A multi-tool approach for assessing fruit growth, production and plant water status of a pear orchard

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Abstract

Only very little is published on simple tools for monitoring seasonal information relating plant water status to fruit growth/yield in horticultural crops. This paper analyses data recorded in 2014 from the end of cytokinesis (early July) on 'Abbè Fetel' trees grafted on four different rootstocks (Farold, Sydo®, MH and MC) grown in the Fratelli Navarra Foundation Experimental Farm, in Ferrara, Italy. Trees were irrigated according to the "Irriframe" scheduling system designed by the "Consorzio per il Canale Emiliano Romagnolo (CER)" of the Emilia-Romagna Region based on the water balance method. Soil moisture was calculated from water inputs (rainfall and irrigation) and outputs identified as crop evapotranspiration (ET_c). For each rootstock, three treatments were studied: fully irrigated following the Irriframe scheduling or 50 and 0% of the recommended water volume. Relevant information of plant development, fruit growth and leaf water status were recorded. In addition, a new approach for measuring plant activity, called I_{PL} index, was undertaken. This index involves the measurements of chlorophyll fluorescence, carboxylation activity of RuBisCo, and air and leaf temperature. In high-quality pear production systems, water/fruit growth control is a must, but growers lack an objective methodology for assessing management decisions. The data collected were used to evaluate possible assistance services in management decisions taken by the growers and/or the consultants throughout the season. The goal was to assist the growers in improving the efficacy of crucial decisions along fruit growth, and to help and ensure high production levels without losses in quality. The presented work also intended to prove the concept of this methodology. Satisfying results may indicate that it is close to large-scale adoption.

Keywords: fruit size forecast, chlorophyll fluorescence, tree crops, decision support system

INTRODUCTION

The concept of tree performance measurements is fundamental for horticultural production since the detection of the plant/fruit status during the season could allow modulating all growing practices to maximize yields without wasting resources. One of the main drivers of fruit development is water availability (Morandi et al., 2014a). This resource affects a large number of physiological processes at tree level, such as canopy gas exchanges, tree water relations and fruit growth. The later results from the balance among the different fluxes (xylem, phloem and transpiration) in/out of the fruit (Morandi et al., 2014b). Many studies report how water shortage negatively affects fruit growth and harvested yields in several fruit crops, such as apple (Naor et al., 1997), peach (Berman and DeJong, 1996), kiwifruit (Miller et al., 1998) and pear (Morandi et al., 2014a, b). In pear, this is very often connected to the rootstocks used (Musacchi et al., 2006; Losciale et al., 2014). Growth and, hence, yield reduction are generally attributed to reduced stomatal conductance and the consequent decrease in canopy carbon assimilation (Flexas et al., 2006). Leaf photosynthesis

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and stomatal conductance are considered some of the most reliable indicators of plant performance, as they give information about leaf functionality and water consumption, but their determination is quite time consuming (~3 min $leaf^{-1}$). Losciale et al. (2015) modelled a plant performance index, called I_{PL}, estimating net leaf photo-assimilation performance, using few and easy-to-measure variables. The model, parameterized and validated for apples and pears, uses chlorophyll fluorescence analysis, air and leaf temperature as independent variables. Other techniques for estimating the tree/orchard performance took into account parameters such as fruit diameter (DeSilva et al., 1997; Morandi et al., 2007), crop load (Palmer et al., 1997; Manfrini et al., 2009) or calculated production information (Manfrini et al., 2012). Manfrini et al. (2015) reported on a decision support system (DSS) for managing fruit growth along its development stage. The rationale was that total fruit growth and its rates can be effective indicators of the plant performance. They can also be easily implemented in commercial realities.

The aims of this work are: i) to analyse the behaviour of four different pear rootstocks grown under three different water regimes; ii) to evaluate the possible integrations of the I_{PL} index and the fruit based DSS as an effective tool to estimate the crop performance and to release important real-time information to funnel management decisions, particularly for fruit development and water management practices.

MATERIALS AND METHODS

The study was conducted during 2014 at the "Fratelli Navarra" experimental farm, close to Ferrara, Italy (44°51'33.0"N; 11°39'22.4"E), on four- to five-year-old trees of 'Abbé Fetel' pears (*Pyrus comunis* L.) grafted on three quinces rootstocks (*Cydonia oblonga* Mill.), Sydo®, MH, MC and one clonal pear rootstock (Farold) during 2014. Because of the different rootstocks' vigour, trees were spaced at various distances (Table 1). All of them were trained as spindle bush, North-South oriented and managed according to standard cultural practices in terms of fertilization, thinning and pruning. The orchard setup considered 3 blocks for each rootstock with 3 replicates of each treatment in each block, where 3 trees were considered for the measurements (total of 9 trees for each treatment).

