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# Use of a smart irrigation system to study the effects of irrigation management on the agronomic and physiological responses of tomato plants grown under different temperatures regimes

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ABSTRACT

The increase in the air temperature due to climatic change is increasing the temperature inside greenhouses, which reduces the production and fruit quality of the crops. To alleviate this negative effect it is necessary to optimize the greenhouse water management. In this experiment, a smart irrigation system was used to evaluate different types of irrigation management of tomato plants grown in two greenhouses, where the average daytime temperatures were 26 °C and 32 °C, respectively. The plants were watered on demand, and the irrigation event was activated when plant water consumption was 0.4 L (FR1), 0.8 L (FR2) or 1.2 L (FR3). During the experiment, parameters related to production and fruit quality were measured, as well as physiological parameters such as plant-water relations and gas exchange. With this type of irrigation management, the plants from treatments FR2 and FR3 used 16 and 33% less water than the plants from FR1 in greenhouses at 32 °C, and 1% and 20% less at 26 °C. The total volume applied per plant showed that plants grown at 32 °C needed more water than those grown at 26 °C. Water potential and net $CO_2$ assimilation rate, as well as the stomatal conductance, progressively decreased as the frequency of watering decreased, and these values were lowest in plants grown at 32 °C. Commercial production of fruit was lesser for plants grown at 32 °C, due to the decrease in the number and average weight of the fruit at this temperature. As for the management of irrigation at both temperatures, the FR1 and FR2 treatments gave a similar production of fruit, which was greater than for the FR3 treatment. For the greenhouse cultivation of tomato a temperature of 26 °C is better than 32 °C and, for both these temperatures, high frequency irrigation (in this case, FR1) is optimal. However, at 32 °C the irrigation management is less influential than at 26 °C.



## 1. Introduction

Tomato (*Solanum lycopersicum* Mill.) is considered one of the most economically important vegetable crops in the world. This crop is characterized by high water needs and is considered moderately sensitive to salinity (Cuartero and Fernández-Muñoz, 1998). In arid and semi-arid areas of the Mediterranean zone, water scarcity limits its yield, so it is necessary to develop strategies to optimize the efficiency of water use, while maintaining the quantity and quality of the production (Nangare et al., 2016; Pereira et al., 2012; Patanè et al., 2011).

In addition to the scarcity of water resources, another problem that occurs in protected crops in the Mediterranean agricultural areas is the high temperatures reached in greenhouses. In general, if the greenhouses do not have a suitable cooling system the temperatures often exceed 35 °C; this temperature, although inducing several physiological, metabolic, and molecular plant responses, is not lethal to the tomato plants (Rivero et al., 2014). Depending on the growth stage, a set of optimal temperatures have been established for the plants. Thus, in the tomato crop, the optimum temperature for vegetative growth is 22 °C, and for flowering, fruit set, and fruit development it is about 26 °C (Adams et al., 2001). As for the physiological processes, when the optimal temperature is exceeded changes occur in the biochemistry, cell physiology, and structure of proteins and enzymes, affecting respiration and photosynthesis (Hasanuzzaman et al., 2013). Camejo et al. (2005) observed a decline in the $CO_2$ assimilation rate in Campbell-28

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tomato plants at 45 °C due to effects on the Calvin cycle and also on the functioning of photosystem II (PSII). As a result of all these changes, alterations in the metabolism and distribution of carbohydrates also occur. Rivero et al. (2014) observed that tomato plants of the variety "Optima" grown in a growth chamber at 35 °C showed increases at 48 h in the leaf concentrations of choline, glucose, sucrose, and starch, and decreased concentrations and glucose and proline, with respect to plants grown at 25 °C. In addition, the reduction of sink and source strength – even at moderately elevated temperatures – leads to a depletion of available carbohydrates at critical stages of plant development, resulting in a decline in fruit set and in the values of other, yield related parameters (Sato et al., 2006). High temperatures also affect negatively the development of tomato flowers and anthers and the viability of tomato pollen (Bita and Gerats, 2013). Although there is much information in the literature describing the physiological and biochemical responses of tomato plants to elevated temperature, there is little information on how this abiotic stress affects the agronomic performance of tomato crops.

