ORCHARDS LAI ESTIMATION THROUGH THE RADIATION EXTINCTION COEFFICIENT

STIMA DEL LAI DI FRUTTETI ATTRAVERSO IL COEFFICIENTE DI ESTINZIONE DELLA RADIAZIONE

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Abstract

Light interception is an indicator of crop vigor and phenological phase. Although algorithms found in literature are useful for calibration of direct measurement tools, they are difficult to replicate since optical corrections are needed to account for different canopy shapes. During 2016-17 growing seasons non destructive, cheap and easy to use methods to assess plant-light interaction characteristics were developed and tested in six orchards in Emilia-Romagna (Italy). The Photosynthetically Active Radiation (PAR) was detected below and above crown by an AccuPAR LP80 ceptometer, Canopy Cover (CC) was derived through hemispherical photos from a smartphone equipped with a fisheye lens, leaves for direct LAI were collected from sample plants, and measured in laboratory. The below PAR was adjusted according two geometrical corrections. The ratio above-to-below PAR was inverted to obtain the fraction of absorbed PAR (FAPAR), and to estimate the indirect LAI. Correlations between direct and indirect LAI according to plant geometry, and regardless the species, is presented. Trend lines equations were used to calculate the extinction coefficient (K), allowing LAI estimation in other orchards with similar geometrical characteristics. These studies were part of the activities supported by the MOSES European project (http://moses-project.eu/moses_website/).

Keywords

Leaf Area Index, Canopy Cover, orchard, FAPAR, radiation extinction coefficient.

Parole chiave

Indice di Area Fogliare, copertura vegetale, frutteto, FAPAR, coefficiente di estinzione della radiazione.

Introduction

In orchards photosynthetically active radiation (PAR) affects fruit tree health and growth (Beaudet and Messier 2002). Size, shape, position and orientation of plants, as well as the distribution of optical properties, characterize and affect the canopy structure (Weiss et al. 2004). As a consequence, light environment in the fruit zone and radiation interception are indicators of crop vigor and phenological phases (Gilardelli et al. 2018). In particular, Leaf Area Index (LAI), Canopy Cover (CC), and extinction fraction coefficient (K) data are key variables for describing crop and environment interactions (Ramirez-Garcia, Almendros, and Quemada 2012).

LAI is defined as the total one-sided area of leaves per unit ground surface area (Watson, 1947), and it is measured through direct and indirect methods (Zarate-Valdez et al. 2012). Direct methods, such as leaves measuring, are generally destructive and more used for annual species; in addition, they are time consuming, expensive and difficult to apply. Indirect -or optical- methods are based on the transmittance of radiation through the canopy (Duchemin et al. 2006; Khabba et al. 2009). The AccuPAR LP-80 (Decagon Devices, Inc. Pullman, WA, USA, www.decagon.com/, LP-80 thereafter), and hemispherical (fisheye lens) photography are examples of well known and widely used indirect methods based on the analysis of either the sky gap fraction, or the gap size distribution of light transmitted through the canopy (Bréda, 2003). Digital Hemispherical Photographs (DHP) capture the fraction of light absorbed and transmitted through the canopy, according to its structure (Beaudet and Messier 2002). For leaves randomly distributed, the extinction coefficient K, is the leaf unit mean projection on surface, which is perpendicular to the radiation beam; it is mainly determined by leaves distribution angle, and the radiation direction (Bréda 2003; Wang, Li, and Su 2007).

Numerous published studies (e.g. (Bacour et al. 2006; Jonckheere et al. 2004)) report significant positive correlations between direct sensor measurements and indirect photographic estimates of PAR transmission. Algorithms found in literature, mainly according to zenith angle (θ) and leaves angle distribution (χ), are useful for calibration of direct measurement tools (Chianucci 2016). Nevertheless, these algorithms are not easily replicable, since optical corrections are needed to account for different canopy shapes (Orlando et al. 2016).

