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Daily forecasting of reference and strawberry crop evapotranspiration in greenhouses in a Mediterranean climate based on solar radiation estimates

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ABSTRACT

This paper presents a method for carrying out daily forecasting of strawberry crop evapotranspiration (ET_c), using forecasted greenhouse reference evapotranspiration values ($ET_{o\ green}$) and crop coefficients. $ET_{o\ green}$ was estimated using two methods, the first based on incoming solar radiation and the second using the Makkink FAO-24 equation. In both cases, $ET_{o\ green}$ was estimated using daily meteorological variables forecasted by the Spanish Meteorology National Agency (AEMET) and then comparing it with the result obtained using measured meteorological data under greenhouse conditions. In addition, values of estimated ET_c using measured and forecasted meteorological data were also compared. Lastly, these values were compared with ET_c measurements using drainage lysimeters. Incoming solar radiation was estimated from forecasted temperatures and sky cloudiness conditions. Forecasted outdoor and indoor incoming solar radiation values were more accurate using the method based on temperatures. Small differences and high correlations were observed when comparing forecasted and weather measured $ET_{o\ green}$ and ET_c. With respect to forecasted $ET_{o\ green}$, the errors were smaller when incoming solar radiation was estimated from forecasted temperature data, especially when using the Makkink equation, with underestimations below 3%. Therefore, these results suggest that the latter method is best suited to the task. Also, the use of forecasted ET_c, especially from Makkink FAO24 equation, provided more accurate estimates when compared with lysimeter-measured values.

1. Introduction

Spain is the world's third largest producer of strawberries. According to estimates by the Department of Agriculture, Fisheries and Rural Development of the Government of Andalusia, an area of 7500 ha was dedicated to strawberry cultivation in the province of Huelva in the 2013/2014 season (Consejería de Agricultura y Pesca, 2012). The strawberry generates high economic value goods and employment, however, the fact that it is cultivated in the vicinity of the Doñana National Park, the most important protected wetland in Europe, requires the reconciliation of environmental conservation and productive activity. Consequently, finding ways to reduce agricultural water use are of considerable interest.

Strawberry crops in Spain are irrigated solely by drip irrigation but the irrigation efficiency for this crop is unknown. Despite the widespread use of this method of irrigation in this crop, there is still uncertainty about the precise amount of water needed to maximize strawberry crop production. Strawberry farmers schedule their irrigations based on past experience, observation of weather conditions and visual plant indicators of stress. As the lateral drip irrigation pipe is placed under the plastic mulch, the water applied from the drip pipelines is not visible to field managers. Therefore, over-irrigation easily occurs when managers believe they have to water the entire field area, including the row middles. Furthermore, for the time being, water in this area is a relatively inexpensive input and is often managed carelessly.

Most of the research on strawberry irrigation has been carried out in California and Florida (USA), where open-field cultivation is the standard strawberry production method (Clark et al., 1996; Grattan et al., 1998; Hanson and Bendixen, 2004; Trout and Gartung, 2004). However, in many of the winter and early spring production areas outside the USA, strawberries are grown under

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clear plastic tunnels (Childers, 2003; Hancock, 1999). Almost all strawberries are grown in tunnels in Spain.

Efficient water use requires an efficient and uniform irrigation system and correct scheduling of water applications. The FAO methodology based on reference evapotranspiration (ET_o) and crop coefficient (K_c) has been used worldwide to determine crop water requirements (ET_c) under open-field conditions. This methodology can also be applied to greenhouse crops (Bonachela et al., 2006). In addition, K_c values have been determined for the main greenhouse crops cultivated on the southeast Spanish Mediterranean coast (Orgaz et al., 2005). A standardized method for estimating outdoor ET_o was defined in the FAO-56 Irrigation and Drainage Paper (Allen et al., 1998). However, there is no standardized method for greenhouse crops. The most comprehensive comparison of methods for estimating greenhouse ET_o was performed by Fernández et al. (2010) on the southeastern Mediterranean coast. In this work Penman, radiation and evaporimetric tank methods, in their version FAO24, and Penman–Monteith FAO56 and Hargreaves equations were evaluated. In addition, an equation based only on incoming solar radiation was proposed to estimate $ET_{o\ green}$. The latter method requires only greenhouse transmissivity (τ) and measurements or estimations of incoming solar radiation. It is, therefore, the most practical way to determine greenhouse ET_o. Also, its accuracy is similar to that of the Makkink FAO24 and Penman–Monteith FAO56 methods.

The water-holding capacity and available water of most sandy soils around the Doñana National Park are low in comparison to other soils with higher silt and clay fractions. In sandy soils, lateral movement of water is limited to 15–30 cm from a drip or point source emitter (Clark et al., 1993) and rapid vertical movement of water can occur (Clark and Smajstrla, 1983). Therefore, these soils need real-time irrigation scheduling and pulse drip irrigation. Accordingly, a daily ET_c forecast would help save water.

