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Research Paper

Real farm management depending on the available volume of irrigation water (part I): Financial analysis

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ABSTRACT

The MOPECO model tries to maximize the gross margin of farms through a more efficient use of both the irrigable land and the irrigation water. The objective of this work was to compare the profitability of a real irrigation farm managed following two different strategies. The Traditional strategy (T) consisted in applying full irrigation (F treatments) to a distribution of three crops (barley, maize, and onion) considering several volumes of irrigation water (from 1000 up to 8000 m^3 ha^{-1}) and four scenarios of harvest sale price. Depending on the availability of irrigation water, the MOPECO strategy (M) consisted in applying to the same crops full irrigation or the combinations of water deficit per growing stage determined by the optimized regulated deficit irrigation (ORDI) methodology developed for this model (O treatments). The optimal global deficits calculated by MOPECO for these crops were: 70% ET_m for barley, 90% ET_m for maize, and 90% ET_m for onion. The experiment was conducted during years 2014 and 2015 in the semiarid province of Albacete (Spain). For low availabilities of irrigation water (between 2000 and 5000 m^3 ha^{-1}) the M strategy reached a profitability up to 8.2% higher than T in the most favorable scenario. This value is similar to the predicted by MOPECO for the average conditions of the area. In the rest of scenarios, the profitability was lower than expected due to the drought conditions of the two experimental years, the unfavorable climatic conditions during 2015 for onion and maize, and the prices progression during both seasons. MOPECO may also be used for decreasing the amount of pumped water from the aquifer (around 43.9 hm^3 $year^{-1}$ for average conditions), achieving the same profitability than the T strategies.

1. Introduction

Farms are businesses that intend to get profits through the production of food. This sector is highly conditioned by numerous economic (i.e. harvest price, labor costs...), political (i.e. customs duty, production subventions, laws for the protection of the environment...), social (i.e. food security, maintain rural population...), technical (i.e. machinery, crops...), and environmental (i.e. climate, soil, diseases...) factors.

In arid and semiarid areas, the lack of water resources for irrigation is a relevant determinant for agricultural production. Moreover, the progressive price increase of the energy required for supplying irrigation water to crops (MINETUR, 2015), as well as the low price of harvests in the international market (FAO, 2016), are conditioning the profitability of irrigated farms in these areas.

Maximum yield is reached keeping crops under optimal environmental conditions, suitable water and nutrients supply, and free of pests and diseases. However, the water productivity may increase by causing stress to crops through a certain level of water deficit (Chai et al., 2016). Crop sensitivity to water deficit depends on the developmental stage (Doorenbos and Kassam, 1979). For the same total irrigation depth, the final yield will be higher if water stress is decreased during the most sensitive growth stages, restricting the irrigation in other stages. This technique is called Regulated Deficit Irrigation (RDI) (English and Raja, 1996), which implies control of the water stress level in relation to crop yield. In water scarce areas, this methodology may be relevant in both economic and productive terms. Nevertheless, compared with the traditional irrigation strategy consisted on supplying crops their full irrigation requirements, this methodology is difficult to be used by farmers and technicians. Therefore, the productive sector requires tools that advise it in the management of farms and deficit irrigation (Le Gal et al., 2011; Chai et al., 2016).

MOPECO model (Ortega et al., 2004) was conceived for optimizing the gross margin (GM) of irrigated farms, especially in arid or

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semiarid areas with water scarcity and/or high crop costs that may affect the profitability of agricultural activities. The model determines the area and the amount of water to be dedicated to each crop for maximizing the GM of a farm, depending on the availability of both irrigable land and volume of irrigation water (López-Mata et al., 2016). The volume of irrigation water is translated into full irrigation or into the level of deficit that must be reached at the end of the cropping period. In this last case, the ORDI (optimized regulated deficit irrigation) methodology determines the level of deficit to be applied at each development stage in order to reach the maximum yield for that global deficit at the end of the cropping period (Domínguez et al., 2012b). This model has been calibrated for the main extensive crops in Castilla-La Mancha (CLM) (Spain) as maize (Domínguez et al., 2012a), onion (Domínguez et al., 2012c), and barley (López-Urrea et al., 2017) among others.

The aim of this study is to improve the gross margin of a real farm with a limited amount of irrigation water and dedicated to cultivate barley (*Hordeum vulgare* L.), maize (*Zea mays* L.), and onion (*Allium cepa* L.) by using the strategies of irrigation management proposed by MOPECO. The specific objectives of this work are: (1) to determine the optimal distribution of crops according to the availability of irrigable land and volume of irrigation water, (2) to determine the irrigation strategy that maximizes the profitability of the farm for each crop, and (3) to compare the results obtained by the strategies proposed by MOPECO with the results obtained by the traditional management of the crops (full irrigation).

