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Adaptive strategies of on-farm water management under water supply constraints in south-eastern Spain

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ABSTRACT

The study analyses the effect of irrigation water constraints on-farm management in the Campo de Cartagena Irrigation District (south-eastern Spain), which is characterised by a semi-arid climate with a marked structural water deficit. The methodology applied was the comparative assessment of management indicators during two periods with very differing water availability. A set of performance indicators was selected and calculated to assess the effects on on-farm water management and productivity.

The results indicate low productivity sensitivity to water supply constraints since the farmers adopt a number of adaptive strategies, such as intensifying the extraction of brackish groundwater, reducing the irrigated surface area of short-cycle crops, applying deficit irrigation, and even desalinating brackish groundwater in the more sensible to salinity crops. As a consequence of managing water with a greater salinity the leachable fraction needed is increased, giving rise to greater irrigation requirements. Moreover, the greater salinity of the irrigation water causes lower yields in the majority of crops. Although these adaptive strategies let the farmers maintaining their activity under water scarcity periods, their effect in the groundwater and soil salinization as well as in the crop production costs and yields can be unsustainable in the mid-long term.

1. Introduction

Agriculture must face the challenge of supplying the increasing demand for food resulting from current population growth rates. In the current way, without technical progress and agricultural intensification, agriculture would need an area equivalent to one-half, and two-thirds of the current terrestrial land area by 2030, and 2070, respectively (Schneider et al., 2011). The availability of irrigation water is another factor which limits the growing production of foodstuffs, especially in arid and semi-arid zones, where water is scarce and to a great extent will diminish further still as a consequence of climate change. In this sense, agriculture already demands between 60 and 90% of the fresh water in the Mediterranean area, reaching a total of 87% in the south east of Spain (Grindlay et al., 2011). In the light of such perspectives it becomes clear that it is essential to optimise the management of irrigation water, especially in arid and semi-arid zones.

Benchmarking is a technique which seeks the optimisation of production systems; the tool used for this is the comparative assessment of different types of indicators. The principal guidelines for the application of benchmarking techniques in irrigation were promoted by the World Bank (Malano and Burton, 2001). Subsequently, other authors (*e.g.* Córcoles et al., 2010; Uysal and Atis, 2010; Pereira et al., 2012; Borgia et al., 2013) have progressively proposed new indicators, or have revised the existing ones to complete, improve and facilitate both the analysis as well as the interpreting of results.

The application of benchmarking techniques has also been extended to the search for better working practices at plot level (Lacy, 2011); this objective has led to the need for new indicators to be defined. In this sense, the annual relative irrigation supply (ARIS) is the most frequently used indicator to analyse on-plot water management efficiency for different crops and irrigation systems (Salvador et al., 2011; Kittas et al., 2012; Moreno-Pérez and Roldán-Cañas, 2013). However, as will be seen below, it poses certain vagueness when interpreting the results. It is also habitual to analyse the on-plot water productivity (Fernández et al., 2007; Al-Said et al., 2012), to thus evaluate the competitiveness of farms using indicators such as the crop yield per annual irrigation water application (WP_Y); the output per unit annual irrigation water application (WP_{VP}); or the gross margin per unit annual irrigation water application (WP_{GM}).

In addition to comparative studies, benchmarking can also be applied to the analysis over time of the effects of certain processes in a specific irrigable zone. García-Vila et al. (2008) studied the impact of water scarcity in the agriculture of an Irrigation District

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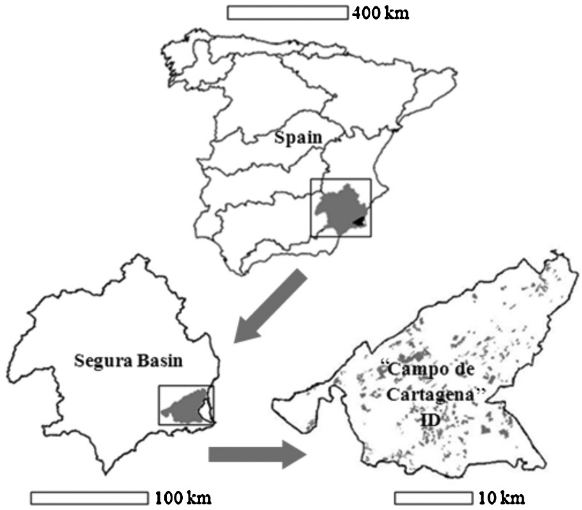

Fig. 1. Location of the "Campo de Cartagena" Irrigation District and the surveyed plots (Segura Basin, Spain).

(ID) in the south of Spain. To do so they analysed the evolution of the crop pattern, of the irrigation management, and ultimately, the strategies employed by the farmers in periods with water supply constraints. The effect of water scarcity on irrigation productivity and the strategies adopted by the farmers have also been analysed by other authors employing different types of indicators (Quiroga and Iglesias, 2009; Lawes and Kingwell, 2012; Serra and Pons, 2013).