Table 1. Rootstocks used in the experiments and their planting density expressed in number of plants ha^{-1}.

Rootstock	Tree density (m)	Plants ha^{-1}
Farold	4.0×2.0	1250
MC	3.0×0.5	6667
MH	3.5×0.8	3571
Sydo®	3.5×1.0	2857

Irrigation was scheduled according to the regional web-based platform 'Irriframe' (Consorzio per il Canale Emiliano Romagnolo – CER, www.irriframe.it). 'Irriframe' provides irrigation scheduling based on the Penman-Monteith equation, orchard-specific parameters (soil, training system, density, cultivar, rootstock, irrigation system, etc.) and meteorological data collected by a weather station located in the proximity of the orchard. Soil moisture was calculated by measuring and estimating the water inputs (rainfall and irrigation) and outputs identified as the crop evapotranspiration (ET_c). It is maintained within a certain target range varying throughout the season according to cultural coefficients, which vary with plant phenological stages. Starting from fruit set and for the entire vegetative season, trees were either fully irrigated or supplied with 50, or 0% of the recommended water volume.

Net photosynthesis was estimated on July 4 and 16 and August 6 and 18 during the summer 2014 using the I_{PL} index. I_{PL} allows to accurately and reliably estimate net photosynthesis rate in less than 30 s $leaf^{-1}$ (Losciale et al., 2015). The I_{PL} semi-mechanistic model considers a multiple linear combination of the photosynthetic electron transport rate (J_{PSII}) aggregated with the Michaelis-Menten constants for carboxylation (K_C) and photorespiration (K_O) forming a new variable, $P_{KO/KC}$=JPSII×K_O/K_C, and the leaf to air temperature difference. Chlorophyll fluorescence parameters, leaf and air temperature, necessary for the I_{PL} computation, were measured with a leaf fluorimeter with actinic light set at 1500 µmol m^{-2} s^{-1}, similar to the natural irradiance occurring inside the orchard and a thermocouple (Li-COR 6400, LI-COR Inc., Lincoln Nebraska USA). Measurements were performed between 10:30 and 13:00 solar time in a random way among the treatments on mature and well exposed leaves placed on the east side of the canopy (the most exposed at that time of the day) on a total of 3 leaves per replicate (total of 9 leaves per treatment).

Fruit maximum equatorial diameter was measured on 80 fruit coming from a group of 3 trees per replicate (total of 240 fruit per treatment). Measurements were taken in 2014 on July 4 and 16 and August 6 and 18. Data were recorded by Calibit (calibit.it/en), a digital calliper fitted with an on-board data logger. This calliper allows a single person to record an average of 1500 dimensions in less than 1 h. Following a standard protocol (Manfrini et al., 2015), average fruit dimensions at harvest were calculated since the second date of fruit dimension measurements. Fruit diameters (Table 2) were predicted from the average of July 16, August 6 and 18 measurements. As a tree vigour parameter, the trunk cross sectional area (TCSA, cm^2) was registered on 9 trees of each treatment.

Table 2. Production parameters (crop load, yield and average fruit size), vegetative parameters (trunk cross sectional area (TCSA) and predicted fruit diameter, analysed for rootstocks and volumes of water restitution.

Rootstock	Water volume (% ET_c)	Crop load (fruit $tree^{-1}$)	Yield (t ha^{-1})	TCSA (cm^2)	Average fruit mass (g)	Fruit harvest diameter (mm)	Predicted diameter (mm)[1]
Farold	0	49.9 a	12.9 e	15.8 abcd	195.1 e	64.7 e	65.7 e
	50	55.2 a	15.0 de	18.8 ab	211.0 de	66.5 de	67.0 d
	100	57.3 a	15.1 de	20.4 a	215.2 de	67.0 de	67.0 d
MC	0	20.2 b	29.4 bc	10.9 d	224.2 de	68.0 de	68.0 d
	50	23.6 b	37.5 ab	10.9 d	243.9 cd	70.1 cd	69.9 cd
	100	24.7 b	42.6 a	12.3 cd	268.8 bc	72.6 bc	71.5 c
MH	0	31.6 b	31.6 bc	15.4 abcd	292.1 ab	74.9 ab	75.6 ab
	50	32.7 b	36.1 ab	17.4 abc	308.9 ab	76.4 a	76.1 a
	100	28.4 b	31.9 bc	15.4 abcd	322.7 a	77.6 a	77.2 a
Sydo	0	29.3 b	24.2 c	13.6 bcd	293.2 ab	74.9 ab	74.6 ab
	50	33.2 b	26.2 c	13.9 bcd	286.2 ab	74.3 ab	74.5 ab
	100	28.9 b	23.2 cd	13.7 bcd	288.5 ab	74.5 ab	74.8 ab

Significant differences within columns were identified by a two-way ANOVA ($p<0.05$).
[1]Mean value of three sets of measurement for predicting harvest diameter. The supposed harvest date was set on August 29.

