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Distribution of limited irrigation water based on optimized regulated deficit irrigation and typical metheorological year concepts

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ABSTRACT

Under limited availability of irrigation water during the growing season, farmers must avoid a premature depletion of this resource that may lead to a sizeable decrease in yield. Four levels of net irrigation availability were considered for an onion (*Allium cepa* L.) crop cultivated in Castilla-La Mancha region (Spain): 1.0 $I_{N\ ref}$ (typical net irrigation requirements in the area: 743.3 mm); 0.9 $I_{N\ ref}$; 0.8 $I_{N\ ref}$; and 0.7 $I_{N\ ref}$. The available amount of irrigation water was distributed during the growing period by combining the modified optimized regulated deficit irrigation (ORDI) [which determines the actual evapotranspiration (ET_a) and maximum evapotranspiration (ET_m) ratios (ET_a/ET_m) per growing stage that maximize yield for a certain amount of irrigation water] and the typical meteorological year (TMY) methodologies. So, optimized irrigation schedules that reach the optimized ET_a/ET_m ratios per stage and yields were calculated for three TMYs (dry, intermediate, and wet) obtained from a 54-year climatic series (1951–2004). The six months before sowing of each year were analysed to determine if that period was dry, intermediate, or wet. The yield obtained for each level of irrigation availability and the corresponding TMY was considered as the forecasted yield for the current year. Optimized irrigation schedules were corrected during the growing period by replacing the daily climatic data of the TMY by those of the current year. At the end of each growing stage, optimized irrigation schedules were recalculated taking into account the real amount of irrigation water available for the following periods and the forecasted climatic conditions. The effect of this methodology on final yield was simulated by MOPECO (economic optimization model for irrigation water management) during 8 seasons (2005–2012). As a result, onion yields at harvest were approximately 5.1% lower than the forecasted yield at the beginning of the growing period for the different availabilities of irrigation water. As a consequence of premature depletion of irrigation water, only 3 of 24 analysed scenarios reached excessive deficit during the last stage.

1. Introduction

In areas with water scarcity like the Hydrogeological Unit "Eastern Mancha" (HUEM) (Spain) (Fig. 1), farmers are not allowed to use more water than assigned by the water authority at the beginning of the irrigation season. In consequence, during dry years exists a risk of premature depletion of available water that may lead to a sizeable decrease in both yield and profitability of the farms.

The suitable distribution of a limited amount of water during an irrigation season requires a methodology that estimates the climatic conditions affecting the crop in the future and may advise about the most proper distribution of water during the growing period. In this paper, typical meteorological year (TMY) (Hall et al., 1978) and optimized regulated deficit irrigation (ORDI) strategy (Domínguez et al., 2012a) have been merged. TMY represents the conditions considered "typical" over a long time period and was adapted by Domínguez et al. (2013) for forecasting irrigation schedules. A TMY consists of 12 months statistically selected from individual years and concatenated to form a complete year, resulting in a perfect correlation among the daily values of the climatic variables (*i.e.* temperature, rainfall, and radiation). This methodology may be used for improving the management of irrigable areas through a better design of irrigation systems, the estimation of the typical irrigation requirements of crops, or the determination of the irrigation demand peak of an irrigators association. The ORDI strategy maximizes yield for a certain water deficit target by determining the ET_a/ET_m ratios to be applied at each growing stage. However, under a limited amount of available irrigation

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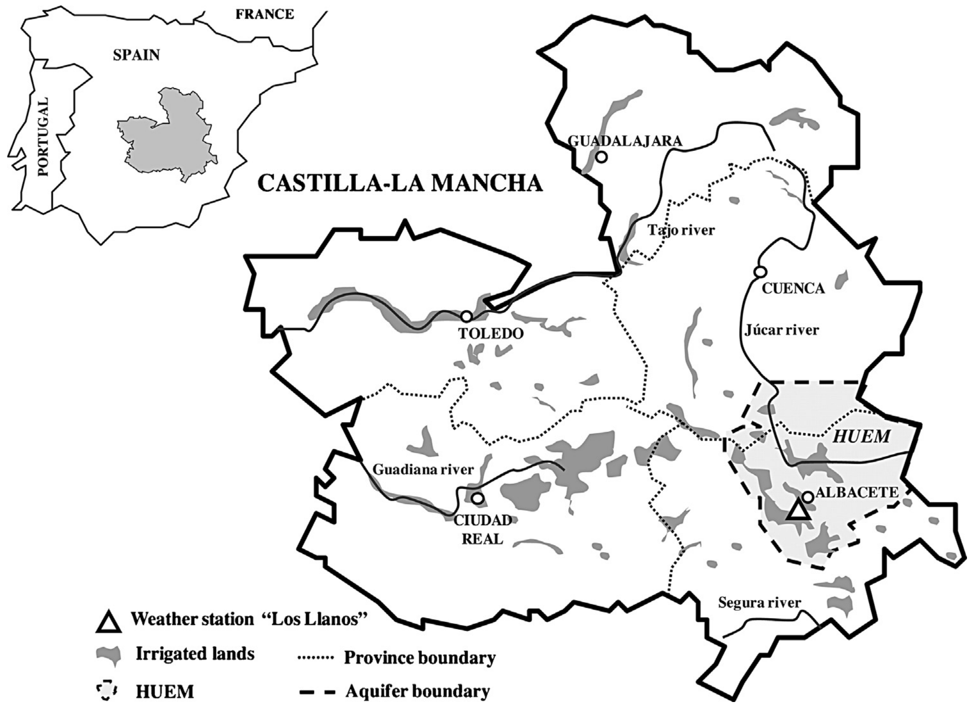

