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Effects of irrigation uniformity on yield response and production economics of maize in a semiarid zone

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ABSTRACT

Optimized irrigation scheduling to better match applied water to crop requirements can reduce the consumptive use of water and energy, improve water use efficiency, and increase gross profit margin. However, the distribution uniformity of applied irrigation can modify the way reduced water applications influence field-averaged performance, especially for crops sensitive to water stress as maize, in which the most sensitive stages are those related with reproduction and grain formation. We evaluated the effect of irrigation uniformity on the yield and profitability of maize (*Zea Mays* L.) in Albacete, Spain in two adjacent sectors equipped with a solid set sprinkler irrigation system of a field managed according to FAO-56 methodology throughout the growing season to maximize grain yield without water stress (Sector S1) or irrigation scheduling determined by an experienced producer (Sector S2). Irrigation uniformity was evaluated using catch cans in both fields and grain yield was harvested within zones exhibiting 75% (Z1), 100% (Z2), and 125% (Z3) of area-averaged volume applications throughout the year. The average coefficient of uniformity (CU) in both sectors (S1 and S2) was 83.5%, and the net amount of applied irrigation water totaled 709 mm in S1 and 832 mm in S2. Average grain yield in sector S2 approached the maximum expected yield of 18.4 Mg ha^{-1} and exhibited no significant differences in yield among zones. In contrast, sector S1 exhibited significant yield differences ($p < 0.05$) among zones with a measured yield in Z3 of 18.5 Mg ha^{-1} and a yield reduction of 1.6 Mg ha^{-1} and 4.0 Mg ha^{-1} in Z2 and Z1, respectively. Consequently, the area-averaged yield in S1 was 8% less than in S2. This last treatment was positively influenced by a higher amount of irrigation water supplied to the crop (17%), which decreased the effect of low CU (83.5%). The grain yields simulated by MOPECO for each monitoring zone within the sectors exhibited similar magnitude and trends. Because of these yield differences and the relatively low cost of irrigation water, area averaged gross margin in S1 was 18% less compared with S2. Simulations with MOPECO over a range of CU's demonstrated that improved irrigation uniformity increased area-averaged yields and gross margin when following S1 instead of S2 strategy. The main innovations of this work were to quantify the effect of irrigation uniformity on the gross margin of a maize crop, and to highlight that in arid and semiarid areas with water scarce conditions, it is a better strategy to improve the irrigation uniformity than supply a higher amount of irrigation water to mask the lack of uniformity.

1. Introduction

Increasing world population, risks of floods and droughts associated with climate change, and demands for fresh water for urban and environmental services are leading to a decline in water resources available for agriculture (Fallon and Betts, 2010). This calls for an improvement in the efficiency and productivity of water used in agriculture to ensure sustainable production of food and fiber. Improvements in the application efficiency of irrigation water within the framework of precision farming is one approach that has the potential to increase productivity yet reduce the environmental impact of irrigated agriculture (Monaghan et al., 2013; Smith et al., 2010).

Smith et al. (2010) proposed that a precision irrigation system permits (i) the determination of the time, amount, and spatial pattern of the next irrigation water application to maximize yield, water use efficiency or profitability, (ii) the regulation of the applied volume as close as possible to what is recommended, (iii) the estimation of the magnitude and spatial pattern of the irrigation applications based on

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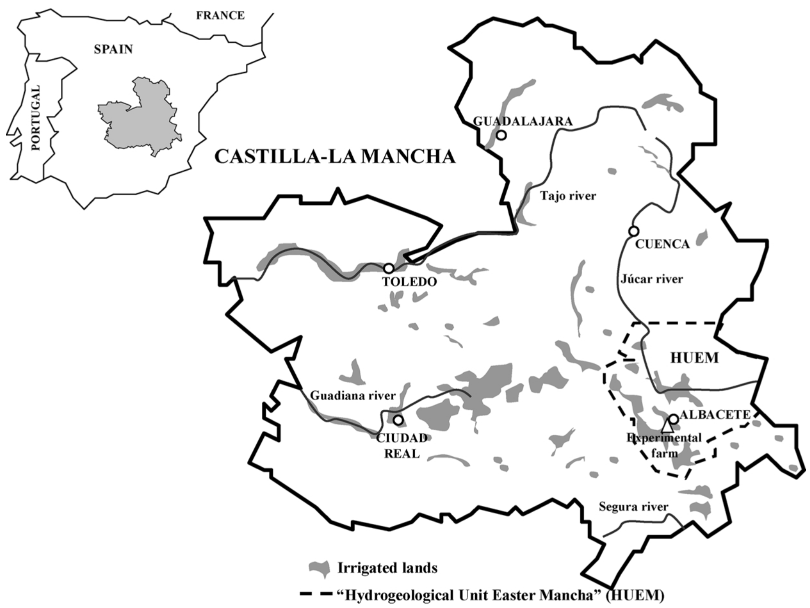

Fig. 1. Location of the study area.

direct measurements or simulations, and (iv) uses these responses as feedback to plan the next irrigation. Improving the use of water, energy, and production practices therefore requires a holistic approach using tools and models that consider all the factors that influence crop response.

