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# Effects of modernization and medium term perspectives on water and energy use in irrigation districts

I. Fernández García [a,*], J.A. Rodríguez Díaz [a], E. Camacho Poyato [a], P. Montesinos [a], J. Berbel [b]

[a] Department of Agronomy, University of Córdoba, Campus Rabanales, Edif. Da Vinci, 14071 Córdoba, Spain
[b] Department of Agricultural Economics, University of Córdoba, Campus Rabanales, Edif. C5, 14071 Córdoba, Spain

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A B S T R A C T

Increasing of water use efficiency has been a key strategy for dealing with water scarcity in semiarid countries. In Spain modernization of irrigation schemes has consisted in the substitution of old open channels systems by pressurized networks. However, this improvement has represented a significant increase in water costs, mainly due to the higher energy requirements.

Five irrigation districts of Andalusia, Southern Spain, have been analyzed using performance indicators, before and after the improvement actions. Results indicate an average reduction in water diverted for irrigation of 23%, but water costs increased in 52%. Consequently, farmers are migrating to more profitable crops, such as citrus, with higher water requirements. Furthermore, managers' predictions about the cropping patterns for the 2020s suggest that the area devoted to citrus production will increase by 12%, implying even higher potential maximum irrigation water demand. Hence, farmers will have to adapt to a future scenario by using deficit irrigation and other water saving technologies. Consequently, the vulnerability of the irrigated agriculture to the typical droughts of the Mediterranean climate may increase.


## 1. Introduction

In semiarid countries, crop production must be ensured by irrigation. In Spain, characterized by Mediterranean climate with scarce and irregular rainfall, irrigation agriculture is essential and consumes around 58% of the water resources (Hardy et al., 2012) and more than 80% in the driest regions (higher than 80%). In Spain, the irrigated area is around 3.5 M ha, accounting for almost a third of European Union irrigated land (Lopez-Gunn et al., 2012).

Excessive water consumption is the main problem in maintaining a good environmental status in water resources (European Commission, 2012). Irrigation water saving technologies have been the main measure used to reduce quantitative water stress in Spain since the Spanish National Plan for Irrigated Areas (MAPA, 2001). This plan consisted in the modernization of water distribution infrastructure from old open channel distribution systems to pressurized networks. Annual water savings of 3000 $Mm^3$ were expected (Lecina et al., 2010a). Most of the analysis of the cost and efficiency of the investment to improve water distribution efficiency (called 'modernization') has been made by ex-ante models. Related to this, Berbel et al. (2011) studied the implementation of the Program of Measures according to Water Framework Directive in Guadalquivir river basin (Andalusia, Spain).

The objective of this research was to gain knowledge about the real cost and impacts of modernization in Southern Spain. Preliminary analyses of national data show that:

(a) As a result of the modernization process, surface irrigation has decreased from 42% in 2002 to 30% in 2011 whereas drip irrigation has increased from 30% to 47% over the same period (MAPA, 2002; MAGRAMA, 2012). Thanks to the continuous efforts to improve the conveyance efficiency, water use for irrigation per unit of irrigated area has been reduced by 21% from 1950 to 2007 (Corominas, 2010).
(b) However, the energy consumption has increased by 657% over the same period involving higher energy costs for farmers (Corominas, 2010).
(c) Furthermore, farmers must face the amortization, operations and maintenance costs of the new irrigation infrastructures (Rodríguez Díaz et al., 2012a).

Several researchers have used performance indicators for the evaluation of the water use in irrigation districts (Alexander and Potter, 2004; Malano et al., 2004; Rodríguez Díaz et al., 2008). However, in most previous research these indicators have been

* Corresponding author.
*E-mail addresses:* g52fegai@uco.es (I. Fernández García), jarodriguez@uco.es (J.A. Rodríguez Díaz), ecamacho@uco.es (E. Camacho Poyato), pmontesinos@uco.es (P. Montesinos), berbel@uco.es (J. Berbel).

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applied to comparative benchmarking analyses of different irrigation districts within a single year.

Benchmarking is defined as 'a systematic process for securing continual improvement through comparison with relevant and achievable internal or external norms and standards' (Malano and Burton, 2001). This methodology has been rarely used for the evaluation of modernization processes. Lecina et al. (2010a, 2010b) evaluated the effects of the transformation of hydraulic infrastructure on water quantity and quality in the Ebro river basin based on hypothetical scenarios. They concluded that the new pressurized systems lead to more intensive cropping patterns and, therefore, to increments in evapotranspiration.

The rise of energy consumption is becoming a major issue in the irrigation supply. Rodríguez Díaz et al. (2011) evaluated the joint use of water and energy in ten Andalusian irrigation districts with pressurized systems during one irrigation season. They confirmed the increased energy requirements of the pressurized networks (0.4 kW h $m^{-3}$) and highlighted that energy represents almost 40% of the water costs. Rodríguez Díaz et al. (2012a) reported that in Bembézar Margen Derecha irrigation district (Southern Spain), water diverted for irrigation was reduced by 40% after modernization due to the migration to more efficient conveyance and application systems. Conversely, water costs per hectare are four times bigger due to higher energy costs.

