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Leaf wetness duration in irrigated citrus orchards in the Mediterranean climate conditions

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ABSTRACT

Leaf wetness (LW) is a key environmental variable for the development of foliar fungal diseases of citrus. However, little information of LW duration (LWD) in Mediterranean citrus-growing areas is available. LWD in six canopy positions and two leaf sides was studied with visual observations and Spectrum LW sensors in a citrus orchard in Spain. The performance of Spectrum and Hobo LW sensors, and CART/SLD and RH LW models was assessed by receiver operating characteristic (ROC) curve analysis. The dynamics of LWD in three citrus orchards with flood irrigation and three with drip irrigation were evaluated using time-series models. LWD data from all experiments and recordings in 14 commercial citrus orchards illustrated the high frequency of LW periods, particularly those associated with dew. No substantial differences in LWD were detected among citrus canopy positions and leaf sides. An optimal dry/wet threshold of 2.85 for the Spectrum LW sensor, 75.88 for the Hobo LW sensor, 15.99 for the CART/SLD model, and 87.45% for the RH model was selected by ROC curve analysis. All the sensors and models evaluated showed a substantial strength of agreement with visual observations of LW, with area under the ROC curve of 0.89–0.93 and Cohen's Kappa index of 0.61–0.77. The RH model was recommended because of easier implementation in citrus orchards in Spain. Time-series models did not detect any significant increase in LWD associated with flood irrigation, but only after some rain events. High mesoclimatic relative humidity in the study area outweighed possible microclimatic changes induced by flood irrigation. Thus, negligible effects of flood irrigation in the infection of foliar fungal pathogens would be expected, but longer LWD in the lower canopy as well as potential effects on inoculum dynamics in the leaf litter cannot be excluded.

1. Introduction

As in many other crops, in citrus trees leaf wetness (LW) is a critical environmental factor for the epidemic development of foliar fungal diseases causing serious yield and quality losses. The incidence of melanose, caused by *Diaporthe citri* (H.S. Fawc.) F.A. Wolf., citrus scab, caused by *Elsinoë fawcettii* Bitanc. & Jenkins, and post-bloom fruit drop, caused by *Colletotrichum acutatum* J.H. Simmonds, increases with longer LW duration (LWD). The epiphytic growth and infection of citrus leaves by *Zasmidium citri-griseum* (F.E. Fisher) U. Braun & Crous causing greasy spot disease was also enhanced by LW. Likewise, the presence of LW influenced the infection of *Phyllosticta citricarpa* (McAlpine) van der Aa, the causal agent of citrus black spot (Timmer, 1999). Alternaria brown spot, caused by ACT-toxin-producing strains of *Alternaria alternata* (Fr.) Keissl., is the main fungal disease of mandarin in the Mediterranean Basin. Studies conducted in Spain found a positive relationship of LWD with the incidence of this disease (Bassimba et al., 2014).

Surface wetness was defined by Magarey et al. (2005) as the visible presence of water on a plant surface, such as leaves, stems, flowers or fruit which is driven by rain, dew, overhead irrigation and guttation. Dew can occur when water condensates from the air (dewfall) or evaporates from the soil (dewrise or distillation) and

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then is intercepted by the canopy (Garratt and Segal, 1988). LWD is a key component of disease prediction models and for decision support systems used for foliar fungal plant pathogens (De Wolf and Isard, 2007). However, despite its importance in plant disease epidemiology and the number of studies conducted elsewhere, LW is still considered a non-standard micro-meteorological variable and a standard system for its measurement is not available (Magarey et al., 2005).

The distribution and the duration of LW in citrus canopy were studied under the humid subtropical conditions of Florida, USA, by Santillan et al. (2010), who found heterogeneity among sensor heights and horizontal positions. Visual observations of LW in plants are usually carried out during the night and are labour consuming and can be affected by human error, so they are not routinely conducted. There are different types of sensors available for LW monitoring, including static, mechanical or electronic systems, but their accuracy is variable and frequent calibrations are usually needed (Rowlandson et al., 2015). Moreover, their operational capacity can be greatly reduced by some chemicals applied in the field such as copper (Magarey et al., 2005). Although widely used in research studies, LW sensors are rarely employed by growers.

Physical and empirical models have been used as an alternative to visual LW observations and sensoring (Magarey et al., 2005). Physical models, mostly based on energy balance equations, have good accuracy and are more suited for extrapolation. However, these process-based models need some specific data inputs, such as net radiation, which are not usually available in agro-meteorological stations. On the other hand, empirical models estimate LW building on statistical relationships with meteorological variables, like relative humidity (RH) or its variation in time, which are readily available under commercial field conditions (Sentelhas et al., 2008). In general, empirical LW models are relatively easy to handle, but their accuracy strongly depends on proper local calibration and evaluation. Both types of models, process-based and empirical, should consider specific plant architecture traits and thermal properties of the targeted plant and organ (Magarey et al., 2005). The evaluation of LW models for citrus under Mediterranean conditions would help to implement decision support systems, leading to a more efficient management of foliar fungal diseases, such as Alternaria brown spot of mandarins (Bassimba et al., 2014).