Aim of this work was to develop a tool to assess LAI of orchards using non- destructive, low cost and easy to use methods, independent by crop species. In the framework of the MOSES project, PAR and CC were measured in six orchards in Emilia-Romagna, Italy, and in three replications dates, during two growing seasons (2016-17). Direct LAI was also measured at the end of the season for instruments calibration. Four crops were investigated: peach (*Prunus persica*), plum (*Prunus domestica),* kiwi fruit (*Actinidia chinensis*), and pear (*Pyrus communis).* A correlation was found between measured direct LAI, CC from DHP, and PAR from ceptometer. Trend lines equations were used to calculate K, allowing the replicability in other orchards with similar optical characteristics.

Materials and Methods

Emilia-Romagna has a continental climate, with hot summers, slightly rainy, and rather humid. The Forlì-Cesena province (FC) is located between the Apennines and the Adriatic Sea. For the two-years of the survey (2016-17), yearly mean temperature was 15°C, and mean yearly cumulated precipitations were 534 mm. Measurements were taken between June and July, at the farms listed in Tab. 1, on date reported in Tab. 2.

Tab.1 - Characteristics of the experimental farms.
Tab.1 - Caratteristiche delle aziende sperimentali.

Lat	Lon	Farm	Crop	Training system	Irrigation system
44,13	12,19	Casetti	peach	Slender spindle	Drip
44,13	12,20	Fungo	peach	V-shape	Drip
44,14	12,21	Paci	peach	V-shape	Drip
44,15	12,20	Lazzari	plum	V-shape	Micro-sprinkler
44,13	12,20	Romini	pear	Slender spindle	Micro-sprinkler
44,29	12,16	Plazzi	kiwi	Pergola	Drip

Tab.2 – Survey date and measured parameters.
Tab.2 - Date delle rilevazioni e parametri misurati.

Repetition	Survey date	Type of data
I	20/05/16 24-25/05/16	Plant height (h) Plant width (L) PAR DHP
II	29/06/16 06-07/07/16	
III	28-29/07/16	
I	10/05/17 24-25/05/17	
II	14-15/06/17	
III	20-24/07/17	

Every orchard had four measurement points, GPS localized. Each of the points is divided in two sections, named as transept A and transept B (Fig. 1). Seven detections per transept were taken at the same time to obtain comparable data for both Photosynthetically Active Radiation (PAR) and CC. Since they affect the pattern of light transmission through the canopy (Beaudet and Messier 2002), height and width of four plants were measured at each sampling point.

PAR was detected with the LP-80 ceptometer. This parameter was then inverted into the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR=1-PAR) (Gobron and Verstraete 2009) for LAI definition, in relation to a vegetation cover, using several variables.

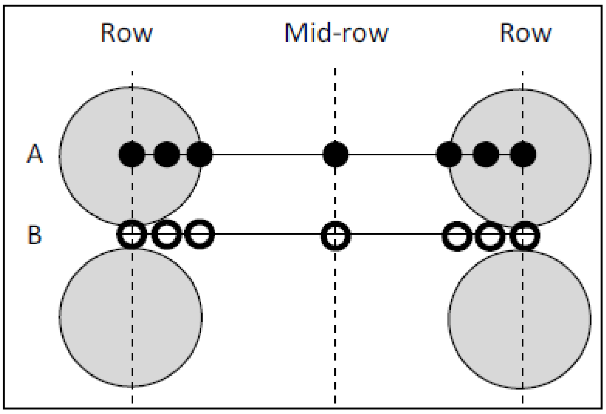

Fig. 1 - Survey site description: 4 measurement points, 2 transepts (A, B), 7 sampling points per each measured parameter.
Fig. 1 – Descrizione del sito di rilievo: 4 punti per azienda, in ciascun punto 2 transetti (A, B), 7 punti per transetto per ogni parametro misurato.

