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Irrigation modernization and water conservation in Spain: The case of *Riegos del Alto Aragón*

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ABSTRACT

This study analyzes the effects of irrigation modernization on water conservation, using the Riegos del Alto Aragón (RAA) irrigation project (NE Spain, 123354 ha) as a case study. A conceptual approach, based on water accounting and water productivity, has been used. Traditional surface irrigation systems and modern sprinkler systems currently occupy 73% and 27% of the irrigated area, respectively. Virtually all the irrigated area is devoted to field crops. Nowadays, farmers are investing on irrigation modernization by switching from surface to sprinkler irrigation because of the lack of labour and the reduction of net incomes as a consequence of reduction in European subsidies, among other factors. At the RAA project, modern sprinkler systems present higher crop yields and more intense cropping patterns than traditional surface irrigation systems. Crop evapotranspiration and non-beneficial evapotranspiration (mainly wind drift and evaporation loses, WDEL) per unit area are higher in sprinkler irrigated than in surface irrigated areas. Our results indicate that irrigation modernization will increase water depletion and water use. Farmers will achieve higher productivity and better working conditions. Likewise, the expected decreases in RAA irrigation return flows will lead to improvements in the quality of the receiving water bodies. However, water productivity computed over water depletion will not vary with irrigation modernization due to the typical linear relationship between yield and evapotranspiration and to the effect of WDEL on the regional water balance. Future variations in crop and energy prices might change the conclusions on economic productivity.

1. Introduction

The economic growth of Spain during the last decades has substantially increased national water demand. However, water availability has barely increased because of the lack of significant increases in water storage capacity. These facts have strengthened competition for water resources, and cyclical droughts have brought social conflicts between uses, users and regions within Spain (INE, 2006; MARM, 2006).

The Spanish Government has implemented reforms to manage water demand. One of the most ambitious plans is irrigation modernization. Spain has around 3.5 M ha of irrigated land, and although this area only represents 13% of total agricultural land, it generates about 50% of the agricultural Gross Domestic Product (Forteza del Rey, 2002). Before the establishment in 2002 of these irrigation modernization plans, traditional surface irrigation amounted to 59% of the irrigated area, and 71% of this area used structures more than 25 years old (MARM, 2002). The irrigated area of Spain is mostly located in land-locked provinces (72%) (INE, 1999). Surface irrigation is predominant on these provinces, in which field crops occupy 74% of the irrigated area (MARM, 2007).

The two National Irrigation Modernization Plans (*Plan Nacional de Regadíos* and *Plan de Choque de Modernización de Regadíos*) were designed with two main objectives: (1) to increase the competitiveness of the irrigation sector, preparing it for the liberalization of agricultural markets and the reduction of subsidies, and (2) to save 3000 Mm^3 water per year, a volume expected to alleviate the effects of cyclical droughts on alternative uses. This foreseen water saving represents about 15% of the yearly average national agricultural water use. These plans will invest a total of 7400 M€ during this decade to improve the irrigation structures of nearly 2 M ha. The decision to engage in these irrigation modernization projects is taken by farmers and irrigation districts, since farmers contribute

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with at least 34% of the investment in collective irrigation structures (MARM, 2002, 2006).

These 3000 Mm^3 prospects on water saving are based on reductions in water use due to expected improvements in on-farm irrigation efficiency. The efficiency concept has traditionally been used to design irrigation systems and to schedule irrigation. However, several authors have pointed out (mainly since the 1990s) that this concept is not appropriate for assessing the hydrological impact of irrigation in a basin (Willardson et al., 1994; Seckler, 1996; Perry, 1999; Seckler et al., 2003; Jensen, 2007; Perry, 2007). Efficiency does not take into account issues such as water reuse, the distinction between total water use and water consumption, the influence of location of use within the basin, and water quality. These issues are particularly important for water management in a context of water scarcity. The abovementioned authors, as well as others (Huffaker, 2008; Ward and Pulido-Velázquez, 2008), reported examples of misunderstandings in water management practices and water conservation programs due to an inadequate use of the efficiency concept.

Several authors have proposed the distinction between the "classical" concept of irrigation efficiency and the "neoclassical" concept (Keller et al., 1996; Seckler et al., 2003; Haie and Keller, 2008; Mateos, 2008). This approach includes the abovementioned hydrological issues in a new formulation called "effective efficiency". However, Perry (2007) and Perry et al. (2009) consider that this terminology could lead to misconceptions despite its proper hydrological basis.

Water accounting has been proposed as an alternative to the irrigation efficiency approaches for hydrological purposes (Willardson et al., 1994; Molden and Sakthivadivel, 1999; Clemmens et al., 2008; Perry et al., 2009). This methodology applies the law of conservation of mass through water balances. Balances identify the destination of the water used and distinguish between consumptive and non-consumptive uses. Several fractions among balance components have been proposed to characterize the performance of irrigated areas and other water uses.