2. Materials and methods

2.1. Site description

The agricultural area of CLM consists of 3,764,930 ha, 507,697 ha of which are irrigated land (MAGRAMA, 2015). Although the percentage is only 13.5%, compared to the national average of 28.4% (MAGRAMA, 2015), irrigated land plays an important social and economic role in the region, as this activity generates 40% of the regional agrarian income (JCCM, 2008). The use of irrigation in the area is a result of low average annual precipitation of about 400 mm $year^{-1}$ (CES, 2006). However, reference evapotranspiration values surpass 1100 mm, characterizing the agricultural area as semiarid (Domínguez and de Juan, 2008). For this reason, 1595 hm^3 of water were used for irrigation in 2013 (INE, 2016), making up more than 87% of regional water consumption. This provides insight on the importance of reaching a high water productivity in this sector.

About 70% of the irrigable land of CLM are located over groundwater sources, given that mostly surface water resources are used in other regions on the borders. The most common crops in these areas are grapes, cereals (maize, barley, and wheat), garlic, onion, melon, watermelon, pepper, and other crops such as sunflower, potato, and alfalfa.

2.2. The water management in the Hydrogeological Unit Eastern Mancha

One of the main irrigation areas in CLM is the Hydrogeological Unit Eastern Mancha (HUEM) that is located in the Júcar basin (Fig. 1). The area of the HUEM is 8500 km^2 with 100,000 ha of irrigable land, being 4000 $m^3\ ha^{-1}\ year^{-1}$ the average availability of irrigation water (Domínguez and de Juan, 2008). The institution in charge of managing the water resources in the Júcar basin is the “Confederación Hidrográfica del Júcar” (CHJ), which depends on the Spanish Ministry of Agriculture, Fishery, Food, and Environment (MAGRAMA). In order to reach an integrated management of water in the HUEM, the CHJ works together with the “Junta Central de Regantes de la Mancha Oriental” (JCRMO) that represents all the water users (i.e. farmers, local government, industries, etc.).

In order to avoid the overexploitation of the Eastern Mancha aquifer, every year the CHJ determines the maximum volume of groundwater that is possible to pump for irrigation according to the progression of the piezometric levels. Therefore, the available volume for irrigation is variable every year and the JCRMO is the institution in charge of distributing this amount of water among its associates (JCRMO, 2013).

Moreover, the JCRMO is also in charge of monitoring the suitable use of the assigned resources by the users. Thus, before the beginning of the irrigation season, all the farmers must submit their “Exploitation Plan” (EP) for its approval. In this document, farmers state the crops they are going to cultivate, the total area dedicated to each crop, and the cadastral reference of the plots where they will be cultivated. The theoretical consumption of irrigation water of each EP (calculated as the addition of the area of each crop multiplied by its estimated irrigation consumption) must be equal or lower than the amount of water assigned by the JCRMO to each individual farmer. Therefore, the control of water is performed through limiting the irrigable area.

With this strategy of management, it is not possible to know the real volume of water used by each farmer and supplied to each crop. Anyway, these volumes are assumed to be close to the average full irrigation requirements of the crops in the area. Of course, during warm and dry years, the total volume of water supplied to crops is higher than the one established by the CHJ at the beginning of the season. On the contrary, this unbalance is made up for cold and wet years and, if necessary, by the annual adjustments established by the CHJ.

Progressively, some producers are installing flow meters in their farms for measuring the real amount of water used by their irrigation systems. This option allows them to cultivate and irrigate as many areas as they consider without fulfilling the restrictions of the EP. Nevertheless, they cannot use a higher volume of water than the one assigned by the JCRMO at the beginning of the irrigation season, neither during warm and dry years. This is the main inconvenience of this option, and for that reason, the majority of the farmers prefers the EP methodology.

2.3. Field experiments

The experiment was conducted during 2014 and 2015 in the farm “Balsillas” (UTM coordinates: X 561,095; Y 4,344,568), located in the province of Albacete (Spain). (Fig. 1). The irrigable area consists of 240 ha equipped with centre pivot and permanent solid set systems, which supply groundwater from the Eastern Mancha aquifer. In the farm, there is a reservoir with a capacity of 15,000 m^3 and four wells that provide an instant flow up to 350 $L\ s^{-1}$. Soils are not deep (<40 cm) and the texture is sandy-clay-loam, with a water content between field capacity and wilting point equal to 1.18 mm cm^{-1}. The electrical conductivity of the irrigation water is the usual in the area (0.8 $dS\ m^{-1}$).

Three common crops were selected for the experiment: barley (Scarlett cv.), maize (LG 30.681 cv.), and onion (Valero cv.). In both years, the irrigation system was permanent soil set system. Each crop was managed following two irrigation strategies: 1) full irrigation (F), which is the traditional management in the area; and 2) deficit irrigation (O), by using the optimized regulated deficit irrigation (ORDI) strategy proposed by Domínguez et al. (2012b).

The low climatic variability in the area (Domínguez et al., 2013) allowed to determine the irrigation scheduling by using the data registered by the weather station “El Sanchón”, placed 12.1 km far from the farm. This station belongs to the national network of the agroclimatic information system for irrigation (SIAR, 2016) managed by the MAGRAMA (http://eportal.magrama.gob.es/websiar/