DHP were taken using a Huawei smartphone with a fish-eye lens attached, which enlarges the field of view (V_f), mounted on a monopod, and being sufficient far from the researcher. Among the 14 measurements per measurement point, only FAPAR and CC detected at the first and last sampling points (at trunk for transept A, between trunks for transept B) were used for the correction method here presented. For CC data collection, DHP were taken from the ground upwards (DHP_{CC}), while for Ground Cover (GC) data, meaning the vegetation ground covering the orchard, DHP were captured from top to down (DHP_{GC}). DHP_{CC} were processed with PBP-v1.0 (Plant Biophysics with Python - version 1.0), a software ad-hoc developed (Montanari, 2016) to accurately identify shadow and light zones below tree crowns. DHP_{GC} were analyzed with Easy Leaf Area (Easlon and Bloom, 2014), a software that allows to estimate CC by distinguishing leaf area on background soil. The measurement of direct LAI was carried out with a destructive method at the end of each growing season, by weighting and scanning in laboratory the leaves collected from one -or two- plants per farm, at point measurement 1. These data were analyzed with ImageJ software (Schneider et al. 2012).
Starting from Eq. 1, as reported in the LP-80 manual, PAR from ceptometer was adjusted to account for canopy geometrical characteristics (Fig. 2).

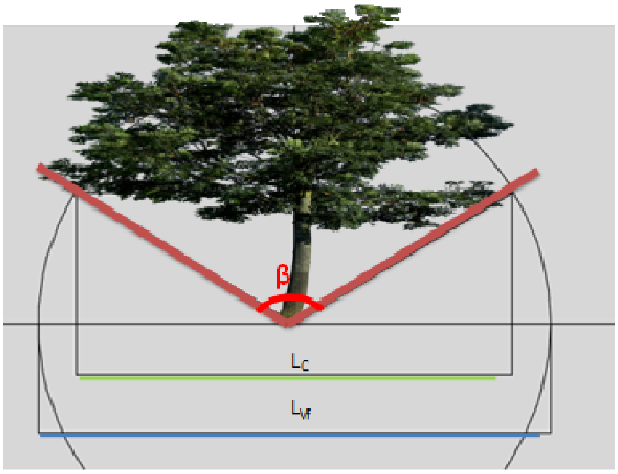

Fig. 2 - Geometrical correction for Below TAU adjustment. τ_{proj} corresponds to the ratio of the fraction of view angle (β) and π, since the crown perimeter is similar to a arch of a circumference having the maximum tree height as radius. τ_{emi} is equal to the ratio between the crown width (L_C) and the fraction of view width (L_{Vf}).

Fig. 2 - Correzione geometrica del Below τ. τ_{proj} è il rapporto tra la frazione dell'angolo β e π, poiché il perimetro della chioma può essere approssimato l''arco di una circonferenza che abbia l'altezza dell'albero come raggio. τ_{hemi} è uguale al rapporto tra la larghezza della chioma (L_C) e la frazione dell'angolo di visuale (L_{Vf}).

The Tau (τ) parameter is defined as the above-to-below PAR ratio. The zenith angle (z) is defined as the angle between the sun in its position during the measurement, and that it would have at zenith. The instrument calculates z according to the geographic coordinates, the day and time at which the measurement is carried out. Beam fraction (f_b) is the direct radiation from the sun (r_s), and the radiation from other sources (or diffuse) ratio. The instrument calculates f_b by comparing the value of PAR below the canopy, with the r_s value directly derived. Leaf distribution parameter (χ) refers to the leaves distribution angles within the canopy (α).

$$LAI = \frac{\left[\left(1-\frac{1}{2K}\right)f_{b-1}\right]ln\tau}{A=(1-0{,}47f_b)} \quad \text{Eq. (1),}$$

Where A is equal to: $A=0.283+0.785\alpha-0.159\alpha^2$, with α =0.9, as the LP-80 manual defines.