Seasonal or monthly ET_o and crop water requirement forecasts, useful for mid- to long-term irrigation planning, can be produced using historical weather data, thanks to the periodicity of ET_o and crop coefficients. Irrigation advisory services provide excellent information on near-real-time ET_o but do not provide a daily ET_o forecast, which is useful for real-time irrigation scheduling, especially for high-frequency irrigation systems, shallow-rooted vegetation or sandy soils (Luo et al., 2014). Real time irrigation scheduling using weather data forecasts has proven appropriate to estimate ET_o and applications are reported for several crops (Gowing and Ejieji, 2001; Wilks and Wolfe, 1998; Cabelguenne et al., 1997). Also, public weather forecasts are now easier to access and to understand. Cai et al. (2007) compared weather forecasted ET_o estimations with the ET_o values computed with full data sets from synoptic stations and non-synoptic locations (Cai et al., 2009). More recently, Perera et al. (2014) quantify the performance of forecasted daily ET_o using numerical weather prediction outputs for different lead times and Luo et al. (2014) reported a short-term ET_o forecast based on data from daily temperature forecasts using the Hagreaves-Samani model.

Since 2011, the Andalusian Institute of Agricultural Research and Training (IFAPA in Spanish) has conducted studies on drip irrigation of strawberries in the vicinity of the Doñana National Park, southern Spain, in order to help strawberry growers to irrigate efficiently. These studies have included measurement of ET_c and estimation of K_c, determination of irrigation efficiency and calculation of water productivity (Gavilán et al., 2014). For these studies, two meteorological stations were installed outside and inside the strawberry greenhouses to monitor meteorological variables and to estimate outdoor and greenhouse ET_o

The objectives of this study were: (1) to estimate greenhouse reference evapotranspiration ($ET_{o\ green}$) and strawberry crop evapotranspiration (ET_c) using daily meteorological forecasts from the Spanish Meteorology National Agency (AEMET); (2) to compare these estimations with those obtained from meteorological measurements and lysimeter data.

2. Material and methods

2.1. Experimental site

The studies were carried out in Almonte (Huelva) on a commercial strawberry (*Fragaria x ananassa*) farm. The farm is near the village of El Rocío, in the vicinity of the Doñana National Park (longitude 6° 31′ 39″ West, latitude 37° 05′ 13″ North, altitude 24 m above mean sea level). The mean annual rainfall is 467 mm and average annual mean, maximum and minimum temperatures are 17.4, 24.5 and 11.0 °C, respectively. The soil of the study area is classified as sandy (USDA classification), with 90% sand and 10% clay.

Two experiments were conducted in order to measure strawberry consumptive water use, irrigation efficiency and water and land productivity using different amounts of water applied. In the first growing season, the transplant was performed on October 9th 2012 with a planting density of 71,888 plants per ha. The experiment finished on June 6th 2013. In the second season, the transplant was performed on October 10th 2013 with a planting density of 62,000 plants per ha and the experiment finished on May 15th 2014. For both experiments, the greenhouses were set up on November 10th 2012 and November 11th 2013. The berries were planted in trapezoidal beds measuring 0.60 m at the base, 0.50 m at the top, with a height of 0.50 m, and 1.1 and 1.2 m apart for the first and second growing season, respectively. There were six and five beds at each tunnel for the first and second growing season, respectively. Two rows of plants were placed along the bed with a drip irrigation tape in the center installed during bed construction. The tape used was able to apply 5 l m^{-1} h^{-1} flow rate at a pressure of 0.55 MPa.

Both trials were arranged as a randomized complete block design with three treatments with different irrigation volumes replicated four times. The first treatment (T1) was set up to apply the crop water requirements, based on $ET_{o\ green}$ and estimated crop coefficients, using an irrigation efficiency of 85%. T2 and T3 applied 25% and 50% more water than T1, respectively. The experimental unit was a complete parabolic tunnel $70 \times 6.6\,m^2$ and 3 m high, and the trial consisted of 12 tunnels (Gavilán et al., 2014). The tunnels were covered with 0.15 mm-thick thermal polyethylene plastic film. Irrigation scheduling based on crop water requirements was applied each day to replace ET_c and maintain non-limiting soil water content. ET_c was calculated by the well-known FAO56 method (Allen et al., 1998):

$$ET_c = ET_{o\ \ green} \times K_c \quad (1)$$

where $ET_{o\ green}$ was estimated inside the greenhouse, as proposed by Fernández et al. (2010). For this, we used meteorological forecasts from the Spanish Meteorology National Agency (AEMET) and meteorological data measured inside the tunnels. K_c was estimated as function of crop coverage recommended by Hanson and Bendixen (2004) and Trout and Gartung (2004) for the first and second season, respectively.

2.2. Forecasting meteorological variables

For estimating forecasted $ET_{o\ green}$, meteorological forecast provided by AEMET (http://www.aemet.es) was used. It provides sky cloudiness conditions, rainfall probability, maximum and minimum temperatures and relative humidity of the air and wind speed and direction.

Forecasted greenhouse temperature and relative humidity data were estimated from the correlations between outdoor and indoor values of both variables measured during two previous growing