Agricultural Water Management 98 (2011) 1451–1461

Contents lists available at ScienceDirect

Agricultural Water Management

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

Deficit irrigation under water stress and salinity conditions: The MOPECO-Salt Model

A. Domínguez[a,*], J.M. Tarjuelo[a], J.A. de Juan[a], E. López-Mata[a], J. Breidy[b], F. Karam[c]

[a] Centro Regional de Estudios del Agua (CREA), Universidad de Castilla-La Mancha, Ctra. de las Peñas, km 3.2, 02071 Albacete, Spain
[b] Department of Plant Breeding, Lebanese Agricultural Research Institute, P.O. Box 287, Zahleh, Lebanon
[c] International Center for Agricultural Research in the Dry Areas, P.O. Box 2897, Aleppo, Syria

ARTICLE INFO

Article history:
Received 15 October 2010
Accepted 26 April 2011
Available online 17 May 2011

Keywords:
Salinization
Leaching fraction
Water stress
AquaCrop
Solanum tuberosum L.
Allium cepa L.

ABSTRACT

In both arid and semi-arid areas the use of saline water for irrigation is a common practice, even though it may cause a drop in crop yield and progressive soil salinization. In order to determine the most suitable irrigation strategy for higher yield, profitability, and soil salinity management of certain crops, the MOPECO-Salt Model has been developed. This model was first validated in the Eastern Mancha Agricultural System in Albacete (Spain) through a test carried out on onion crop in April–September 2009, where the simulated yield was 2% lower than the observed one. The model was then tested at Tal Amara Research Station in the Central Bekaa Valley Agricultural System (Lebanon) using data from a 5-year experiment on the effects of deficit irrigation on two cultivars of potato (Spunta: July–October 2001, and June–September 2002; and Agria: March–August 2004, 2005, and 2007). Furthermore, these results were compared with those obtained through AquaCrop, which does not currently assess crop response to salinity. Differences between observed and simulated yields were lower than 3% for MOPECO-Salt and up to 12% for AquaCrop. According to findings from simulations, the irrigation strategies without leaching fraction employed in both areas are remediable since the off-season rainfall is sufficient to wash out soluble salts supplied with irrigation water. Results showed that as much as 14.4% water could be saved when this strategy was adopted for onion crops.

1. Introduction

Salinity has long been identified as a major threat to agriculture, leading to policies aimed at improving irrigation and drainage practices in many parts of the world (FAO, 2007). In arid and semi-arid areas, where 25% of the irrigated land is currently affected by salts (Arshi et al., 2010), salinity has become a great hindrance for agricultural production. So, a wide range of processes such as seed germination, seedling growth and vigor, vegetative growth, flowering and fruit set are affected by high salt concentration in the soil, ultimately causing poor crop quality and diminished economic yield (Hasegawa et al., 2000; Sairam and Tyagi, 2004; Qadir et al., 2008). With this in mind, it is of utmost importance to address this serious environmental issue.

Many authors have modelled the behaviour of crops when undergoing water or salt stresses (Childs and Hanks, 1975; Letey et al., 1985; Bresler, 1986; Majeed et al., 1994; Castrignanò et al., 1998; Allen et al., 1998; Ferrer-Alegre and Stockle, 1999; García et al., 2006; Pereira et al., 2007). Three of these models were used in this study: Allen et al. (1998) (Model 1) relate actual crop evapotranspiration (ET_a) to soil water and soluble salts content in the root zone. Inputs required in this model are the Readily Available soil Water in the root zone (RAW) and the depletion factor (p), which is a fraction of Total Available soil Water in the root zone (TAW) that a crop can extract from this zone without suffering water stress. According to Allen et al. (1998), the main limitation of this model is the assumption that RAW and p are kept constant for any soluble salts content in the root zone. In order to solve this handicap Pereira et al. (2007) developed a model (Model 2), based on Model 1, which allows balancing the values of RAW and p depending on the variable soil salinity conditions. Finally, García et al. (2006) (Model 3) relate potential evapotranspiration of the crop (ET_m) to osmotic potential and matric pressure head in the root zone.

