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Seasonal on-farm irrigation performance in the Ebro basin (Spain): Crops and irrigation systems

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ABSTRACT

Irrigation performance assessments are required for hydrological planning and as a first step to improve water management. The objective of this work was to assess seasonal on-farm irrigation performance in the Ebro basin of Spain (0.8 million ha of irrigated land). The study was designed to address the differences between crops and irrigation systems using irrigation district data. Information was only available in districts located in large irrigation projects, accounting for 58% of the irrigated area in the basin. A total of 1617 records of plot water application (covering 10,475 ha) were obtained in the basin. Average net irrigation requirements (IR_n) ranged from 2683 $m^3\,ha^{-1}$ in regulated deficit irrigation (RDI) vineyards to 9517 $m^3\,ha^{-1}$ in rice. Average irrigation water application ranged from 1491 $m^3\,ha^{-1}$ in vineyards to 11,404 $m^3\,ha^{-1}$ in rice. The annual relative irrigation supply index (ARIS) showed an overall average of 1.08. Variability in ARIS was large, with an overall standard deviation of 0.40. Crop ARIS ranged between 0.46 and 1.30. Regarding irrigation systems, surface, solid-set sprinkler and drip irrigated plots presented average ARIS values of 1.41, 1.16 and 0.65, respectively. Technical and economic water productivities were determined for the main crops and irrigation systems in the Aragón region. Rice and sunflower showed the lowest productivities. Under the local technological and economic constraints, farmers use water cautiously and obtain reasonable (yet very variable) productivities.

1. Introduction

All water users share responsibilities in water quantity and quality conservation. Among these users, farmers must obtain adequate irrigation performance standards, since water is a decisive input in their farming operations. Irrigation performance assessments are required for hydrological planning and as a first step to improve water management. The different levels of Public Administration are currently increasing control on water resources, and focusing on the river basin as the primary geographical unit of water policy (Jensen, 2007). At the European level, the implementation of the Water Framework Directive (European Parliament, 2000) requires water application data from all economic sectors. In water-short Mediterranean countries there is a need for structured analyses on irrigation water consumption and irrigation performance.

A number of procedures have been described to assess on-farm irrigation efficiency. The classical work by Merriam and Keller (1978) was one of the first compilations of irrigation performance indicators. Burt et al. (1997) produced an update of irrigation performance indexes, stressing the hydrological implications of irrigation performance. These authors proposed three irrigation performance indexes that could be applied to time intervals exceeding one irrigation event: irrigation efficiency, irrigation consumptive use coefficient, and irrigation sagacity.

In this work, the ARIS index (annual relative irrigation supply), proposed by Malano and Burton (2001), was used to estimate irrigation performance. This index represents the ratio of irrigation supply to crop irrigation demand as:

$$ARIS = \frac{IWA}{IR_n} \quad (1)$$

where, IWA is the irrigation water applied ($m^3\,ha^{-1}$) and IR_n are the seasonal net irrigation requirements ($m^3\,ha^{-1}$).

An ARIS value of 1.00 implies that irrigation water application is equal to the net crop water requirements. This situation can not lead to a fulfilment of water requirements since 100% irrigation efficiency cannot be attained under commercial field conditions. Clemmens and Dedrick (1994) classified irrigation systems according to their potential application efficiency. In an optimistic scenario, the best systems attained 90% efficiency. If water application is made equal to the net irrigation requirements with an efficiency of 90%, the resulting ARIS value is 1.11. Under this efficiency hypothesis, any ARIS value below 1.11 implies seasonal underirrigation. Accordingly, ARIS values above 1.11 imply sea-

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sonal overirrigation. Since ARIS is a seasonal index, during short periods percolation may happen even with ARIS < 1.11, and deficit may happen even with ARIS ≥ 1.11. A detailed analysis of a particular irrigation system would be required to assess its efficiency, and therefore to establish the specific ARIS value separating seasonal deficit from seasonal excess irrigation.

The ARIS index can be used to estimate the degree of seasonal over- or underirrigation at a given field. If a field is overirrigated, ARIS will be related to irrigation efficiency. Improving irrigation efficiency constitutes a major goal for irrigation engineers and managers, since it means adjusting irrigation to crop water requirements (including salt leaching requirements). However, improving irrigation efficiency does not imply saving water. Lecina et al. (2010), analysing a large irrigation project in the Ebro Basin, concluded that irrigation modernisation (changing from surface to sprinkler irrigation) will result in improved irrigation efficiency, increased water consumption (the sum of estimated beneficial and non-beneficial consumption increased by 19–46%, depending on the future scenario) and improved quality of the return flows. This reference illustrates with numbers the impact of improving irrigation efficiency in the area of study, and further supports previous analyses (Perry, 1999, 2007; Playán and Mateos, 2006; Ward and Pulido-Velázquez, 2008).

