Agricultural Water Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Agricultural Water Management

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

Assessing yield, water productivity and farm economic returns of malt barley as influenced by the sowing dates and supplemental irrigation

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ARTICLE INFO

Article history:
Received 15 December 2015
Received in revised form 24 May 2016
Accepted 25 May 2016
Available online xxx

Keywords:
Crop transpiration
Dual crop coefficient
Economic water productivity
SIMDualKc water balance model
Stewart's water-yield model

ABSTRACT

The previously field calibrated approach of coupling the SIMDualKc soil water balance model with the Stewart's water-yield model was used to assess the impacts of alternative sowing dates and irrigation schedules upon malting barley (*Hordeum vulgare* L. cv. Publican) yields. To properly support modelling, the study was based upon field observations in a farmers' field during 2012 and 2013 crop seasons, respectively a dry and a wet year. The study aimed at assessing alternative sowing dates and irrigation management in terms of water use, yields, water productivity and the economic water productivity ratio (EWPR) that relates the yield value with the production costs referring to a given total water use. The feasibility of rainfed barley was assessed under a wide range of climatic conditions mainly focusing on the drought years. Results show that in terms of water use sowing by mid-November is advantageous since more rainfall is generally available. In contrast, results in terms of yield, water productivity and farm economic returns, represented by EWPR, show that delaying sowing to early January and using supplemental irrigation is the best alternative for both the dry and wet years, as well as for drought years. Under water scarcity conditions, a trade-off between water use, yield and economic water productivity is advisable; thus, "mild" to "moderate" supplemental irrigation could be adopted since they are profitable but requiring appropriated irrigation management support. Furthermore, results have shown that rainfed barley is not economically feasible in drought years in the study area; however, under wet climatic conditions, rainfed barley could be adopted with caution if late sowing is practiced.

1. Introduction

Barley (*Hordeum vulgare* L.) is the third winter-spring cereal crop in Portugal in terms of production. Particularly for malt, it is mainly produced in the Ribatejo region where it represents 22% of the cropped area with winter-spring cereals and where this study was performed. In the Mediterranean area, barley and most of the winter-spring grains are rainfed cropped. Due to the uncertainty of the amount and time distribution of rainfall throughout the crop season, supplemental irrigation is often required to attain high yields especially when water is applied during the most critical crop growth stages (Austin et al., 1998; De Ruiter, 1999). Considering the interest of farmers for adopting supplemental deficit irrigation, research was developed in farmers fields focusing on wheat (e.g., Pereira et al., 2002; Rodrigues et al., 2003; Rodrigues and Pereira, 2009) and, lately, on malt barley (Pereira et al., 2015). Irrigation management research has various objectives including to support farmers in achieving improved water use and productivity, appropriate economic returns, adaptation to droughts and climate change, and irrigation scheduling using seasonal weather forecasts (Paredes et al., 2015). Several studies have been performed to assess the impacts of various abiotic stresses on barley yields, mainly water stress (e.g. Day et al., 1987; Yau and Ryan, 2013). Water stress impacts on barley yields depend on duration and intensity of the water deficit and the growth stage when it is enforced (Szira et al., 2008; Francia et al., 2011). The most critical stages are likely those between double ridge to anthesis (Cossani et al., 2009) and/or flowering and ear formation (Thameur et al., 2012). Some studies demonstrated that barley grain yield may also be largely influenced by severe water stress imposed throughout the whole crop cycle (Day et al., 1987; Francia et al., 2011). Other

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http://dx.doi.org/10.1016/j.agwat.2016.05.033
0378-3774/

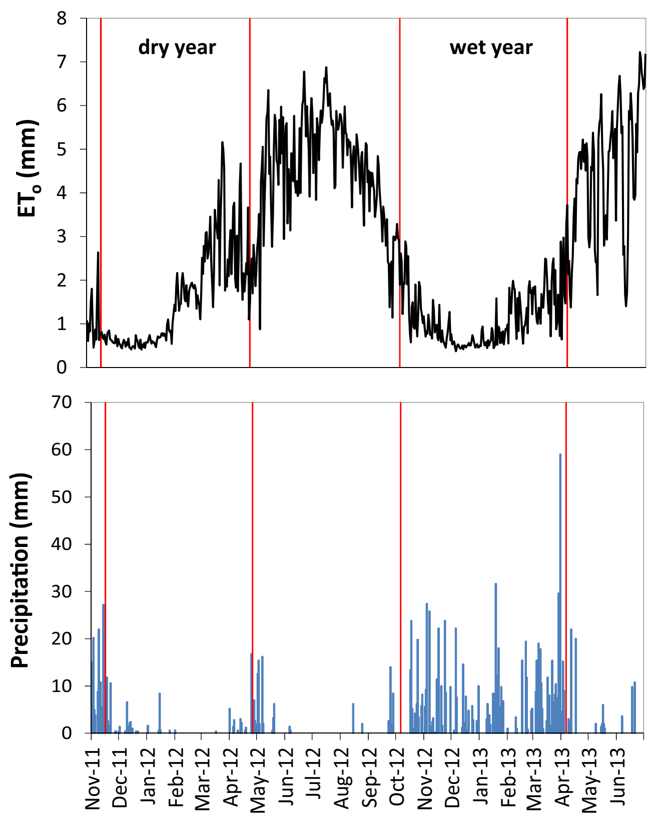

Fig. 1. Daily precipitation (▮) and reference evapotranspiration (ET_o) (—) during the barley seasons of wet (2012) and dry (2012-13) years.

