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Estimating strawberry crop coefficients under plastic tunnels in Southern Spain by using drainage lysimeters

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A B S T R A C T

Water is the major limiting factor in the irrigated agriculture of Southern Spain. This fact is even more determining for strawberries cultivated in the vicinity of environmentally sensitive areas such as the Doñana National Park; the major protected wetland of Europe. In the last few years, there is a growing interest on maximizing the efficient use of irrigation water in this area, aiming to achieve the equilibrium between agricultural practices and environmental protection. This work shows the local crop coefficients (K_c) for strawberries (*Fragaria x ananassa cv*. Sabrina) grown under plastic tunnels in the coast of Huelva (Spain). Crop coefficients were estimated *in situ* during the 2014/15 and 2015/16 seasons by using three drainage lysimeters installed along the raised beds where plants were grown, and filled with the same soil (sandy soil). Estimated K_c values were defined on the basis of the agro-climatic information provided by two weather stations located inside and outside of the tunnels (macro-tunnels). Values ranged between 0.3 and 0.8, when outside data were used, and between 0.4 and 1.4, when using the climatic data provided by the weather station inside the macro-tunnel. However, discrepancies in estimations of K_c inside were observed depending on the methodology used to determine the reference evapotranspiration (ET_0) under the plastic tunnel. Polygonal and polynomial models were fitted to K_c data *versus* the days after planting (*DAP*) and the growing degree days (*GDD*) in order to provide a useful tool for growers to be able to estimate crop water needs. These results represent an important contribution for the improvement of irrigation water use in strawberry cultivation in the Southern Spain.

1. Introduction

Strawberry (*Fragaria x ananassa* Duch.) is the third most important horticultural crop in Andalusia (S Spain), being the province of Huelva the major producer of the EU, with 6400 ha and a crop production of 327,680 Tm, representing a benefit of 257 million of euros during 2015–16 (CAPDR, 2016). Most of the production (≈ 78%; 255.000 Tm in 2016) is exported to international markets where its fruit quality is highly appreciated. This reveals the economic importance of this crop for the region being the main source of rural employment in the area (CAPDR, 2016).

However, due to its cultivation in the proximity to the Doñana National Park, the most important wetland in Europe, complaints have arisen related to the increasing crop water consumption leading to excessive water withdrawal from aquifers and their pollution by leaching of phytochemicals (García-Morillo et al., 2015). This situation leads to a conflict of interests between Agricultural and Environmental administrations claiming for a sustainable solution for strawberry cultivation in this environmentally sensitive area.

In this sense, strawberry production systems must have a proper irrigation management, focused on improving water use efficiency and minimizing ground water pollution (Létourneau et al., 2015) maintaining profitability and fruit quality. This is especially tough under current drought situations and under the predicted climate change scenarios in which water scarcity is the major limiting factor for irrigated agriculture in the region (García-Tejero et al., 2011; Martinez-Ferri et al., 2013).

Strawberry requires large amounts of water because of its high leaf area development, the large fruit water content and the morphology of its root system; being necessary to take into account the variations

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between the different cultivars (Martinez-Ferri et al., 2016). In the same vein, strawberry development in South Spain requires of irrigation during the entire production cycle because of being developed under plastic tunnels and the very poor water holding capacity of soils where this crop is grown (Ariza et al., 2012; García-Morillo et al., 2015). Moreover, the effects of water stress on strawberry crop have been previously discussed, evidencing significant effects in terms of loss yield and fruit-quality (Martinez-Ferri et al., 2014). Moreover, authors such as Klamkowski and Treder (2008), Grant et al. (2010), or Bordonaba and Terry (2010) have discussed the differential effects of water stress in terms of plant growth, physiological response and fruit-quality, depending on the cultivar, when this crop is subjected to water stress situations.

Thus, one of the main hotspots for strawberry water management is to assess accurately the crop water needs under the conditions of the cultivation system in the area (*i.e.* plastic tunnels). The methodology proposed by FAO (Allen et al., 1998) is the most used to estimate irrigation water requirements based on crop evapotranspiration (ET_c). This method uses the reference evapotranspiration (ET_0), calculated by means of different climatic parameters (Doorenbos and Pruitt, 1977), and a crop-coefficient (K_c), which is highly dependent on the cultivar (Klamkowski and Treder, 2008; Krüger et al., 1999), local conditions, crop management, among other factors (Wright, 1982; García-Tejero et al., 2015; Stanghellini et al., 1990; Annandale and Stockle, 1994). Many authors have reported that the methodology proposed by Allen et al. (1998) is suitable for a proper irrigation management in strawberries (Hanson and Bendixen, 2004; Lozano et al., 2016), but it is necessary to adapt K_c values to the particular cropping conditions. Thus, K_c values reported in the literature for open-field conditions (Tarantino and Onofrii, 1991; Létourneau et al., 2015) may substantially differ from the actual ones under the current growing conditions, crop-management, or irrigation systems of the conventional cultivation system of Huelva area (Martinez-Ferri et al., 2016), as it has been already discussed by Gavilán et al. (2015) and Lozano et al. (2016).