More in detail, the above PAR remained the same, while the below PAR was corrected to exclude the radiation not intercepted by the canopy, according to a projected (τ_{proj}) and a hemispherical correction (τ_{hemi}), as Fig. 2 explains, and in particular having defined:

$$\tau_{proj} = \beta/\pi \quad \text{Eq. (2),}$$

$$\tau_{hemi} = L_c/L_{Vf}, \quad \text{Eq. (3),}$$

where β is the fraction of view angle, L_C is the minimum crown width, L_{Vf} is the fisheye view width, and h is the height of branch insertion. The entire CC and indirect FAPAR data sets (2016-17) were compared with direct LAI measurements, adjusted for farm-specific dry matter percentages. In order to account for both the fraction of CC from tree crops, and the ground cover from herbaceous crops, the equation reported in Ramirez-Garcia (2012) was considered (Eq. 4). For LAI <4.01, CC is equal to LAI as follows:

$$GC(\%) = 47.82*LAI - 5.96*LAI^2 \quad \text{Eq. (4)}$$

This formula was applied for LAI calculation, by replacing GC values with CC mid-row data, estimated from DHP_{CC} and analyzed as previously described.

Results

The ad-hoc program PBP-v1.0, was applied to accurately identify shadow and light zones below tree crowns. This software for CC images analysis allow to: i) eliminate the distortion of images captured with a fisheye lens attached to the smart-phone camera; ii) modify images chromatic scale, through the transition from RGB images (Red, Green and Blue) to binary images (black and white); iii) determine single images intrinsic parameters.

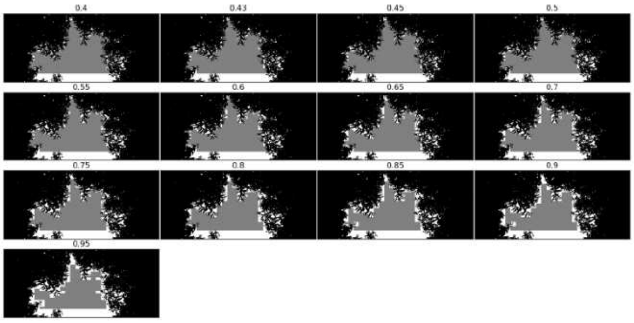

Fig. 3 - Different thresholds of images corrections, obtained from different CC values, which were calibrated using direct LAI values, measured at the end of the 2016-17 growing season.

Fig. 3 – Soglie di correzione delle immagini, ottenute dai vari valori di CC, calibrati con i valori di LAI diretto misurati alla fine della stagione di crescita 2016-17.

For the model validation based on the comparison of the results obtained by the specially developed PBP-v1.0 with direct LAI data (2016), different thresholds were applied. A correct threshold helps to better discriminate in the pictures sky from leaves and trunks, and the best threshold resulted in the sixth one (Fig. 3), i.e. the one that allows the calculation the sky fraction according to the size of the tree crown as S (sky pixels)/T (total pixels), with a ratio higher than 0.60.

As expected, considering only detections at trunk, or between trunks (for A, and B transept, respectively), increased the amount of the intercepted radiation.

Results of the comparison for direct and indirect LAI estimation methods are presented in Fig. 4. After inversion of PAR into FAPAR parameter, trend line equations for $FAPAR_{proj}$, $FAPAR_{hemi}$, and CC were outlined. They have a R^2 equal to 0.88, 0.70, and 0.66, respectively. Between these two geometrical corrections, FAPARproj results in the highest correlation with direct LAI, since FAPARproj values are lower.

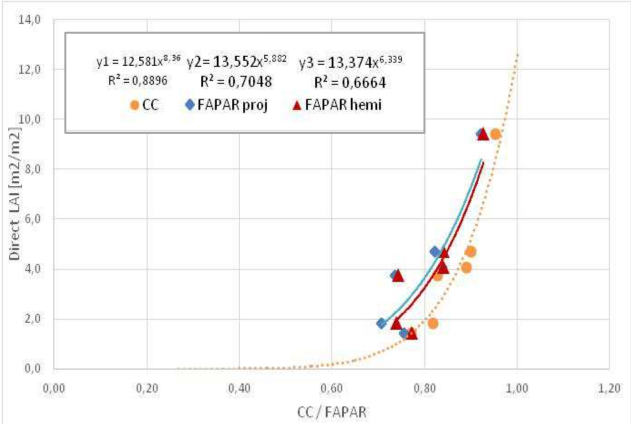

Fig. 4 – Direct LAI, FAPAR, and CC values comparison. The direct Lai compared with the CC values are orange colored. The comparison of the direct LAI with the FAPAR evaluated by LP-80 and adjusted is red for the hemispherical correction, and blue for the projected correction. The R^2 *values are: 0.89 (CC), 0.70 (FAPAR proj and 0.67 (FAPAR hemi).*