The incorporation of new communication technologies (ICTs) into intensive agriculture enables irrigation management to be performed with greater precision (López et al., 2011; Zhang et al., 2013). The use of ICTs requires the integration of sensors in the software that controls the irrigation. This software has to be able to take data in real time, analyze it, and make decisions. In the case of irrigation of greenhouse crops, this means that the software has to decide when to irrigate and how much water to apply. In soilless systems in greenhouses these two aspects depend on a number of variables such as the quality of irrigation water, cultivation system, phenological state of the plants, irrigation system, electrical conductivity (EC) of the nutrient and drainage solutions, quantity of nutrients required by the plants, solar radiation, vapor pressure deficit, and ambient temperature (Qiu et al., 2013; Granados et al., 2013; Rubio et al., 2010; Ameri et al., 2012; Katerji et al., 2013; Zhang et al., 2015; Katsoulas et al., 2015). Mohammad et al. (2013) observed, in tomato crops under Mediterranean conditions, that intelligent irrigation scheduling techniques are able to increase the crop water use efficiency by increasing production and saving irrigation water. These authors implemented intelligent irrigation management based on prediction of the ETo by monitoring of real time weather parameters. The Department of Plant Nutrition at the CEBAS-CSIC (Murcia, Spain) has developed a smart irrigation system, named "HortiControl Expert", that is capable of managing irrigation automatically and simply based on the real-time monitoring of solar radiation, volume of applied irrigation, and volume and EC of the drainage solution (DS; L $plant^{-1}$). This system allows irrigation water to be supplied according to the needs of the plants, so it is very useful to accurately assess the agronomic responses of crops to different irrigation management regimes. Its potential importance is emphasized by the need to know how plants will have to be managed in a high temperature environment, under the likely climate change scenario, in order to maintain crop productivity and food security in the coming years (Anwar et al., 2013). In this experiment, "HortiControl Expert" was used to determine how to manage the frequency of irrigation in greenhouses with differing ambient temperature, in order to optimize the efficiency of water use in soilless culture. Another objective was to elucidate the physiological and agronomic responses of the tomato plants to high temperature over a complete culture cycle.

## 2. Materials and methods

### 2.1. Plant growth conditions

The experiment was carried out in two polycarbonate greenhouses (462 $m^2$ each) in Santomera (Murcia, Spain) during the spring–summer season of 2012. Seedlings of tomato 'Anairis' (*Solanum lycopersicum* Mill) were obtained from a commercial nursery and transplanted (April 2012) into 40-L (15 cm × 18 cm × 120 cm) bags containing expanded perlite (A3, Projar, Valencia, Spain) with an available water capacity of 27.4% (volumetric water content, easily available water plus buffering water capacity).

In each greenhouse, a total of 54 plants were grown in two blocks. Each block consisted of three rows with three plants per bag and three bags per row, resulting in a total of nine plants per row with spacing of 1.2 m between rows and 0.33 m between plants in a row. The plant population density was 2.5 plants $m^{-2}$. The plants were cultivated for a period of 150 days. Fertigation was carried out with an automatic drip irrigation system, with three emitters (3 L $h^{-1}$) placed in each bag of perlite. The nutrient solution (NS) used in the irrigation was constituted by 6 mM $KNO_3$, 4 mM $Ca(NO_3)_2$, 1 mM $KH_2PO_4$, 1 mM $MgSO_4$, and micronutrients (μM): Fe, 32.2; Mn, 12.7; Zn, 1.83; B, 13.8; Cu, 1.1; Mo, 0.52.

### 2.2. Temperature and irrigation treatments

The temperature was set at a maximum of 25 °C for greenhouse 1 and 35 °C for greenhouse 2. Once this temperature was exceeded, the greenhouse climate control system set in motion a series of actions to activate or deactivate the opening of the zenithal windows, the "air cooling" system, and the shade nets, to control the temperature. For that the solar radiation was similar in both greenhouses, shade nets were activated simultaneously in both, from 08:00 to 20:00. The zenithal windows were opened from 06:00 until the air temperature in the greenhouse reached 20 °C, then it was closed and the "air cooling" system was switched on. A battery of sensors recorded the solar radiation, temperature, and relative humidity, both outside and inside the greenhouse. During the experiment the average climatic characteristics for greenhouses 1 and 2 were: daytime temperatures 26 °C and 32 °C, daytime relative humidity 58% and 45%, solar radiation 548 and 544 W $m^{-2}$, air vapor pressure deficit (VPD) 1.51 and 2.58 kPa, respectively.

For irrigation management "HortiControl Expert" software was used. This is able to manage the irrigation automatically based on the real-time monitoring of solar radiation, the volume of irrigation water applied, and the volume and EC of the DS (see Image 1). Three different irrigation treatments were established, the irrigation being applied when the plants had consumed 0.4 L (FR1), 0.8 L (FR2), or 1.2 L (FR3). Any irrigation treatment exceeded the amount of water non-available for the plant inside the bags of perlite. The software calculated the consumption of NS in each irrigation event as the difference between the volume of NS applied to the crop and volume of the DS; this value was related to the cumulative solar radiation ($Rad_{ACUM}$) between two consecutive irrigations. When $Rad_{ACUM}$ reached a value equivalent to the consumption of water, irrigation was activated. The program, in addition to deciding when to irrigate, also calculated automatically the amount of water applied in each irrigation event according to the EC of the DS. At the beginning of the experiment the irrigation water applied was 15% greater than the water consumed by the plants, but this value was increased if the EC of the DS exceeded a threshold value of 3 dS $m^{-1}$, to avoid high salt accumulation in the bags of perlite.

The design of this experiment was bifactorial, with two temperatures (26 °C and 32 °C) and three irrigation management treatments (FR1, FR2, FR3). In each greenhouse there were two blocks, in which the treatments were distributed randomly.

### 2.3. Yield parameters and plant growth

Fruits were harvested weekly at the red mature stage, from 114 days after transplanting until the end of the experiment. To cal-

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