AGRICULTURAL WATER MANAGEMENT 85 (2006) 77–84

available at www.sciencedirect.com

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

Simulating the effects of extreme dry and wet years on the water use of flooding-irrigated maize in a Mediterranean landplane

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ARTICLE INFO

Article history:
Accepted 17 March 2006
Published on line 19 April 2006

Keywords:
Flooding irrigation
Climate variability
Maize water-use
Mechanistic modelling
Weather generator

ABSTRACT

The effects of years of extreme rainfall events on maize water-use under traditional flooding irrigation in a Mediterranean landplane were estimated through a simulation assessment; combining a weather generator with an agrohydrological simulation model. Two options: "Fully Irrigation" and "Deficit Irrigation" were considered in the simulations as the extreme water-management situations. Besides, a 2 m depth shallow water table and Free Drainage were considered as the typical extreme situations that can be found at the bottom of the simulated soil layer. Thirty "Dry" (DY) and "Wet" (WY) years were randomly selected from the weather generator output. The model SWAP was used to simulate the relative transpiration (RT), i.e. ratio between actual and maximum maize transpiration, actual maize evapotranspiration (ET_C), percolated water and capillary rising during wet and dry years and for each of the irrigation and bottom condition options. According to the modelling results, average mean RT is about 80% and 90% in dry and wet years, respectively. RT and ET_C variability are very high under dry conditions although such variability is notably reduced if a suitable irrigation option is considered. Capillary rising can play a very important role during dry years in those places where irrigation is not enough, but water table is relatively shallower. On the other hand, a shallower water table can carry out RT reductions during wet years, due to water excess, although these negative effects are comparatively lower than those produced by rain scarcity. Besides, percolated water during wet years is very high, particularly in well-irrigated farms.

1. Introduction

Irrigation is needed to achieve reliable maize yields at the landplanes of Spain and other Mediterranean countries. Flooding irrigation has been traditionally conducted and it is still the most common irrigation method in the Mediterranean area. Due to environmental and water-constraint issues, a quite large irrigation modernisation is being conducted in Spain (Beceiro, 2003), aimed to replace flooding by sprinkler and other more-efficient techniques with governmental aids. However, it usually implies large investments and farmers need to be convinced that modernisation is worthy enough. Maize water-management in Spanish landplanes has been established by farmers through the historical experience

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doi:10.1016/j.agwat.2006.03.010

(Farre, 1998). Flooding irrigation management depends on water-availability in some specific days, as well as on ancient ''water rights'' that are very inefficient under variable climate conditions (Neira et al., 2005).

However, global climate seems to be changing (IPCC, 2001). Olesen and Bindi (2002) predicted reduced cereal productivity in the Mediterranean countries, due to water-availability constraints in a future warmer and drier climate. On the other hand, climate variability and the frequency of extreme event could be incremented in the near future as a consequence of climate change (IPCC, 2001). Weather variability has been estimated as the most important climate-change risk in agriculture (Katz and Brown, 1992; Mearns et al., 1996; Riha et al., 1996; Rosenzweig et al., 2002).

Traditional flooding-irrigation management might be probably not enough to fulfil the crop-water requirements in the near future, particularly if droughts become more frequent. Besides, not only droughts but also heavy rainfalls might affect cropping systems. Rosenzweig et al. (2002) draw attention over the possible water-excess effects on crop yields, as result of extreme rainfall events associated to climate change. Modelling assessments could help to estimate how inefficient flooding irrigation could be under variable weather conditions, as well as to support the decision of where and how to invest in irrigation, taking in account climate variability. These assessments can be done combining climate scenarios and crop-growth simulation models (Sivakumar, 1999; Hoogenboom, 2000).