Fig. 1. Distribution of the irrigated lands in Castilla-La Mancha and Hydrogeological Unit Eastern Mancha (HUEM).

water and unknown climatic conditions the higher ET_a/ET_m ratios may be not reached, or some water may be not used. Therefore, a modification of this methodology is required.

The use of models for testing new methodologies may be of interest as a preliminary step before their implementation under real conditions. The MOPECO (economic optimization model for irrigation water management) model was conceived for optimizing the gross margin (GM) of farms through a better use of irrigation water (de Juan et al., 1996). MOPECO has been calibrated in several irrigable lands of the world: Bekaa Valley in Lebanon (Domínguez et al., 2011); Fortaleza and Rio de Janeiro in Brazil (Leite et al., 2014; Carvalhoa et al., 2014); and San Luis in Argentina (Garbero et al., 2014). In Castilla-La Mancha (CLM) region (Spain), this model has been calibrated for several crops such as maize (*Zea Mays* L.) (Domínguez et al., 2012a), garlic (*Allium sativum* L.) (Domínguez et al., 2013), melon (*Cucumis melo* L.) (Leite et al., 2014), and onion (*Allium cepa* L.) (Domínguez et al., 2012b).

Onion is a relevant crop in CLM due to its high profitability and because 63.1% of national production is cultivated in this region (MAGRAMA, 2013). The irrigation amounts in the area under no deficit conditions should be around 700 mm (López-Urrea et al., 2009a). Results of several deficit irrigation (DI) experiments (Shock et al., 2000; Martín de Santa Olalla et al., 2004; Kadayifci et al., 2005; Bekele and Tilahun, 2007) indicate that to obtain maximum yield it is necessary to avoid water deficit, especially during the bulb development, while during the vegetative and ripening periods the crop appears to be less sensitive to water deficit.

The aim of this work was to develop a methodology able to advise farmers with limited availability of irrigation water to reach the most efficient distribution of this resource during the growth cycle, minimizing the loss in yield resulting from using up assigned water resources too early in the crop cycle. The specific objectives were: (1) to develop a methodology able to estimate irrigation requirements of the crops at the beginning of the irrigation season based on TMY. (2) To develop a methodology based on ORDI for distributing allotted irrigation water throughout the growth cycle, thereby minimizing loss in yield from using up assigned irrigation water. (3) To merge both methodologies and test them on an onion crop in the HUEM using MOPECO model. (4) To analyse the results in terms of yield and gross margin.

2. Materials and methods

2.1. Site description

The HUEM occupies an area of 8500 km^2 and supplies water for irrigation to about 105,000 ha (Fig. 1) mainly provided with sprinkler and centre pivot systems, and for urban consumption, including industrial demand, to a population of over 275,000 equivalent inhabitants. Since the 1950's decade, the average annual precipitation (P) is 400 mm year^{-1}, distributed from September to June, and reference evapotranspiration (ET_o) is high (> 1100 mm year^{-1}), characterizing the area as semi-arid. Most irrigated crops are sown between January and May, and rainfed crops are sown between September and November. The most common crops in the area are grapes (*Vitis vinifera* L.), cereals [mainly barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.)], garlic, onion, and other crops such as sunflower (*Helianthus annuus* L.), potato (*Solanum tuberosum* L.) and alfalfa (*Medicago sativa* L.) (Domínguez and de Juan, 2008).

2.2. MOPECO description

The aim of MOPECO is to maximize GM through the efficient use of irrigation water. A set of data (Fig. 2) is required for the simulation of the optimal "Yield *vs.* Total Net Water" (Y *vs.* TW_N), function of each crop under the climatic conditions of a certain year. In this function, TW_N = net irrigation (I_N) + effective rainfall (P_e). To obtain Y *vs.* TW_N, the model simulates a range of deficit irrigation schedules using the optimized regulated deficit irrigation (ORDI) methodology, considering the effects of irrigation uniformity (López-Mata et al., 2010) and electrical conductivity of water (Domínguez et al., 2011) on yield. The Y *vs.* TW_N function is translated into "Yield *vs.* Total Gross Water" (Y *vs.* TW_G), where TW_G = gross irrigation (I_G) + P_e, to include the application efficiency of the irrigation system. The GM *vs.* TW_G function is then calculated