Agricultural Water Management 113 (2012) 64–75

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Simulation of onion crop behavior under optimized regulated deficit irrigation using MOPECO model in a semi-arid environment

A. Domínguez[a,*], M. Jiménez[a], J.M. Tarjuelo[a], J.A. de Juan[a], A. Martínez-Romero[a], K.N. Leite[b]

[a] Centro Regional de Estudios del Agua (CREA), Universidad de Castilla-La Mancha (UCLM), Ctra. de Las Peñas, km 3.2, 02071 Albacete, Spain
[b] Travessa Dom Jose Lourenço, 130, 60450-245 Fortaleza, CE, Brazil

ARTICLE INFO

Article history:
Received 12 March 2012
Accepted 22 June 2012
Available online 12 July 2012

Keywords:
Water productivity
Allium cepa L.
Optimized regulated deficit irrigation (ORDI)
Irrigation uniformity
Gross margin
Growing-degree-days (GDD)

ABSTRACT

This paper describes the calibration (year 2005) and validation (year 2003) processes for the simulation of an onion crop (Himalaya cultivar) in a two-year field test under deficit irrigation conditions in Castilla-La Mancha (Spain) using the MOPECO model. Results show that MOPECO is suitable for simulating the yield versus total water use under the climatic and soil conditions in this study (RMSE = 7462 kg ha^{-1}, and relative error = 10.1%, between observed and simulated yields). Growing-degree-days (GDD) for the whole growth cycle is around 2283.4 °C, while the crop coefficient (K_c: 0.65, 1.20, and 0.75) and calibrated crop yield response (K_y: 0.45, 0.8, and 0.2) values for the growth stages proposed by FAO are similar to those presented in the literature. The electrical conductivity of the irrigation water in the area (0.85 dS m^{-1}) can be neglected when simulating the yield response of onion to water (over-estimations up to 7% without considering the effect of salinity). Under the current harvest sale price scenarios (0.12 € kg^{-1} if onions are sold after harvest and up to 0.20 € kg^{-1} if onions are stored to sell at a higher price later), this crop is one of the most profitable in the area, reaching a gross margin between 1750 and 2620 € ha^{-1}, respectively, for an average yield (70,000 kg ha^{-1}). Even though optimized regulated deficit irrigation (ORDI) may slightly increase yield by 3–7%, the gross margin may significantly raise up to 30% compared with an irrigation strategy where the stress levels remain constant during the whole growth cycle. Hence, for medium and high water deficit conditions it is of interest to guarantee nascence and to favor the bulb formation stage as much as possible. For low and medium-low water deficit scenarios, nascence and establishment are guaranteed, and the model assigns more water to vegetative development than to ripening.

1. Introduction

The efficient use of water and energy in agriculture is gaining importance due to a general decreasing tendency of water availability for agricultural uses and increasing energy costs. These aspects condition the viability of irrigation activities in many areas of the world (Ortega et al., 2004; Martínez-Valderrama et al., 2011).

Worldwide, the production of onion (*Allium cepa* L.) is the 3rd most important among vegetables (FAO, 2011). This crop is also important in Castilla-La Mancha (CLM) region, Spain (Fig. 1a) because of its high profitability and its significance in national production (CLM produces 62.7% of the total onion crop in Spain, with the province Albacete the main producer (Fig. 1b; MARM, 2010). After the recent increases in the energy price, energy used for pumping groundwater and for pressurized irrigation systems, the area of onion cultivation has raised from 6825 ha in 1996 (MARM, 1999) to 11,668 ha in 2009 (MARM, 2010), replacing less profitable crops. The recommended irrigation amount for this crop has decreased from 610 mm in 2000 (JCRMO, 1999) to 520 mm in 2012 (JCRMO, 2011), with the objective of decreasing the use of over-exploited groundwater resources (Martín de Santa Olalla et al., 2007). In this way, according to the lysimeter measurements of onion crop carried out by López-Urrea et al. (2009) in the area, the irrigation amounts under no deficit conditions should be around 700 mm.

Due to its importance, a great effort has been put in to improve the water productivity of onion through deficit irrigation (DI). To obtain maximum yield it is necessary to avoid water deficit, especially during the bulb development (Martín de Santa Olalla et al., 2004; Kadayifci et al., 2005; Bekele and Tilahun, 2007). During the vegetative and ripening periods, the crop appears to be less sensitive to water deficit (Shock et al., 2000; Kadayifci et al., 2005; Bekele and Tilahun, 2007), but excessive irrigation during the first period can lead to a delayed and reduced bulb development. DI during late bulb formation greatly reduces yield and the grade of onion (Shock et al., 2000). The treatments which received the greatest volumes

* Corresponding author. Tel.: +34 967 599 200; fax: +34 967 599 269.
E-mail address: alfonso.dominguez@uclm.es (A. Domínguez).