Several long-term assessments of global-change effects on Mediterranean agriculture appeared in the last years (Guereña et al., 2001; Wolf and Van Oijen, 2003; Villalobos and Fereres, 2004; Chartzoulakis and Psarras, 2005). Most of these predictive assessments considered the positive effects of the future atmospheric CO_2 rising (IPCC, 2001). Nevertheless, recent results point out that these CO_2-due positive effects have been overestimated in modelling approaches (Craft-Brandner and Salvucci, 2004; Ainsworth and Long, 2005), which reduces the reliability of such long-term assessment results for practical decisions concerning irrigation and other crop-management issues.

However, the same modelling tools can be used to estimate the effects of climate variability at a more short term. Agricultural impacts of climate variability rather than long-term climate change impacts have received more attention in the last years (Sivakumar, 2005).

The weather generators have been used in many of the assessments regarding climate effects on agriculture, as well as several other downscaling tools (Hoogenboom, 2000; Wilby and Wigley, 2000). A weather generator produces synthetic daily time series of climatic variables that can be used as input in crop models (Hoogenboom, 2000; Semenov and Jamieson, 2001). The weather generator usually mimics correctly the mean values of the climatic variables but underestimates their variability (Gregory et al., 1993; Mearns et al., 1996; Mavromatis and Jones, 1998; Semenov and Jamieson, 2001; Mavromatis and Hansen, 2001; Wilby and Wigley, 2000).

On the other hand, despite many crop-growth simulation models are currently available, only mechanistic models, i.e. those based on the physical laws of the soil–water–plant–atmosphere continuum, are able to account on all the possible weather, soil and crop management that can be found (Hoogenboom, 2000). According to Eatherall (1997), mechanistic models should be used for assessing climate variability impacts on crop yields, rather than non-mechanistic or statistically based models. Particularly, those models that simulate soil-water movement solving the Richards equation, produce better results than the model based on the ''cascade approach'' (Ritchie, 1998) since they are able to simulate capillary rising, fast and slow drainage and other processes that occur in nature (Gabrielle et al., 1995; Maraux and Lafolie, 1998; Mastrorilli et al., 2003).

Accordingly, this paper is aimed to assess the reliability of maize flooding-irrigation management under the extreme drought and heavy rainfall conditions. The assessment is based on extreme-weather scenarios obtained from a weather generator, used as input of a mechanistic water-use simulation model.

2. Materials and methods

2.1. *General experimental features*

The simulations were conducted at Zaragoza (41° 43′ N, 0° 48′ W, 225 m altitude), which is located in the Ebro Valley, Northern Spain. The climate in the experimental site is Mediterranean semiarid, with mean annual maximum and minimum daily air temperatures of 21 and 8 °C, precipitation of 353 mm, air relative humidity of 74% and average wind speed at 2 m height of 2.4 m/s (Faci et al., 1994).

The soil is Typic Xerofluvent. Cavero et al. (2000) reported some physical and chemical soil properties of the experimental area which comprises texture, soil bulk density and organic matter content.

Although the sprinkler irrigated area has increased dramatically in the last 20 years (ANPC, 2003), flooding irrigation is the most common water-supply technique in the maize growing in the zone. The irrigation timing and water depths in such Mediterranean flooding-irrigation systems are quite variable (Neira et al., 2005). Farre (1998) evaluated ten flooding irrigation managements at different maize stages. A ''Full Irrigated'' (FI) option comprised nine irrigations with an average water depth of 65 mm at each 15 days. On the opposite, a ''Deficit Irrigation'' (DI) option comprised only three irrigation events with the same average depths. The Farre (1998) results were highly dependant on the yearly weather behaviour. However, significant differences between the ''Fully Irrigated'' and the ''Deficit Irrigated'' options were found at all the experimental years. Despite the variability in irrigation managements across the Mediterranean flooding-irrigation systems, most of them fall between these FI and DI options (Neira et al., 2005). Consequently, these two irrigation managements were chosen as the extreme representative alternatives to be evaluated under drought and heavy rainfall conditions.

2.2. *The generated weather scenarios*

A daily climate series of maximum and minimum temperatures, global soil radiation and precipitation were available from 1971 to 2002 at the experimental site. Since maize crop season is comprised between May and October (Farre, 1998),