Water accounting is a valuable tool to characterize water use in a basin. However, there is also a need to assess how well water is used in relation to agricultural production. Water productivities applied to irrigation represent the output obtained per water input. A number of indices have been proposed to estimate water productivity, depending on the use of physical or economic terms and on the expression of water input (i.e., water use or water consumption) (Molden et al., 1998, 2003, 2010; Hussain et al., 2007). Likewise, different space scales can be considered, as well as average or marginal production values. These indicators are used to describe overall performance and to support decision making processes about investments or water allocation strategies, among other applications. Irrigation modernization can contribute to increase water productivity. However, Playán and Mateos (2006) and Perry et al. (2009) pointed out from a general perspective that irrigation modernization projects aiming at increasing crop production would actually increase water consumption in a basin.

This study applies the water accounting and water productivity concepts to the assessment of irrigation modernization in terms of water conservation. The analysis has been applied to the case study of the *Riegos del Alto Aragón* (RAA) irrigation project, representative of large irrigation projects in interior Spain and in similar semi-arid areas. The objective of this work is to contribute to the optimization of water use in irrigation projects. The application of water accounting concepts to irrigation modernization constitutes a secondary objective of this study.

This publication is divided into five sections including this introduction. The second section presents the main characteristics of RAA and the socio-economic factors which lead farmers to invest on irrigation modernization by switching from surface to sprinkler irrigation. The third section discusses the differences between these irrigation systems in RAA from a productive and a hydrological perspective. The fourth section applies the water accounting approach to determine water balances, fractions and productivities in RAA before and after irrigation modernization. Finally, the fifth section summarizes the most important conclusions of this work.

2. The *Riegos del Alto Aragón* (RAA) irrigation project

2.1. General characteristics

RAA is located in NE Spain, in the central Ebro River Basin (Fig. 1). Development of this irrigation project started in 1915, intensified in the 1940s to 1960s and is still ongoing. The current irrigated area is 123354 ha, covering a territory of 2500 km^2, and with an altitude ranging from 200 to 425 m above mean sea level. RAA is distributed among five sub-basins: Gállego, Flumen, Alcanadre, Cinca and Ebro. Irrigation water originates at the Central Pyrenees Mountains and its quality for irrigation is high (electrical conductivity $<0.4\,dS\,m^{-1}$; sodium adsorption ratio $<2\,(mmol\,l^{-1})^{0.5}$) (Isidoro and Aragüés, 2007).

The local climate is semi-arid Mediterranean continental, with a mean annual temperature of 14.5 °C, and an annual precipitation oscillating between 300 mm in the South and 450 mm in the North. A dry period typically extends from July to September. The annual reference evapotranspiration (Hargreaves and Samani, 1985) varies from 949 mm in the North to 1149 mm in the South. The average wind speed (at 2.0 m height) is about $1.9\,m\,s^{-1}$ in the North and $2.6\,m\,s^{-1}$ in the South.

Two geomorphologic units (with respective dominant soil types) can be distinguished in RAA. The first corresponds to platforms sitting on tertiary materials covered with gravel. Platform soils are highly productive because of their low slope and adequate drainage. These soils often result in low surface irrigation application efficiency due to their low available water holding capacity (AWHC) and high infiltration (Playán et al., 2000). The second unit corresponds to slopes and alluvial terraces, characterized by high AWHC but poor drainage. Some of the soils in this unit are naturally salt-affected, while others were man-made salinized because of improper land levelling, lateral seepage, low internal drainage and development of shallow water tables. Spots of saline-sodic soils occur in this geomorphologic unit, although sodicity is generally associated to areas lacking gypsum (Herrero and Snyder, 1997).

The RAA project uses six head reservoirs with a total storage capacity of 930 Mm^3, 223 km of main canals, 2000 km of secondary canals, and 3000 km of drainage collectors. Almost all irrigation canals and ditches are lined. In addition to irrigation water delivery, the project supplies domestic water to a population exceeding 66000 inhabitants, ten industrial areas, and 765 livestock farms.

RAA is divided into 53 irrigation districts. Due to its gradual transformation over the past century, water structures are heterogeneous. For this reason, and following the water delivery terminology proposed by Clemmens (1987), three groups of irrigation districts can be distinguished: (1) districts transformed in recent years with on-demand pressurized water conveyance networks, sprinkler irrigation systems and volumetric water meters (11686 ha); (2) districts transformed in the 1980s and early 1990s, with pressurized networks and sprinkler systems, but with arranged water distribution based on prepaid volumes of water (21168 ha); and (3) surface irrigation districts transformed prior to the 1980s, mostly using border irrigation. In these districts water delivery is arranged, based on previous volumetric water orders (90500 ha). In the three groups of districts the daily irrigation period is 24 h. RAA is still expanding: 12000 new hectares