



# An enhanced method to infer gas exchange function in peach trees having different canopy shapes based on canopy quantum flux absorption assessment



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## ABSTRACT

Functionality of training systems different in size, shape and geometry are primarily a function of their ability to intercept and distribute light effectively within the canopy. In peach, methodologies for a rapid and reliable assessment of such features are still lacking. In this study we propose a systemic approach that as unique data entry requires diurnal ground monitoring of the light-shadow windows of a tree canopy. Case studies for canopy shapes were a pyramid ( $\blacktriangle$ , Delayed Vase), a parallelogram ( $\blacklozenge$ , Palmette) and a Y (Tatura trellis) chosen within a 3-year-old peach orchard. Canopy geometrical and structural parameters calculated from above and below canopy radiation readings taken at full canopy development include Silhouette ( $S$ ) as sunlit canopy area projected orthogonal to the sunbeam, leaf layer index (LLI), canopy leaf projection coefficient computed orthogonal to sunbeam direction ( $K_j$ ), instantaneous canopy photon influx ( $Q_{CA}$ ), instantaneous canopy intercepted photon flux in the 300–1100 nm waveband ( $Q_C$ ) and canopy photon influx capture efficiency ( $\varepsilon_{Q_{CA} \rightarrow Q_C}$ ).

Whole-tree gas exchange was also continuously monitored for a week on each canopy shape to gain a direct measurement of canopy net assimilation rate ( $A_C$ ) and canopy transpiration rate ( $E_C$ ). A positive  $Q_C$  vs.  $A_C$  correlation was shown by any canopy type, with  $r = 0.93$ ,  $0.97$  and  $0.92$  for  $\blacktriangle$ ,  $\blacklozenge$  and  $Y$ , respectively. By contrast, while  $Q_C$  and  $E_C$  were weakly correlated in  $\blacktriangle$  and  $\blacklozenge$ , a close positive correlation ( $r = 0.87$ ) was found between these two variables in  $Y$ . The Tatura trees also showed, regardless of timing of the day, the highest  $E_C/A_C$ , hence better water use efficiency. This study validates the hypothesis that a systemic assessment of canopy quantum flux absorption ( $Q_C$ ) leads to reliable prediction of actual net canopy photosynthetic rates paving the way to: (a) easier and faster evaluation of efficiency of canopy systems differing in size and shape and (b) simplification in whole-canopy photosynthetic models.

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## 1. Introduction

Defining “efficiency” of a given canopy system in fruit trees is a quite debated issue, although it is reasonable assuming that efficiency should successfully compromise the following desirable features: (i) capacity to intercept a high fraction of the incoming solar radiation; (ii) capacity to distribute light effectively within the canopy in order to avoid either too dense foliage clumping or

too large gaps causing a high fraction of light to be directly lost onto the ground and (iii) capacity to partition adequate dry matter to the economically viable organs (i.e. fruits) at no detriment for maturation of the wood retained for next season cropping (Genard et al., 2008).

Solar light radiation intercepted by leaves represents the main driver of the photosynthetic process, whereas the net solar radiation absorbed by the leaves together with the atmospheric evaporative demand are the most important factors influencing transpiration (Monteith, 1965). The attributes identifying the instantaneous quantum flux incident on a canopy, such as density, direct and diffuse fractions (Spitters et al., 1986), and spectral

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## Symbols

◆	parallelogram (Palmette) canopy
▲	pyramidal (Delayed Vase) canopy
Y	Y (Tatura) canopy
Y <sub>e</sub>	Y eastern vegetation hedge
Y <sub>w</sub>	Y western vegetation hedge
χ	absolute air humidity (g H <sub>2</sub> O m <sup>-3</sup> )
D	canopy-atmosphere vapour pressure deficit (kPa)
K <sub>J</sub>	canopy representative leaf projection coefficient computed orthogonal to sunbeam direction
ε <sub>Q<sub>CA</sub>→Q<sub>C</sub></sub>	canopy efficiency at intercepting 300–1100 nm photon influx
ε <sub>Q<sub>C</sub>→A<sub>C</sub></sub>	conversion factor of instantaneous 300–1100 nm canopy intercepted quantum flux into net assimilation rate (μmol CO <sub>2</sub> μmol <sup>-1</sup> photons)
ε <sub>Q<sub>C</sub>→E<sub>C</sub></sub>	conversion factor of instantaneous 300–1100 nm canopy intercepted quantum flux into transpiration rate (mmol H <sub>2</sub> O μmol <sup>-1</sup> photons)
β	sun elevation angle (°)