Several studies highlighted the critical role of dew and irrigation in the epidemic development of foliar fungal diseases in semiarid environments, where rains are scarce most of the year (Agam and Berliner, 2006; Palti, 1981). Overhead irrigation is known to enhance the production, release and spread of fungal spores from infectious plant tissues. Longer LWD and higher infection efficiency have been also associated with this type of irrigation system (Palti, 1981). In fact, it was specifically recommended avoiding overhead irrigation for the management of foliar fungal diseases of citrus (Timmer, 1999). Nevertheless, overhead irrigation is seldom used in citrus-growing areas in the Mediterranean Basin and citrus orchards are typically flood- or drip-irrigated (Carr, 2012), with micro-irrigation with sprinklers placed at around 50 cm above soil surface being used in some specific locations (Alba et al., 2003).

In contrast to overhead sprinkle irrigation, surface irrigation systems seldom wet the canopy, but may influence orchard microclimate by increasing RH and LWD. Greater amounts of water are applied with flood irrigation, wetting almost all the soil surface whereas only a small proportion is wet by drip. Higher RH, longer LWD, and greater severity of foliar fungal diseases were reported with flood irrigation compared with drip irrigation in row crops and orchards (Goldhamer et al., 2002; Kamel et al., 2008; Palti, 1981; Scherm and van Bruggen, 1995). Information about the dynamics of LWD in irrigated citrus orchards would help to select the most appropriate irrigation system for the integrated management of foliar fungal diseases.

Therefore, the objectives of this study were: (i) to describe the spatial distribution of LWD in the citrus canopy under Mediterranean conditions in Spain; (ii) to compare the performance of two sensors and two empirical LW models for estimating LWD; (iii) to estimate and describe LWD in commercial citrus orchards in different provinces of Spain, and (iv) to evaluate the influence of irrigation system on the dynamics of LWD in citrus orchards.

2. Materials and methods

2.1. LWD observations and sensors

The trial was conducted at a site in Moncada, Spain at the Instituto Valenciano de Investigaciones Agrarias (IVIA) research station (39°N elevation 69 m). The experimental plot of mature bearing trees of tangor 'Ortanique' (*Citrus reticulata* Blanco × *C. sinensis* Osbeck) grafted on Carrizo citrange (*Poncirus trifoliata* (L.) Raf. × *C. sinensis*) was planted in 2005 on a 5 × 3 m spacing with a canopy diameter of about 3 m without intra-row free spaces between trees. Bottom and top canopy heights were about 0.5 and 2.5 m from the soil surface, respectively. The orchard was drip irrigated with four emitters per tree of 4 L h^{-1} each and rows were oriented north-south. The soil area wetted by emitters in the orchard was photographed at 300 ppi by a digital camera (Coolpix 4500, Nikon Corporation, JP) including a rule for scaled dimensioning. The soil area wetted, quantified by using Assess software (APS, USA), was of 11% of the soil surface per tree.

Visual observations of LW were carried out during nine nights (24, 25 January, 14 April, 3 October, 12 December 2012, 17, 18, 22 April, and 27 May 2013) without rain and in calm wind conditions. The percentage of leaf area wet was assessed by a trained observer on both, leaf upperside and underside. At the beginning of the study, visual observations were confirmed by placing a water-sensitive paper (Syngenta AG, CH) on the leaf surface, which changed from yellow to blue in the presence of free water. Observations were made in six canopy positions: two sides of the tree (east and west) and three heights (1, 1.5 and 2 m) in each side.

In each canopy position, 10 leaves were randomly chosen every 15 min starting from 17:00 pm until complete LW deposition during the night, and from sunrise to complete LW depletion in the morning. The average percentage of leaf surface covered with LW in each 15-min period was calculated individually for each canopy position and both leaf sides. Percentage values were converted to binary values: 1 = wet leaf when ≥10% of leaf surface wet and 0 = dry leaf when <10% of leaf surface wet (Dalla Marta and Orlandini, 2010). Daily LWD from noon to noon were analysed descriptively. The Student's *t*-test was used to detect statistical differences among canopy positions and between leaf sides. Normality, homoscedasticity and independence were confirmed prior to analysis. The R software v.3.0.2 (R-Core-Team, 2013) was used in all analyses.

Flat plate LW sensors were fixed at a 30° angle from the horizontal in the same canopy positions indicated above. Spectrum LW sensors (3666, Spectrum Technologies Inc., USA, range 0–15) were placed in all six canopy positions. Hobo LW sensors (Hobo S-LWA, Onset Computer Corp., USA, range 0–100, resolution 0.59%) were placed only at 1.5 m in both sides of the tree. LW sensors were previously tested under field conditions resulting in an average coefficient of variation of 10.62% for Spectrum LW sensors and 11.18% for Hobo LW sensors (Sentelhas et al., 2004). As indicated by the manufacturers, LW sensors were not painted. Temperature and RH (WatchDog 450, accuracies ± 0.7 °C and ±3%) were measured in both sides of the tree at 1.5 m. A rain gauge (7852, Davis Instruments Corp., USA, accuracy ± 4%, resolution 0.2 mm) was deployed