The MOPECO model (Ortega et al., 2004; López-Mata et al., 2010) is a tool for identifying optimal production plans, and water irrigation management strategies. The model estimates crop yield, and gross margin (GM) as a function of the irrigation depth. Finally, these GM functions are used to determine an optimum cropping pattern and irrigation strategy to maximize the GM on a farm in a specific scenario. A major limitation of the MOPECO model is the fact that it does not contain a salinity module; consequently it should not be used to simulate cases where saline water is used

* Corresponding author. Tel.: +34 967599200; fax: +34 967599269.
E-mail address: alfonso.dominguez@uclm.es (A. Domínguez).

0378-3774/$ – see front matter
doi:10.1016/j.agwat.2011.04.015

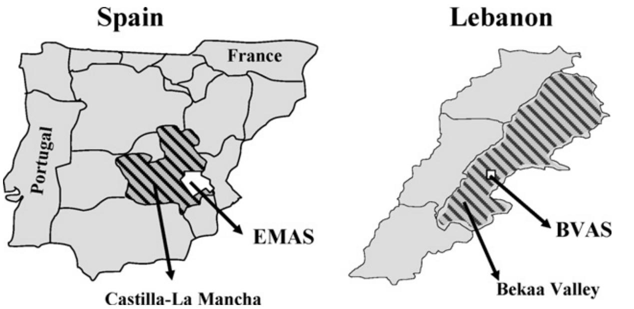

Fig. 1. Location of Eastern Mancha "EMAS" (Spain) and Bekaa Valley "BVAS" (Lebanon) agricultural systems.

for irrigation. This is the case of the Eastern Mancha (EMAS) (Spain) and Bekaa Valley (BVAS) (Lebanon) agricultural systems, where the salinity of the irrigation water may affect crop yields, and where farmers do not apply a leaching fraction (LF) at each irrigation supply, as recommended elsewhere by Doorenbos and Pruitt (1977) and Rhoades (1982), mainly because of the limited available water resources for irrigation in both areas. Therefore, this irrigation management practice may lead to a progressive salinization of the arable lands, which in turn may have negative impacts on the environment and socio-economic conditions of the farmers (Minhas, 1996; De Nys et al., 2005; Darwish et al., 2005). Results obtained in the present study are based on field tests carried out on onion and potato. Many irrigation experiments have shown that these crops are sensitive to water stress (Lynch et al., 1995; Shock et al., 1998; Bekele and Tilahun, 2007; Jimenez et al., 2010) and soluble salts (Wannamaker and Pike, 1987; Patel et al., 2001; Chauhan et al., 2007; Levy and Veilleux, 2007), factors which produce negative effects such as a drop in yield.

The objectives of this paper are (i) to select the most suitable model among the three proposed models for developing the new MOPECO-Salt Model; (ii) to validate the new model under the EMAS conditions, and (iii) to test the new MOPECO-Salt Model under the semi-arid conditions of BVAS in Lebanon. The specific objective is to assess the different irrigation strategies already in use in both areas, where no LF is applied by farmers, using the new proposed MOPECO-Salt Model. The suitability of the irrigation strategies will be evaluated in the light of the results on soil management sustainability and water productivity under saline conditions.

2. Materials and methods

2.1. Description of Eastern Mancha and Bekaa Valley agricultural systems

EMAS belongs to the Júcar River Basin in the Castilla-La Mancha Region (Spain) (Fig. 1). This is a semi-arid climate area with an average annual reference evapotranspiration of 1320 mm and a mean annual rainfall of 377 mm. The irrigated area is about 105,000 ha. Barley and maize are among the most cultivated annual crops. Sprinkler irrigation is commonly used in the area, mainly with center pivot and solid-set systems. About 90% of the irrigation water used originates from the Eastern Mancha aquifer, with an average electrical conductivity (EC) of 0.85 dS m^{-1} (CHJ, 2004) and an average annual irrigation availability of 4400 m^3 ha^{-1} (Domínguez and de Juan, 2008).