The objective of the present work is to analyse the effect of water scarcity on the management of irrigation farms in the south east of Spain, as well as the impact of farmers' adaptive strategies on water use efficiency and farm productivity. The study will specifically be developed in the Campo de Cartagena ID, located in the Segura River Basin, one of the most water stressed basins in the Mediterranean (MED WS and D WG, 2007). To this end, the irrigation water management has been characterised by means of the application of plot-level indicators for the principal crop groups found in the studied zone, and for two periods of time in which there have been major differences in water availability; 2011, a year representative of a normal water supply; and 2008, a year in which there was a major constraint on the supply of water. The comparative evaluation of indicators for those selected periods was the followed methodology. It should be highlighted a novel proposal for calculating and managing the ARIS indicator, so that the information obtained is improved and interpreting the results proves easier, especially for zones with problems of water scarcity and low quality irrigation water.

2. Methodology

2.1. Study zone

The Campo de Cartagena ID is located in south-eastern Spain (Fig. 1). The climate is Mediterranean semi-arid, with an average annual rainfall of 300 mm and a mean annual temperature of 18 °C. The irrigable surface area amounts to some 41,065 ha, of which a total of 32,166 ha were irrigated in 2011. Additionally, due to the need to administer the scant water resources available, the Campo de Cartagena ID has been extensively modernised, and has become a reference in water saving technologies, such as localised irrigation systems, which are used in around 95% of the farms, and information and communication technologies, which are used for the collective water management (Soto-García et al., 2013a). An analysis of global performance indicators dynamic over time at the

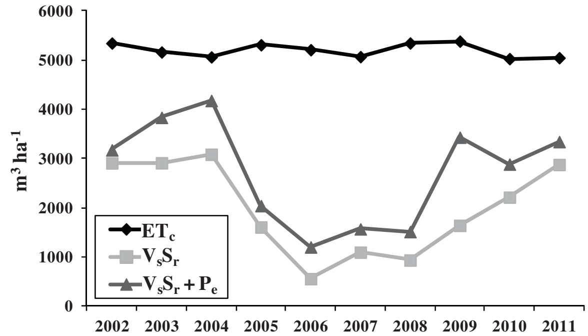

Fig. 2. Evolution of the crops evapotranspiration (ET_c), the irrigation water supplied to users by the ID (V_sS_r), and the V_sS_r plus effective rainfall (P_e), in the period 2002/2011.

Campo de Cartagena ID management level was already reported by Soto-García et al. (2013c).

The theoretical supply, which principally comes from central Spain through the Tagus-Segura water transfer (Soto-García et al., 2013b), is 3500 m^3 ha^{-1} $year^{-1}$.The annual evolution of the water supplied by the irrigation district (V_sS_r) between 2002 and 2011 is shown in Fig. 2. It can be seen that: (1) the theoretical quota of water was not reached in any of the 10 years; (2) the year 2008 corresponds to the third year of a period of major water supply constraints (V_sS_r of 936 m^3 ha^{-1}, less than 30% of the theoretical quota), while 2011 is considered to be a normal supply year (V_sS_r of 2878 m^3 ha^{-1}, more than 80% of the theoretical quota); and (3) the volume supplied, together with the scant effective precipitation (mean $V_sS_r + P_e$ of 2767 m^3 ha^{-1} $year^{-1}$ for the period 2002–2011) are insufficient to cover the ET_c (mean value of 5198 m^3 ha^{-1} $year^{-1}$ for the period 2002–2011). For the above reasons, the farmers usually incorporate groundwater at plot level with an electrical conductivity (EC) of around 4.0 dS m^{-1} from the coastal aquifer. This water supplement is merged on-plot with the water supplied by the ID (≈1.0 dS m^{-1}) in different proportions, depending on each crop's tolerance to salinity.

A wide range of crops are grown in the Campo de Cartagena ID, with a predominance of vegetables and citrus fruits. In order to display and interpret the results obtained, the following grouping has been made based on the agronomical similarity of the crops: winter vegetables (lettuce, broccoli, celery, cauliflower and potato), summer vegetables (melon and watermelon), annual vegetables (artichoke), greenhouse crops (pepper), and citrus crops (orange, lemon and tangerine trees). These crops accounted for 84% of the total cultivated surface area for the period 2002–2011.

2.2. Indicators selected

The selected set of indicators in this study was compiled from those proposed and that showed better performance in the aforementioned referred works, some of them being specifically adapted or redefined for the current study. The indicators selected and how they have been calculated are detailed in Table 1.

The cropping intensity (S_rS_T) offers information on the relative importance of a specific crop group within the ID. Its evolution over time shows the tendencies of the crop pattern when faced with situations such as water scarcity.

To analyse the efficiency in irrigation water management the indicators of V_sS_r, IWA, $ARIS_0$ and $ARIS_r$ have been used. V_sS_r is the volume of water distributed by the ID and the IWA shows the volume of water which the farmer finally used in the plot (after adding on-farm pumped brackish groundwater). $ARIS_0$ and $ARIS_r$ are an adaptation of the traditional ARIS. These indicators have been proposed in order to determine if there is over or deficit