studies have focused on the integrated effects of water and different fertilization rates (Day et al., 1987; Albrizio et al., 2010; Cossani et al., 2012), or the control of water stress through soil management practices (Cantero-Martínez et al., 2003; Fernández-Getino et al., 2015). The quality of barley grain for malt production is highly influenced by soil water availability (Carter and Stoker, 1985; Coles et al., 1991; Verma et al., 2003). In addition, as reported by Forster (2003), irrigation applied late, near harvesting, may cause water-related diseases that reduce the grain quality required for malting. Qureshi and Neibling (2009) reported that the best time for the irrigation to be ceased corresponds to the crop stage of soft dough and that a late irrigation cut-off is detrimental. Thus, irrigation should be ceased few weeks before harvesting.

The sowing date of barley depends upon the climatic and land surface conditions which influence germination and crop establishment, as well as on the rainfall expected throughout the crop cycle, particularly important in case of rainfed barley (Alam et al., 2007; Yau et al., 2011). Selecting dates for sowing may need considering vernalization, although for spring barley varieties this is not required (Saisho et al., 2011). Various studies refer to no-tillage benefices by increasing soil water availability during the first crop stages (Lampurlanés et al., 2002; Morell et al., 2011). Yields may decrease if barley is sown late since it is exposed to higher risks of heat and water deficit during the grain filling period; contrarily, an early sowing and emergence leads to earlier flowering and maturity, allowing to escape from heat and water stress by the late crop season (Yau et al., 2011). Oweis and Hachum (2001) reported on wheat sowing dates influencing the crop water demand. Therefore, it is important to assess the impacts of sowing dates in terms of satisfaction of crop water requirements by rainfall, thus in terms of viability of rainfed cropping or relative to the need of supplemental irrigation. Studies focusing on impacts of sowing dates and relative to adaptation to climate change (e.g., Trnka et al., 2004), are yet lacking in the country but are required for advising farmers and build policies for agricultural water management.

Water management for the malt barley crop requires that, in addition to assessing impacts of sowing date, appropriate selection of supplemental irrigation schedules be performed in order to avoid adverse impacts on yield and grain quality. To support related decisions and to predict barley yields as affected by the sowing date and irrigation scheduling, several modelling approaches may be adopted (Pereira et al., 2015; and quoted studies in there). An example of a crop growth model applied to barley is AquaCrop (Raes et al., 2012; Abi Saab et al., 2015), which has been previously assessed for the study area. However, its results for irrigation scheduling simulation were less good than those of the SIMDualKc model (Rosa et al., 2012); thus, in the present study, the simplified approach of combining SIMDualKc with a modified Stewart's water-yield model was selected because it was positively tested and calibrated for barley using the same data sets of the current study (Pereira et al., 2015).

Considering the above referred, the main objectives of the present study are (1) to evaluate the supplemental irrigation schedules observed during two contrasting rainfall years and to assess related alternative irrigation schedules and sowing dates in terms of water use, yields, water productivity and farm economic returns; (2) to assess the impacts of various sowing dates and alternative deficit irrigation strategies, as well as rainfed conditions, for high climatic demand scenarios; (3) to assess alternative management scenarios aiming at contributing to an adaptation to climate change and climate variability.

2. Material and methods

2.1. Base field data

The present study consists of two main components, field and modelling research. Field studies were carried out in a farmers field with an area of 30 ha. Observed data was used to calibrate and validate the model SIMDualKc as previously described by Pereira et al. (2015). Modeling research consisted in exploring the model using the calibrated parameters and assess the impacts of alternative sowing dates and water management strategies for the same location but extending the use of weather data.

The field is located in Alpiarça (39.27° N; 8.55° W; 24 m elevation), Portugal. According to the Köppen classification (Kottek et al., 2006), the climate is warm temperate (Csa), with dry and hot summers and mild rainy winters, thus a typical Mediterranean climate. A series of 19-years of weather data (1975–1993) from a nearby meteorological station (39.25° N, 8.70°W and 54 m elevation) shows that 73% of the annual precipitation occurs from October to April. Fig. 1 shows the precipitation and the reference evapotranspiration (ET_o, mm) for the studied crop seasons of 2012 and 2013. ET_o was computed with the FAO-PM equation (Allen et al., 1998). The crop seasons under study are clearly contrasting in terms of precipitation, corresponding to a dry year in 2012 and to a wet year in 2013.

The soil in the studied field is a Eutric Fluvisol (FAO, 2006) with a loamy sand texture where most of the sand is fine. Particle size distribution and water retention properties are presented in Table 1. The first two soil layers have a moderate organic matter content of 24.8 g kg^{-1} for the first layer and 9.1 g kg^{-1} in the second layer, which relates to sludge additions and to the incorporation of crop residues from the previous crop associated to direct seeding.

The monitored field was cropped with malting barley (cv. Publican), a spring variety whose sowing period extends from mid-November to mid-January not requiring vernalization. Irrigation