## Abbreviations

[CO <sub>2</sub> ] <sub>air</sub>	atmospheric CO <sub>2</sub> concentration (μmol CO <sub>2</sub> mol <sup>-1</sup> )
Q	photon flux density within the 300–1100 nm waveband detected horizontally (μmol photons m <sup>-2</sup> s <sup>-1</sup> )
Q <sub>A</sub>	above-canopy representative photon flux density within the 300–1100 nm waveband detected horizontally (μmol photons m <sup>-2</sup> s <sup>-1</sup> )
Q <sub>AJ</sub>	above-canopy photon flux density falling on a surface orthogonal (J) to sunbeam direction (μmol photons m <sup>-2</sup> s <sup>-1</sup> )
<sup>700</sup> / <sub>400</sub> Q <sub>A</sub>	above-canopy photosynthetic photon flux density detected horizontally (μmol photons m <sup>-2</sup> s <sup>-1</sup> )
Q <sub>CA</sub>	instantaneous canopy photon influx in the 300–1100 nm waveband (μmol photons canopy <sup>-1</sup> s <sup>-1</sup> )
Q <sub>C</sub>	instantaneous canopy-intercepted photon flux in the 300–1100 nm waveband (μmol photons canopy <sup>-1</sup> s <sup>-1</sup> )
<sup>700</sup> / <sub>400</sub> Q <sub>C</sub>	instantaneous canopy-intercepted photosynthetic photon flux (μmol photons canopy <sup>-1</sup> s <sup>-1</sup> )
a <sub>1-sh</sub>	leaf lamina shadow projected orthogonal to sunbeam direction (m <sup>2</sup> )
a <sub>1</sub>	one-side leaf lamina area (m <sup>2</sup> )
Area <sub>C</sub>	one-side tree canopy leaf surface area (m <sup>2</sup> canopy <sup>-1</sup> )
Area <sub>sh</sub>	ground area shaded by the canopy (m <sup>2</sup> canopy <sup>-1</sup> )
A <sub>sun</sub>	canopy sunlit surface area (m <sup>2</sup> canopy <sup>-1</sup> )
A <sub>C</sub>	canopy net assimilation rate (μmol CO <sub>2</sub> canopy <sup>-1</sup> s <sup>-1</sup> )
E <sub>C</sub>	canopy transpiration rate (mmol H <sub>2</sub> O canopy <sup>-1</sup> s <sup>-1</sup> )
E <sub>C</sub> /A <sub>C</sub>	ratio of canopy transpiration to net assimilation rates (mg H <sub>2</sub> O μg <sup>-1</sup> CO <sub>2</sub> )
g <sub>C</sub>	canopy mean surface conductance (mm s <sup>-1</sup> )
LLI	leaf layer index
PhAR	photosynthetic active range
Silhouette	sunlit canopy area projected orthogonal to sunbeam direction (S, m <sup>2</sup> canopy <sup>-1</sup> )
T <sub>air</sub>	air temperature (°C)
T <sub>db</sub>	dry-bulb temperature (°C)
T <sub>wb</sub>	wet-bulb temperature (°C)

composition (Nobel, 1999) depend on the atmospheric conditions (Monteith and Unsworth, 1990) and are affected by sun-earth geometrical relationships connected to latitude, time of the year and of the day, and by exposure and slope of the ground area. Under non-limiting environmental conditions, a thorough understanding of geometrical, optical and thermal characteristics of leaves – considered as single element (Jones, 1992) and as canopy components (Sinoquet et al., 2001) – is mandatory to investigate the biophysical interaction between canopy and radiation field (Ross, 1981), and to explain canopy photosynthetic and transpiration responses. Moreover, a 3D approach is needed as we are typically facing discontinuous canopies which are further complicated by varying shapes yielding large diurnal variation in the fractions of the intercepted light.

Simplified vegetation geometrical-structural features, such as leaf area index, sunlit canopy area projected parallel to sunbeam direction onto an orthogonal plane (Silhouette according to Oker-Blom and Smolander, 1988), and Silhouette-to-total (canopy) area ratio are used to model plant functions at contrasting spatial and temporal scales. Digitizing measurement techniques are also available to achieve a more detailed canopy geometry description (Sinoquet et al., 1997): their support is fundamental to model, in particular, intra-canopy features and functions (Phattaralerphong and Sinoquet, 2005; Phattaralerphong et al., 2006; Massonnet et al., 2008; Parveaud et al., 2008; Stephan et al., 2008). However, since these digitizing techniques are time-consuming, they are not widely employed in eco-physiological studies carried out on adult trees. In plant eco-physiological studies carried out on different canopy typologies, canopy light capturing efficiency, photosynthesis and transpiration are commonly simulated, but no experimental validation is generally provided (Percy and Yang, 1996; Genard et al., 2000; Molchanov, 2000; Stenberg et al., 2001; Monteith, 1977; Palmer, 1988; Monteith, 1994; Gamon et al., 1997; Rosati et al., 2004; Albrizio and Steduto, 2005; Steduto and Albrizio, 2005; Baldazzi et al., 2014; Cola et al., 2014).

Canopy enclosure systems (Daudet, 1987; Corelli-Grappadelli and Magnanini, 1993; Goulden and Field, 1994; Poni et al., 2014) are commonly used to monitor single tree canopy-atmosphere CO<sub>2</sub> and H<sub>2</sub>O exchanges leading to estimates of corresponding canopy net photosynthetic and transpiration rates (Giuliani et al., 1997; Poni et al., 1997, 2014; Lakso et al., 1999). Besides overcoming inherent limitations of inferring whole canopy characteristics from individual leaf readings (i.e. variability due to position, age, light exposure, health status, etc.) a whole-tree approach represents an ideal tool for calibration of gas exchange canopy function models. Working in potted grapevines (Poni et al., 2006a,b), a “big leaf” model parametrised vs. light interception was successfully calibrated against concurrent whole canopy net CO<sub>2</sub> exchange rate in vertically-shoot positioned cv. Cabernet Sauvignon canopies of moderate vigor (approximately 2.5 m<sup>2</sup> of leaf area per m of row), yet no data are available on more vigorous vines triggering more complex intra-canopy interactions. In addition, suitable methodologies may be applied for quantum flux interception estimates by specific organs within a tree crown or a grapevine canopy (Jackson and Palmer, 1972; McNaughton et al., 1992; Giuliani et al., 2000; Poni et al., 2003; Poni et al., 2006a,b).

Studies conducted on physiology of peach canopies differing in training and geometry also suggest that while the productivity of a peach tree is roughly proportional to light interception, fruit production does not always increase with increased light interception especially when the latter is greater than 50% of the available incoming light (Grossman and DeJong, 1998; Losciale et al., 2010). Thus, it is evident that a finer tuning between light interception and distribution achieved under a given production system and its output in terms of canopy carbon balance is needed. Quite surprisingly, in peach, a modeling approach aimed at releasing reliable estimates

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