Fruit harvest was scheduled on August 29 following the commercial strategy of the orchard. Production measurements allow to calculate the single tree crop load expressed in number of fruit per tree (fruit $tree^{-1}$), mean fruit mass (g $fruit^{-1}$) and fruit production (t ha^{-1}) on each treatment. A two-way ANOVA considering rootstocks and water volume restitution as variables was performed for the analysis of variance and to compare the means of all parameters (Table 2).

RESULTS AND DISCUSSION

Figure 1 represents rainfall, evapotranspiration and irrigation schedule of 2014. Data of the I_{PL} index (Figure 2) indicate that scions on Farold rootstocks showed higher photosynthetic activity (P_n >10 µmol m^{-2} s^{-1}) compared to those crafted on others (mostly less than 10 µmol m^{-2} s^{-1}). On the other hand, scions on MC rootstock had the lowest photosynthetic activity, mainly in the first two days of measurement (July 4 and 16), with values lower than 7 µmol m^{-2} s^{-1}. Negative effects of irrigation shortage (0 and 50% of the ET_c) on net photosynthetic activity were mainly relevant in MC-grown trees on July 4 and 16 and August 18. Also, photosynthesis of Farold-grown trees was low for the low-irrigation-treatment (0%) but only on July 16 and August 6, while for those on MH, PS was low for 0%-treated plants only on July 4. Photosynthesis of Sydo® grown plants was highly irregular variable and low for non-stressed trees in August. In general, late season photosynthetic activity was not very different among stressed and well-irrigated trees. This probably resulted from the seasonal rainfall pattern (Figure 1).

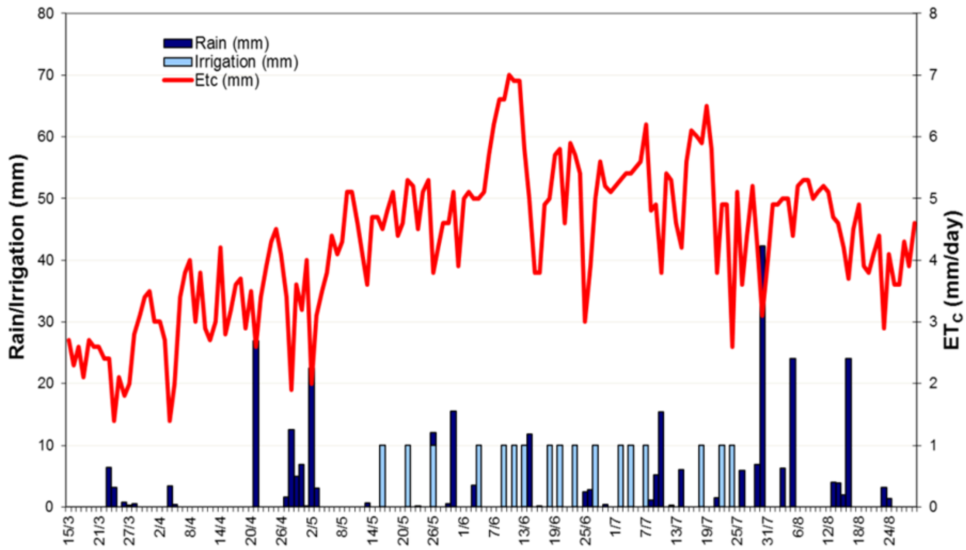

Figure 1. Rain, irrigation and evapotranspiration rate during the 2014 season.