Results of a trial carried out at the "Aguas Nuevas" experimental farm located in Albacete (Spain) (38°56′53″N, 1°53′51″W, 690 m above sea level) on onion crop in 2009 (Domínguez et al., 2010a,b) were used for developing and validating the new MOPECO-Salt Model. Climatic series were obtained from a weather station situated within the experimental plots (http://crea.uclm.es/siar/datmeteo/datos_hist.php).

BVAS extends from the western foothills of the Mount Lebanon Chain to the Eastern foothills of Anti-Lebanon Mountains. BVAS has a well defined semi-arid climate with an average annual reference evapotranspiration of 1500 mm and a mean annual rainfall of 592 mm (Karam et al., 2003). Main crops are winter wheat and potato. The latter is cropped during two different growing seasons: March–August and July–October. In the last two decades, the extensive use of groundwater for irrigation purposes has led to a significant depletion in ground resources along with a salinization of agricultural lands, especially where localized irrigation systems are in use without applying a leaching fraction (Darwish et al., 2005).

Data and results of a five-year experiment (2001, 2002, 2004, 2005 and 2007) on potato (Karam et al., 2005, 2009) were used for testing the MOPECO-Salt Model. Climatic series were obtained from a weather station (AURIA 12E, DEGREANE, France) situated within the experimental plots at Tal Amara Research Station in the Central Bekaa Valley (33°51′44″N, 35°59′32″E, 905 m above sea level).

2.2. Model presentation

2.2.1. Model of Stewart et al. (1977)

MOPECO uses the model proposed by Stewart et al. (1977) for estimating crop yield as a function of the ET_a/ET_m ratio in the different growth stages. When $ET_a < ET_m$, the plant suffers from any stress that may cause a drop in yield (actual yield (Y_a) < potential yield (Y_m)).

$$\frac{Y_a}{Y_m} = \prod_{j=1}^{n=4} \left(1 - k_{yj}\left(1 - \frac{ET_{aj}}{ET_{mj}}\right)\right) \quad (1)$$

where Y_a and Y_m are actual and potential crop yields (kg ha^{-1}); n is the number of growing stages (Allen et al., 1998); j is the actual growing stage; k_y is the crop yield response factor; while ET_a and ET_m are seasonal crop evapotranspiration (mm) yielding Y_a and Y_m, respectively.

In this study, low water content and high salt concentration in the root zone were considered stress-causing factors, corresponding to actual evapotranspiration under water stress conditions (ET_{aw}), salinity conditions (ET_{as}), or both stress conditions ($ET_{a\,ws}$).

The first part of the paper consists in selecting a model from the literature that will estimate actual evapotranspiration (ET_a) under water stress and/or saline conditions, which would be replaced in Eq. (1). To achieve this aim, three models were selected.

2.2.2. Model 1

The evapotranspiration capacity of a crop is directly related to the soil water content in the root zone. If soil water content is higher than p (defined as the fraction of TAW that a crop can extract without suffering water stress), then the crop is not subject to water stress conditions. According to Allen et al. (1998), ET_{aw} may be estimated as follows:

$$\begin{aligned} &\text{If TAW} - \text{Dr} \geq (1-p)\text{TAW} = \text{TAW} - \text{RAW};\ \text{then}\ ET_{aw} = ET_m \\ &\text{Otherwise}:\ ET_{aw} = \frac{\text{TAW} - \text{Dr}}{(1-p)\text{TAW}} ET_m \end{aligned} \quad (2)$$

where Dr is the root zone depletion at a given time (mm).

Allen et al. (1998) stipulated that crops may decrease their evapotranspiration capacity if soluble salts existing in the root zone, expressed as electrical conductivity of the soil saturation extract (EC_e), exceed a threshold value of (EC_{et}). The following equation was proposed by Allen et al. (1998) to evaluate the combined effect