Among others, tools such as DSSAT-CSM (Jones et al., 2003) or ISAREG (Pereira et al., 2003) can facilitate water savings and the elaboration of farm-level cropping strategies with the objective of maximizing the productivity of water and minimizing environmental impacts. However, these models do not take into account the uniformity of irrigation in their simulations. The lack of uniformity may cause the decrease of yield in the areas of the plot receiving a lower amount of water. Consequently, this effect decreases the water and economic productivity (López-Mata et al., 2010).

Castilla-La Mancha (Fig. 1) is a semiarid region of Spain which depends on groundwater resources for irrigation. The increasing price of the energy required for pumping water from the aquifers and the use of pressurized irrigation systems, make necessary the use of decision-making tools that incorporate pumping and energy costs into water management to optimize profitability. MOPECO (Ortega et al., 2004) (model for the economical optimization of irrigation water) has been calibrated for the principal crops cultivated over the Eastern Mancha aquifer (Fig. 1) (maize, barley, wheat, onion, and garlic) using data from full and deficit irrigated field studies. Yield curves as a function of applied irrigation depths for distinct years are determined for a typical meteorological year (Domínguez et al., 2013) generated using historical climate data, and the use of regulated deficit irrigation optimized for each crop growth stage (ORDI) (Domínguez et al., 2012b). Depending on the irrigated area and the total water available for each application, as well as economic data associated with the farm and selected crops, MOPECO helps determine the planted acreage and the level of deficit irrigation applied at each crop growth stage for each crop to maximize farm profitability. Moreover, when the irrigation uniformity is lower than 100%, its effect on crop yield can be considered during the irrigation scheduling by using the coefficient of uniformity module developed for MOPECO (MOPECO-CU) by López-Mata et al. (2010).

The objectives of this work are to: (i) evaluate the effect of the uniformity of sprinkler irrigation applications on the yield and economic profitability of maize using two irrigation scheduling management in the semiarid environment and soils of the Eastern Mancha aquifer in the Province of Albacete, Spain; and (ii) utilize MOPECO to simulate the effect of the uniformity of irrigation applications and determine suitable irrigation strategies for maize cultivation in the zone in relation to pumping and delivery costs of water.

2. Materials and methods

2.1. Study area

The study was carried out during the 2016 growing season in a field within a collective irrigation network with managed allocations, located in Aguas Nuevas, Albacete in Castilla – La Mancha Region, Spain (38°52′59″ N, 1°57′39″ W). The irrigated area lies within the Hydrogeological Unit Eastern Mancha (HUEM) that occupies an area of 8500 km^2 (Fig. 1) and supplies irrigation to more than 110,000 ha, 95% of which are pressurized systems (principally solid set sprinkler and surface drip), with an average annual water allocation of 4000 $m^3\,ha^{-1}$(JCRMO, 2016).

The study area has a semiarid and temperate Mediterranean climate (Papadakis, 1966). The average daily maximum temperature is attained during the summer (33 °C), with a large seasonal variability in mean daily temperatures (3.8 °C in January and 24.4 °C in July). The mean annual precipitation is 360 mm (principally concentrated in the autumn and spring months) and mean cumulative annual reference evapotranspiration (ET_o) is 1300 mm. The soil within the field site is very uniform and is classified (USDA, 2006) as a Torriorthent with a petrocalcic horizon at a depth of 0.4 to 0.6 m, and a clay loam in the upper horizon (300 g kg^{-1} clay and 350 g kg^{-1} sand) with low to medium levels of soil organic matter. According to the soil and water analysis, no salinization problems were detected. The amount of fertilizers applied to the crop was the typical in the area (300 kg ha^{-1} of Diammonium Phosphate (18-46-0) in seeding, 200 kg ha^{-1} of urea (N 46%) in June, and 70 kg ha^{-1} of nitrogen solution (N 32%) in July. The study site consisted of a 2.9 ha level field with two irrigation sectors of equal area, which were independently irrigated. The portion of the plot receiving irrigation water from both sectors was considered as border between the two treatments. The field was equipped with a (fixed) solid set sprinkler irrigation system with buried laterals and sprinkler heads spaced 17.3 × 14.7 m. Each sector was comprised of 72 sprinklers distributed along six laterals with twelve sprinklers per lateral, each tied to the submain at the center of each lateral to permit good application uniformity. Impact sprinkler heads (Agro 35, Cometal, Inc.,