0378-3774/$ – see front matter
http://dx.doi.org/10.1016/j.agwat.2012.06.019

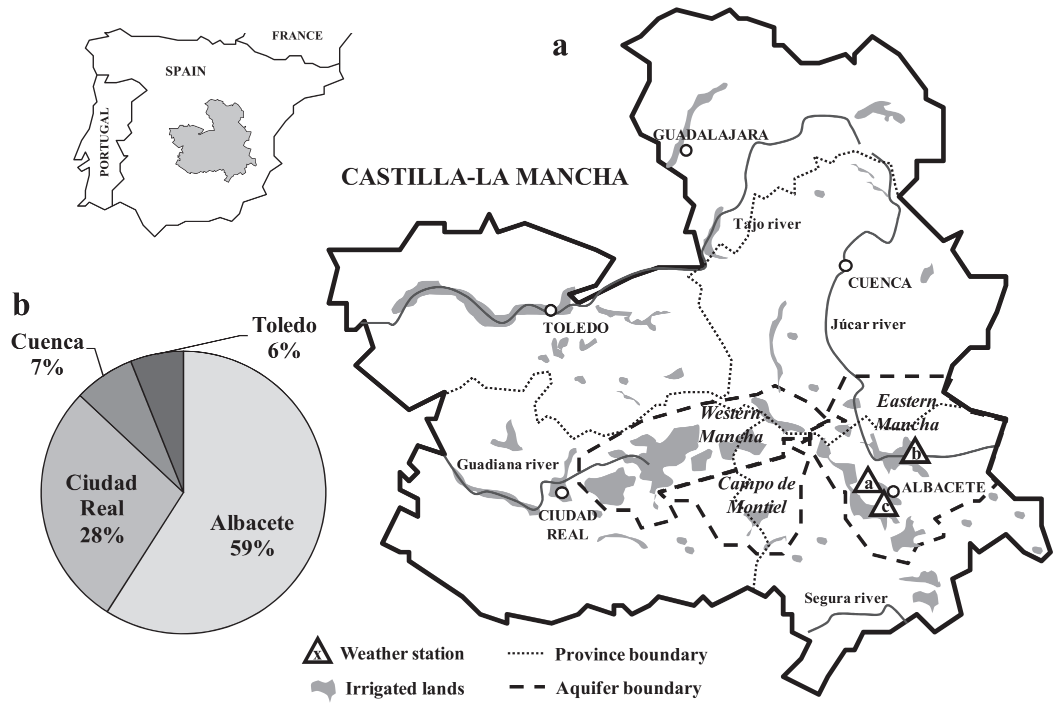

Fig. 1. (a) Distribution of the irrigated lands in Castilla-La Mancha (PNR, 2008) and the weather stations used in the calibration were a: Las Tiesas; b: Motilleja; c: Albacete; (b) percentage of regional onion production per province.

of water during the development and ripening stages yielded harvests with higher percentages of large-sized bulbs, whereas water shortages induced during the growth and bulbification stages lead to higher percentages of small onions (Martín de Santa Olalla et al., 2004). Restricted irrigation during extended periods may negatively affect the conservation of stored bulbs, mainly during the last growth stage (Kumar et al., 2007; Rattin et al., 2011).

Although some authors have simulated onion behavior under different management scenarios, the use of models is still scarce (Brewster et al., 1975; de Visser, 1994; Tei et al., 1996; Greenwood et al., 2001). The MOPECO model (Ortega et al., 2004) was conceived for optimizing the gross margin (GM) of irrigated farms, especially in areas with water scarcity and/or high crop costs. The model also simulates the effect of irrigation uniformity (López-Mata et al., 2010), the use of saline water on yield (Domínguez et al., 2011), and calculates the optimized regulated deficit irrigation (ORDI) strategy that obtains the maximum yield for a certain water deficit target (Domínguez et al., 2012b). For the application in certain areas, MOPECO requires calibrated and validated data on a sufficient number of crops. One area where MOPECO is being calibrated is in the irrigable lands of CLM (Domínguez et al., 2012a). The aim is to develop a Decision Support System, which will be promoted to farmers through the irrigation advisory service (IAS) of CLM (Ortega et al., 2005).

This paper aims to show the processes carried out to simulate an onion crop using MOPECO model under the conditions of the main irrigable areas of CLM. Specific objectives of this work are: (1) to determine the duration of onion growth stages in terms of growing-degree-days (GDD); (2) to calibrate and validate the parameters required for obtaining the yield versus net water (net irrigation + effective rainfall) relationship (Y_a–TW_N); (3) to determine the most suitable irrigation strategy depending on both the availability of water and the commercial objective (sell onions after harvest or store onions to sell at a higher price later); and (4) to obtain the GM versus gross water (gross irrigation + effective rainfall) relationship (GM–TW_G) using Y_a–TW_N.

2. Materials and methods

2.1. Site description

Agriculture in CLM occupies an area of 3,705,436 ha, 554,197 ha of which are irrigated land (MARM, 2010), mainly with sprinkler and drip irrigation systems. The use of irrigation in the area is a result of low average annual precipitation (around 400 mm $year^{-1}$) (CES, 2006). However, reference evapotranspiration values surpass 1100 mm, characterizing the area as semi-arid (Domínguez and de Juan, 2008). Approximately 70% of the irrigable areas of CLM are located close to groundwater sources, given that most surface water resources are used in other regions on the borders (Fig. 1a). The most common crops in these areas are grapes, cereals, garlic, onion, melon, watermelon, pepper, and other crops such as sunflower, potato and alfalfa.

2.2. Field experiments

Data from the field trials by Jiménez (2008) were used for the onion crop simulation. The experiment was conducted in onion fields irrigated with a permanent sprinkler irrigation system located in Madrigueras (39°12′42″N, 1°47′22″W) during the 2003 irrigation season and in Motilleja (39°10′23″N, 1°47′34″W) during the 2005 irrigation season. The two areas are 4 km apart in Albacete province (Spain).

The soils of the experimental plots are representative of the area:luvic calcisol at Madrigueras in 2003 and haplic calcisol at Motilleja in 2005 (FAO, 1998). They have a sandy-loam and a clay-loam texture in the first 50 cm of the soil profile, with estimated available water around 0.09 and 0.13 $m^3\,m^{-3}$, respectively. The effective root depth was 40 cm in both cases. The average conductivity of the saturated soil extract at the beginning of each irrigation season (EC_{ei}) was 0.81 dS m^{-1}, while the electrical conductivity of the irrigation water in the area (EC_{iw}) was 0.85 dS m^{-1} (CHJ, 2004; Domínguez et al., 2011).