The Ebro basin, located in NE Spain, is one of the most intensively irrigated river basins in Europe (Wriedt et al., 2008), with about 0.8 million ha of irrigated land. No work has reported the ARIS index in this area, but the low data requirements that characterize ARIS permit to estimate it from other performance indicators. Thus, Faci et al. (2000) analysed a surface irrigated district in the central Ebro basin grown with field crops, which yielded ARIS values of 2.00 for grain corn and 0.86 for sunflower. Lecina et al. (2005) analysed a similar irrigation district in the Ebro basin, which resulted in average ARIS values of 2.05 for 2000 and 1.51 for 2001. This interseasonal difference was attributed to moderate water scarcity in 2001, which resulted in better irrigation management. Dechmi et al. (2003) analysed a sprinkler irrigated district in the Ebro basin characterized by high energy costs for water pumping. The average crop ARIS were 0.78 for alfalfa and 0.90 for grain corn. In two sprinkler irrigated watersheds Cavero et al. (2003) found ARIS values ranging from 0.94 to 1.12 for corn, from 1.03 to 1.15 for alfalfa and from 0.57 to 1.09 for sunflower. In a wind exposed solid-set irrigation district, Zapata et al. (2009) reported data leading to average estimated ARIS values of 1.25 for grain corn and 1.59 for alfalfa. These authors concluded that the performance of this sprinkler irrigated area was strongly limited by meteorological conditions. The comparison of these works in the Ebro basin suggests that irrigation performance can be related to the irrigation system, to water scarcity and cost and to soil and climatic factors. These limited sources of information do not permit to develop average ARIS information at the basin scale, establishing differences between crops and irrigation systems.

Lorite et al. (2004) applied the ARIS index to the Genil-Cabra irrigation district (7000 ha), located in the Guadalquivir basin, southern Spain. This area is characterized by annual ET_0 and precipitation of 1300 and 600 mm, respectively, and a maximum seasonal water availability for irrigation of 5000 $m^3\ ha^{-1}$ (García-Vila et al., 2008). The district was equipped with hand-move sprinkler and drip systems. The authors focused on seven crops and used data from four irrigation seasons. They found ARIS values ranging from 0.22 in sunflower to 1.19 in sugar beets, indicating severe underirrigation and slight overirrigation, respectively. García-Vila et al. (2008) analysed the ARIS index in the same study area, but used 15 irrigation seasons. The average ARIS value for all crops was 0.60. Considering the different crops, these authors found ARIS values ranging from 0.23 (sunflower) and 0.28 (winter cereals) to 0.79 (cotton). Even though the Genil-Cabra area has some similarities with the Ebro basin, there are some relevant differences: (1) on-farm surface irrigation is common in the Ebro basin but this irrigation method is not used in the Genil-Cabra area; (2) water restrictions apply every year at the Genil-Cabra district; and (3) the Ebro basin is much larger in area than the Genil-Cabra district, and therefore more heterogeneous in climate and cropping patterns.

Research results from other parts of the World also permit to estimate ARIS. Thus, data from Molden et al. (1998) corresponding to surface irrigated areas located in different countries, led to regional ARIS values ranging from 0.50 to 4.16. Regarding crops, Molden (1997) collected data in India leading to ARIS values of 1.54 for wheat and 1.64 in cotton.

In the last years, irrigation performance indexes have been extended to include economic terms. Water productivity has gained importance due to the relevance currently given to economic efficiency in water allocation. Playán and Mateos (2006) presented an analysis on water productivity and discussed formulations based on yield (technical productivity, $kg\ m^{-3}$) or monetary units (economic productivity, € m^{-3}). When productivity is expressed in monetary units, the gross income or the net benefit can be used in the calculation. The type of crop and the production strategy have a relevant influence on monetary water productivity indexes.

The technical productivity of irrigation water (WP_T) can be defined as the yield (Y, $kg\ ha^{-1}$) obtained per volume of irrigation water application (IWA, $m^3\ ha^{-1}$):

$$WP_T = \frac{Y}{\text{IWA}} \tag{2}$$

WP_T has been reported in a number of research works (Igbadun et al., 2006; Fernández et al., 2007; Kahlown et al., 2007). WP_T has two relevant advantages: (1) it is a direct estimation of water productivity; and (2) it is not subjected to the time and space variability of economic data. Unfortunately, WP_T is not adequate to establish comparisons between crops, because yields, profits and costs can be very different. Alternative approaches to productivity are available to solve this problem. One of these approaches is the gross economic productivity of irrigation water (WP_{Eg}). It can be determined as the ratio between the gross income of a crop (I_g) and the seasonal volume of irrigation water (IWA):

$$WP_{Eg} = \frac{I_g}{\text{IWA}} \tag{3}$$

Molden et al. (1998), Perry (2001), Ahmad et al. (2004) and Jalota et al. (2007) determined WP_{Eg} for rice in different areas of the world, ranging from 0.043 to 0.087 € m^{-3}. Perry (2001) and Jalota et al. (2007) obtained values ranging from 0.106 to 0.053 € m^{-3} for grain corn and from 0.121 to 0.100 € m^{-3} for wheat. Buendia-Espinoza et al. (2004) in pressurized irrigation systems in Mexico found that WP_{Eg} ranged from 1.65 to 2.68 € m^{-3} in tomato and from 2.14 to 2.34 € m^{-3} in pumpkin. In Spain, Lorite et al. (2004) found average values of 0.28 € m^{-3} in winter cereals, 0.23 € m^{-3} in grain corn and 2.21 € m^{-3} in garlic.

An accurate economic assessment of water productivity requires using not only income, but also costs. This is the case of the Net Economic Productivity of irrigation water (WP_{En}, € m^{-3}), which permits to compare the water productivity of different areas or crops. WP_{En} is determined as the ratio of the net crop margin (M_n, € ha^{-1}) to IWA:

$$WP_{En} = \frac{M_n}{\text{IWA}} \tag{4}$$

Jalota et al. (2007) and Perry (2001) obtained WP_{En} values from 0.020 € m^{-3} for rice and 0.034 for grain corn to 0.081 € m^{-3} for wheat.

The abovementioned indexes are influenced by factors such as the irrigation system, irrigation scheduling, fertilization, irrigation