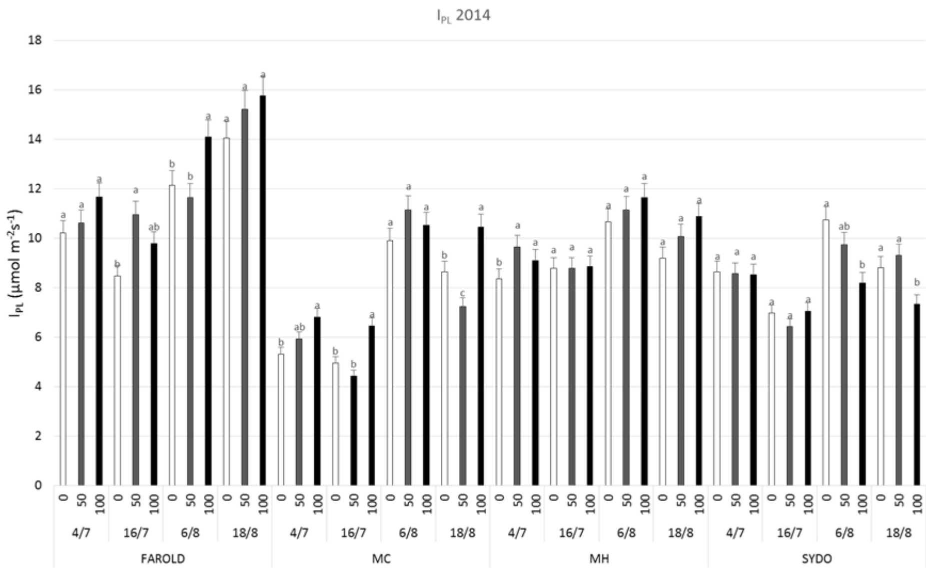

Figure 2. I_{PL} index-estimated net photosynthetic activity (P_n) of trees grown on the 4 rootstocks for 4 different days (July 4 and 16 and August 6 and 18) during growing season. Each measurement was performed on trees either fully irrigated (100% commercial irrigation) or with irrigation at 50 and 0% of the ET_C. Bars represent the means of 9 replicates. Within each day and rootstocks, water volume treatments were compared using a two-way ANOVA with P<0.05.

In July and August, more than 160 mm rainfall was recorded compared to a seasonal average of less than 50 mm (www.arpa.emr.it/). The high precipitation during the final part of fruit growth (Table 2) diminished the irrigation-induced differences in fruit yield between trees grown on different rootstocks. Only MC-grown trees showed a statistically significant lower production in the 0% treatment (29.4 t ha^{-1}) compared to 100% (42.6 t ha^{-1}). No other significant differences on yield were found due to the different irrigation volumes within the rootstocks (Table 2).

Variations in photosynthetic and productive responses due to different rootstocks were reported (Losciale et al., 2008; Musacchi et al., 2006). The clonal rootstock Farold differs from the quinces MC, MH and Sydo®, showing a clear example of slow initial fruit bearing (Table 2). In fact, Farold, even supporting a higher fruit load due to the inherent vigour (see planting density in Table 1), resulted in lower production (less than 15.1 t ha^{-1}) and smaller fruit size (less than 195 g $fruit^{-1}$). On the other hand, Farold invested more in vegetative growth than the other rootstocks as indicated by the higher TCSA (between 15.8 and 20.4 cm^2). As previously discussed, the higher photosynthetic activity of plants on this rootstock indicated that a higher plant activity not necessarily may result in higher yield. In Farold, photosynthates were mainly directed to vegetative growth and plant perennial structures at this stage of orchard development. On the contrary, MC showed lower values of photosynthesis compared to Farold (Figure 2) but very high production values (between 29.4 and 42.6 t ha^{-1}), indicating that this rootstock can reach higher production rates earlier. Sydo® and MH, even showing a quite high vegetative activity (with TCSA between 13.6 and 17.4 cm^2), reached a valuable production coupled with bigger fruits (>286 g $fruit^{-1}$; diameters >74.3 mm).

The protocol used for fruit size estimation during the growing season yielded very precise predictions. The predicted diameter closely reflected the average fruit size at harvest (Table 2), with respect to both the rootstocks pattern and the irrigation schedule. The biggest difference was found in MC rootstock and 100% irrigation, with an average harvest diameter of 72.6 mm and a predicted size of 71.5 mm (underestimation of 1.1 mm). However, for all rootstocks, optimally irrigated trees (100%-treatment) had the biggest fruit, statistically different from those of the 0% treatment in some cases. This highlights the effectiveness of the protocol implemented and the reliability of the forecasting DSS performed during the season.

CONCLUSIONS

This work describes the use of two tools possibly implementable in a single decision support system for precise pear orchard management. It takes advantage of the synergy between two existing protocols for measuring the plant photosynthetic activity affected by rootstocks/tree and environmental changes (I_{PL} index) and the fruit growth pattern along the season. The precise results offered by these tools create the potential opportunity to check in real-time the effect of midseason cultural practices (irrigation) for optimising orchard management by a simple analysis of the information coming from easy field measurements. Because growers and technicians often lack an objective methodology to assess management decisions, this snapshot experiment can be considered as a proof of concept of a decision support system application for the control of quality (size), production (yield) and physiological parameters (net photosynthesis) in pear orchards.

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