Fig. 4 – Confronto tra valori di LAI diretto, FAPAR e CC. Il Lai diretto confrontato con I valori di CC sono rappresentati in arancio. Il confronto del LAI diretto con il FAPAR stimato da LP-80 e corretto è riportato in rosso per quanto riguarda la correzione emisferica e in blu per la correzione proiettata. I valori di R^2 *sono: rispettivamente: 0.89 (CC), 0.70 (FAPAR proj e 0.67 (FAPAR hemi).*

After the calibration previously describes, the derived formula (Eq. 5) for the extinction coefficient (K) was applied:

$$K = \frac{1}{2} + \frac{[ln\tau(f_b - 1)]}{LA(1 - 0{,}47 f_b)} \qquad \text{Eq. (5),}$$

where τ =PAR_{proj} Below/Above.

The K value obtained from Eq. (5) may be used in Eq. (1), instead of table values, to obtain more reliable LAI data from indirect measures, such as canopy cover obtained from DHP, for fruit trees, regardless the tree species. For example, for Romini farm, which crop is pear, K=0.06. This value of K is reliable, since the zenith angle was optimal, and it is rather low due to high measured LAI (in 2017 survey) equal to 9, in comparison with tabular LAI values of about 2-3. This demonstrates that LAI values on orchards depends highly on the training system, and the growing shape of fruit trees, which are tridimensional systems, meaning that further investigations are needed.

Discussion and Conclusions

In literature, there are complementary approaches to describe light and crop interactions, where Leaf Area Index plays a key role as canopy descriptor (Bréda et al. 2003). Although several studies developed algorithms based on vegetation indices in estimating LAI for herbaceous crops, further investigations on canopy structure and light interactions are needed, especially for tree crops (Nguy-Robertson and Gitelson 2015; Viña et al. 2011). In particular, the commonly assumed spherical leaf angle distribution was found to significantly underestimate light transmission through the canopy (Wang et al. 2007). The zenith angle, which affect the separation into sunlit and shaded foliage, is important in scaling canopy processes such as photosynthesis and stomatal conductance, according to the different responses of foliage to diffuse and direct solar radiation (Gu et al. 2002).

In this study, two non destructive, cheap and indirect methods, which are CC from DHP and PAR from a LP-80 ceptometer, were compared with one invasive, time and labour consuming method that is direct LAI, in six orchards, in Emilia-Romagna (Italy), during two growing season (2016-17). While CC from DHP was corrected for the most appropriate threshold (0,60), which was computed by means of the PBP-v1.0 software, and calibrated with direct LAI (measured in January 2017), the LP-80 data were adjusted applying two corrections, considering the 180° fish-eye field of view angle. In fact, while DHP allows discriminating between pixel detecting fraction of sky and canopy, named also leaves gap fraction, the ceptometer data need to be adjusted to obtain the radiation intercepted by canopy, according to its geometrical structure.

Data showed a good correlation between the methods above described. After the opportune calibration, the extinction coefficient (K) was derived. These outputs allow applying indirect methods to estimate LAI in orchards, or in row trees, which is a widely used parameter for plant monitoring purpose (Gilardelli et al. 2018), regardless the tree species, and according to canopy structure. In particular, it can be useful for studies investigating crop and environment exchange, such as water and energy balance at larger scale, as for example irrigation district or water basin, including remote sensed data (Hirose 2005; Duchemin et al. 2009).

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