In fact, up to day, it is not possible to clearly define the total irrigation requirements for this crop in this region since estimations of irrigation needs by using K_c values from other cultivated areas does not match farmer's water supply, who currently use approaches based on historical data, climate conditions and direct observation of plant based phenomena such as leaf guttation (El-Farhan and Pritts, 1997). Therefore, there is a serious lack of knowledge about the suitable K_c values for the cultivation conditions of strawberry in Huelva, which involves inaccurate estimations of strawberry irrigation water requirements. Farmers and local producers are demanding such information and techniques to improve crop management and to achieve equilibrium between strawberries production and the environment conservation in the cultivation areas.

Thus, the aim of this work was to determine *in situ* suitable weekly K_c values for strawberry during two consecutive seasons, and under the climatic conditions and production system in the coast of Huelva, making a special emphasis in those periods where crop water demand is higher and a proper water management is decisive.

2. Material and methods

2.1. Experimental site and cropping system

The trial was conducted during two consecutive cropping seasons (2014-15 and 2015-16) in the experimental farm of "El Cebollar", located in the coast of Huelva, and belonging to the Andalusian Institute of Training and Agricultural Research (IFAPA).

Climate in the study area is typically Mediterranean (*Csa* according to Köpen-Geiger classification) with an annual ET_0 of 1200 mm and an annual rainfall of 506 mm (average data for the period from 2011 to 2015).

Plantlets of one of the most cultivated commercial varieties of strawberry (*Fragaria* x *ananassa*, *cv.* Sabrina) were propagated during summer and autumn at high-elevation nurseries in Castille-Leon (North Eastern Spain; lat. 41°30′N, long. 4°55′W, alt. 900–1200 m.a.s.l.) where chilling requirements for strawberry cold hardening (i.e. 150–200 h at T < 7 °C; López-Aranda, 2008) are provided.

On 16th and 22th October in 2014 and 2015, respectively plants were transplanted into double row mulched raised beds (35 cm high, and 50 and 60 cm wide at the top and at the base, respectively) 1.1 m apart and spaced 25 × 25 cm (70000 plants ha^{-1}).

Prior to planting, the soil was solarized and bio-fumigated (bio-solarisation; Medina-Mínguez et al., 2009) to reduce the presence of soil pathogens. During the initial phases of crop development irrigation was applied by sprinkler and 1550 and 1850 $m^3\,ha^{-1}$ in 2014–2015 and 2015–2016 seasons were supplied, respectively. Three weeks after planting, polyethylene-covered tunnel structures (macro-tunnel; Ariza et al., 2012) were installed and removed at the end of each cropping season. Once the tunnels were installed, plants were fertilized and drip-irrigated by using a single T-tape line with a discharge rate of 5 L $h^{-1}\,m^{-1}$ by using 12 min (on average) irrigation pulses in a variable number (from 1 to 6) in consonance with crop developmental stage. Irrigation scheduling was done combining information from previous years (historical data) and micrometeorological data. Water volume supplied by drip irrigation was 4300 and 3500 $m^3\,ha^{-1}$during 2014–2015 and 2015–2016 cropping seasons, respectively.

The soil of the experimental plot is very similar to the main cropping area and classified as sandy soil, with 0.88, 0.08 and 0.04 g kg^{-1} of sand, silt and clay respectively. Volumetric soil water content (θ) estimated for field capacity (0.3 MPa) and permanent wilting point (1.5 MPa) were $\theta_{fc} = 0.16 \pm 0.02\,m^3\,m^{-3}$ and $\theta_{wp} = 0.09 \pm 0.01\,m^3\,m^{-3}$, respectively.

Mature strawberry fruits were harvested twice a week from January to March and three times a week from March to June. Thus, the harvesting period during the first season encompassed from 31 to 138 day of the year (DOY), and from 8 to 144 DOY during the second season. On each season, total yield was 71000 and 73300 kg ha^{-1}, respectively, these values being within the normal range of productivity of commercial farms and are in agreement with values reported for this same cultivar by Lozano et al. (2016).

2.2. Micrometeorological data acquisition and ET_0 estimations

Two automated weather stations (Davis Vantage Pro™, Valencia, Spain) were installed outside and inside of the macro-tunnel. Data of air temperature, relative humidity, solar radiation, wind speed and direction, were registered every 15 min and recorded into a datalogger. Data provided by these weather stations were used for the determination of the cumulative growing degree day (*GDD*) and the reference evapotranspiration (ET_0).

GDD was estimated according to the methodology proposed by Ring et al. (1983) and Snyder et al. (1999) (Eqs. (1) and (2)).

$$GDD = \sum_{i=1}^{n} (T_m - x) \quad (1)$$

where

$$T_m = \frac{T_{max} + T_{min}}{2} \quad (2)$$

where *GDD* is the cumulative growing degree day from the beginning of the crop system till the harvest; T_m the average between the maximum (T_{max}) and minimum (T_{min}) temperature for a day; and x a threshold temperature value in which there is no increase in crop development (in our case, x = 4 °C as it was suggested by Lozano et al. (2016)).

Weekly values of ET_0 were determined by using two methodologies: i) The modified Penman-Monteith equation (Eq. (3); Allen et al.,