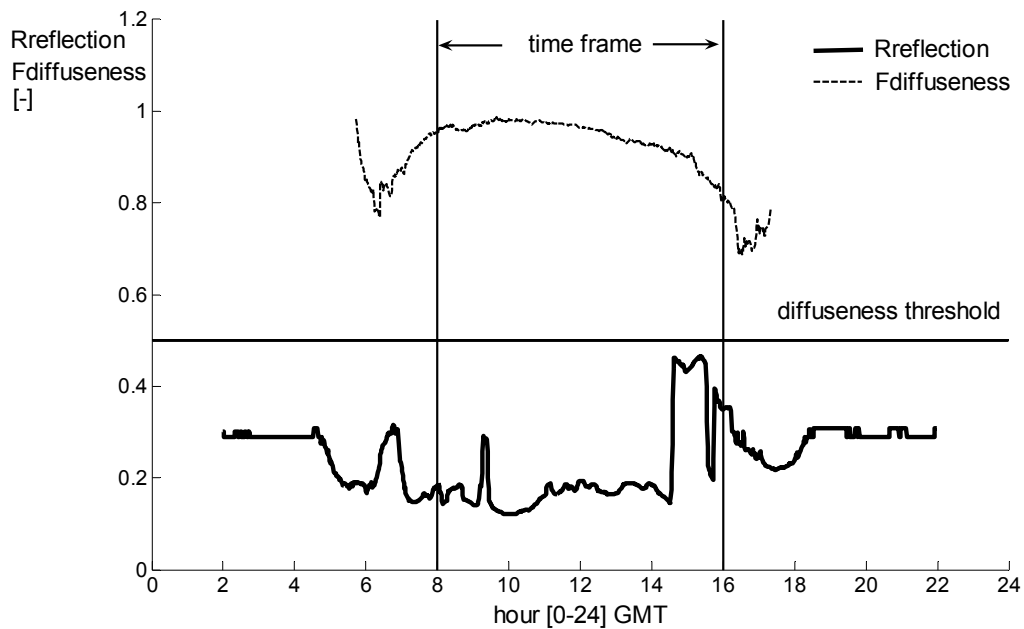


Fig. 4. Example of a clear day where no interception can be calculated (10-Sep-2006).

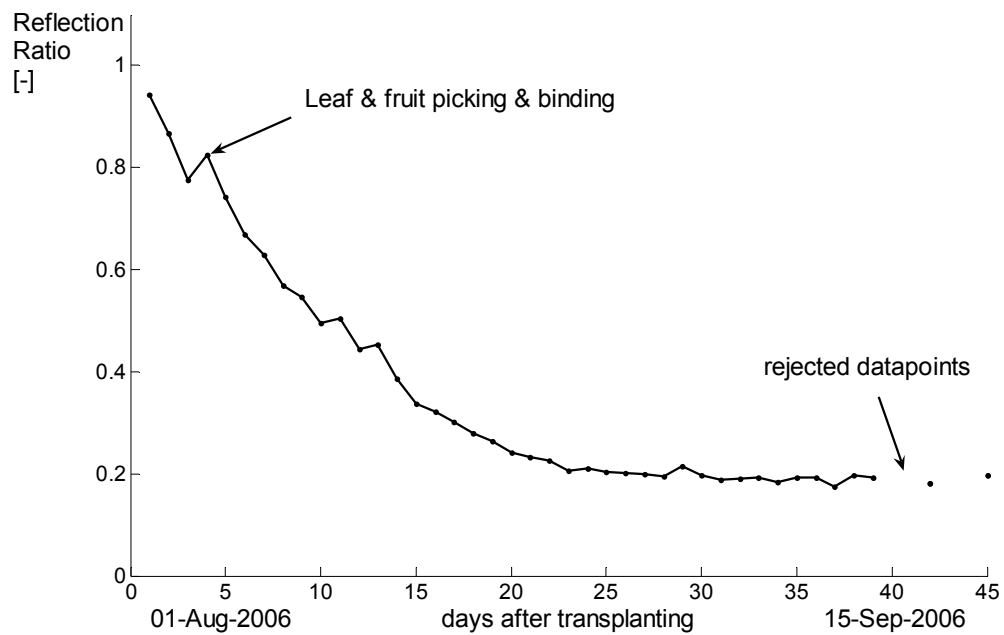


Fig. 5. The daily Reflection Ratio decreases with the increase of the leaf area.

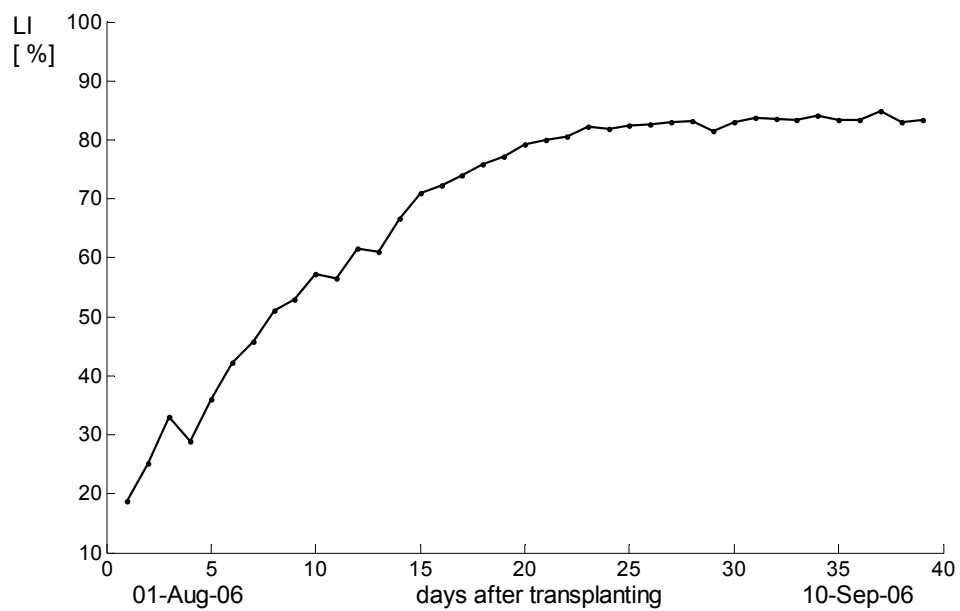


Fig. 6. Daily Estimation of Light Interception from the sensor.