This research continues with the analysis of cost and impacts of modernized irrigated systems but innovates with a dynamic benchmarking exercise analyzing the effects of the ex-post situation (observed data). Then, a comparison is made with both pre-modernization situation and future scenario. In this paper, the impact of modernization in five irrigation districts of Andalusia (Southern Spain) is evaluated applying water, energy and economic indicators. These indicators have been calculated for the 1996 to 2002 irrigation seasons, before modernization was implemented and for two irrigation seasons (2010–2012), when the new hydraulic infrastructures (pressurized networks) were fully operating. Finally, a future scenario developed according to the perceptions of the irrigation district managers is forecasted for the horizon 2020.

## 2. Methodology

### 2.1. Selection of irrigation districts

The irrigation districts selected for this work were Bembézar Margen Izquierda (BMI), Bembézar Margen Derecha (BMD), Sector BXII (BXII), Genil Margen Derecha (GMD) and Guadalmellato (GU) (Fig. 1). All of them were modernized in recent years when the collective pressurized networks replaced the old open channels systems, excepting BXII. This irrigation district already had a pressurized system but without water meters at farm level, so volumetric billing was not possible. In all the districts, before the improvement actions, the water pricing system was a fixed rate per irrigated hectare without considering the volume applied. After the modernization processes, users were charged according to a mixed water pricing system. Energy costs for pumping are paid according to a volumetric pricing system, whilst maintenance, operation and management costs are paid at a fixed rate per unit irrigated area.

Before the modernization, users received water without pressure, and more than 70% of the area used surface irrigation, with only a small percentage using trickle irrigation for fruit trees. These farmers had their own reservoirs and pumping stations. The new infrastructure allows users to irrigate on-demand, so the flexibility has been hugely increased. Drip irrigation is the most widespread system and surface irrigation (predominant before modernization) has virtually disappeared. The total investment was € 123.8 M (€ 3235 $ha^{-1}$).

The selected irrigation districts cover a total irrigated area of 38,285 ha, accounting for 11% of the modernized area in Andalusia (Lopez-Gunn et al., 2012). All of them belong to the Guadalquivir river basin, characterized by Mediterranean climate with scarce and irregular rainfall (annual average around 550 mm) and high potential evapotranspiration rates, around 1335 mm as annual average (Rodríguez Díaz et al., 2007).

### 2.2. Water and energy use indicators

Water and energy use indicators selected in this work were mostly suggested by IPTRID (International Programme for Technology and Research in Irrigation and Drainage) (Malano and Burton, 2001):

1. Annual irrigation water supply per unit irrigated area, *Is* ($m^3$ $ha^{-1}$). This is the ratio of the total annual volume of water diverted or pumped for irrigation and the irrigated area.
2. Theoretical crop water requirements per unit irrigated area, *ETc* ($m^3$ $ha^{-1}$). This indicator shows the ratio of the theoretical crop water requirements and the irrigated area. The crop evapotranspiration is estimated as described in FAO 56 (Allen et al., 1998).
3. Theoretical crop irrigation water requirements per unit irrigated area, *Ir* ($m^3$ $ha^{-1}$). This is the theoretical volume of irrigation water required by the crops divided by the irrigated area. The value of *Ir* is obtained by subtracting the effective rainfall ($P_{ef}$) from crop evapotranspiration.
4. Annual Relative Water Supply, *RWS*. This is the ratio of the total annual volume of water diverted or pumped in the irrigation district, *Is* ($m^3$) plus the effective rainfall, $P_{ef}$ ($m^3$) divided by the theoretical crop water requirements, *ETc* ($m^3$).
5. Annual Relative Irrigation Supply, *RIS*. This indicator represents the total annual volume of water diverted or pumped in the irrigation district, *Is* ($m^3$) divided by the theoretical crop irrigation water requirements, *Ir* ($m^3$).
6. Cost related to the water agency tariff, $C_C$ (€$ha^{-1}$). This is a fixed cost paid by farmers to the water authorities through the irrigation district for their water allocation withdrawn from reservoirs and delivered to the irrigation district. This cost is computed by hectare (Berbel and Gómez-Limón, 2000).
7. Maintenance cost, $C_M$ (€$ha^{-1}$), also computed by hectare.
8. Energy cost. This represents the total annual energy cost divided by the total annual irrigation water supply, $C_{EW}$ (€$m^{-3}$), o per unit of irrigated area $C_{EA}$ (€$ha^{-1}$).
9. Total water costs per unit of irrigated area, $C_{TA}$ (€$ha^{-1}$). This is the sum of all costs associated to irrigation (water agency tariff, maintenance and energy cost) per unit of irrigated area.
10. Total water costs per unit of supplied water, $C_{TW}$ (€$m^{-3}$). This indicator represents the sum of all cost related to irrigation per unit of volume of water delivered to farmers.
11. Ratio of energy to total water costs, $C_{EW}/C_{TW}$. This is the proportion of total water costs related to the energy cost.
12. Output per unit irrigated area, $O_A$ (€$ha^{-1}$). This indicator is obtained dividing the gross value of the agricultural production within the irrigation district by the irrigated area.
13. Output per unit irrigation supply, $O_S$ (€$m^{-3}$). This represents the gross value of the agricultural production divided by the volume of irrigation water delivered to farmers.