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Implementing irrigation: Water balances and irrigation quality in the Lerma basin (Spain)

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ABSTRACT

The growing necessity to develop more productive agriculture has encouraged the expansion of new irrigated lands. However, water use in agriculture may affect the natural regimes of water systems. This study aims to analyze, for the first time, water use and its dynamics during the creation of a newly irrigated land. Water use was studied through the development of water balances and subsequent application of quality indices for irrigation in two unirrigated years (2004–2005) and three years of gradual implementation of irrigation (2006, 2007 and 2008) in the Lerma basin (752 ha, Spain). Increases in evapotranspiration, drainage and water content in the aquifer were verified during the gradual transformation into irrigated land. Water balances closed adequately, giving consistency to the results and enabling the application of quality indices for irrigation. Irrigation quality analysis showed a use of available water resources equal to 84%. However, the estimated irrigation efficiency presented lower values, mainly due to irrigation drainage (15%) and combined losses by both evaporation and wind drift of sprinkler irrigation systems (13%). The results indicate that the use of water in the Lerma basin is at the same management level of other modern irrigation systems in the Ebro basin, although there is still margin for improvement in irrigation management, such as reducing the irrigation drainage fraction and the evaporation and wind drift losses of sprinkler irrigation systems.

1. Introduction

In many areas of the world, especially in arid and semi-arid regions, irrigated agriculture is essential to achieve the desired production. Forty percent of global agrarian production is obtained from the 20% of cultivated areas that are irrigated (FAO, 2003a). Currently, over 250 million hectares are irrigated throughout the world, which is more than five times the area irrigated in the early twentieth century (Rosegrant et al., 2002). Because of the higher yields from irrigated agriculture compared to unirrigated agriculture, it is expected that this proportion of irrigated areas will continue to increase in the future.

The introduction of irrigation in an agricultural area involves a major change in water use. Irrigation water in many cases exceeds the total volume of all other inputs of water to the system (Charbonneau and Kondolf, 1993) and is added to the previously available water resources (precipitation and natural flows).

Due to the large amount of water used in irrigation activities (70% of the total water extracted from natural resources (FAO, 2003b)) and potential negative impact resulting from drainage, there is growing interest in studying and quantifying irrigation management (Clemmens and Burt, 1997). However, it is essential to develop water balances to check the level of accuracy of the measured and estimated components of the water cycle (Burt et al., 1997). Accuracy is crucial to further validate the irrigation management assessment.

Among the several existing irrigation quality indices, those evaluating the use of water resources and the volume of water applied that is not used for crops stand out. It is also important to ascertain the degree with which irrigation is meeting the needs of crops, so as to balance high water productivity (i.e. high crop yield per unit of applied water) and low environmental impacts.

The assessment of water use and quality of irrigation has been the subject of several studies conducted in hydrological basins or experimental plots (Chaudhry, 1978; Zalidis et al., 1997; Faci et al., 2000; Al-Jamal et al., 2001; Tanji and Kielen, 2002; Causapé et al., 2004; Isidoro et al., 2004; Lecina et al., 2005; García-Garizábal et al., 2009). However, until the present date, no study has had the opportunity to start an agroenvironmental monitoring in an area before its transition into irrigated land (i.e. monitoring drainage flow, water use, crops implementation, agricultural management, etc.). This was the objective of the work reported in this paper.

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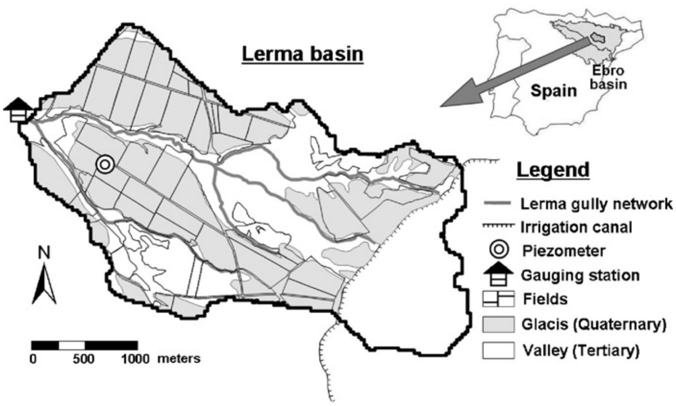

Fig. 1. Geomorphology (Beltrán, 1986) and fields of the Lerma basin, with the location of the gully network, irrigation canal, piezometer and gauging station.

2. Description of study area

The study area corresponds to the Lerma hydrological basin (752 ha), located on the left side of the Ebro river valley in Northeast Spain (Fig. 1). The transition project delimited 405 ha of the Lerma basin to be irrigated, divided into 55 fields (irrigable area of the basin). The agroenvironmental monitoring of the basin began in the hydrological year 2004, before transformation of the area. The first fields were irrigated in 2006, with a gradual increase in irrigated area until reaching 85% of irrigated land in 2008, the last year included in this study.

Fifty nine percent of the soils in the Lerma basin are underlain by two layers (Fig. 1): the first layer is quaternary glacis consisting of layers of gravel with loamy matrix and a maximum thickness of 10 m; below are layers of tertiary materials consisting of limestone, clay and gypsum. The remaining 41% of the land area consists of emerged tertiary materials.

The gravel layers provide excellent pathways for subsurface drainage. The drainage water feeds into lower areas through a network of intermittent streams that flow through, and on top of, the tertiary layers. Before irrigation, flows in these streams occurred mainly during fall and spring, as a consequence of rainfall.

The soils developed on the glacis (Calcixerollic Xerochrepts, Soil Survey Staff, 1992) display loamy textures, with an effective depth of 60–90 cm. The low salinity (electrical conductivity of the saturation extract: $EC_e < 4$ dS/m) and small risk of erosion (slope < 3%) of the soils developed on the glacis allowed for identifying these zones as suitable for conversion into irrigated land (Beltrán, 1986), and therefore most of the irrigation occurs in these zones. In contrast, soils developed in the valleys of the Lerma gullies (Typic Xerofluvent, Soil Survey Staff, 1992) have a much lower effective depth (between 30 and 45 cm), limited by limestone or tabular gypsum levels, which confers slow drainage. Salinity (EC_e between 4 and 8 dS/m) and steep slopes (>10%) are the reasons why these zones are classified as not appropriate for irrigation (Beltrán, 1986).

According to the agro-climatic stations of the Integrated Irrigation Advisory Service (SIAR Network: http://oficinaregante.aragon.es), average rainfall for the five study years (hydrological years 2004–2008) was 408 mm/year with a high annual variability as can be seen in Fig. 2 (coefficient of variation: CV = 37%). The average reference evapotranspiration (ET_0) calculated by Penman–Monteith (Allen et al., 1998) was three times higher (1261 mm/year) than rainfall and was much less variable (CV = 6%). A typical year consists of two dry seasons (summer and winter) and two wet seasons (spring and autumn).

Before irrigation, wheat and barley were grown in winter. After irrigation was established, the typical cropping pattern (Table 1) for 82% of the irrigated fields consists of maize (April to October), winter cereals (November to July), and tomato (May to September). The area under irrigation increased from 124 ha in 2006 to 346 ha in 2008. Sprinkler irrigation accounts for 86% of the applied water with drip irrigation used for the rest of the area (Table 1). The implementation of irrigation not only resulted in a progressive increase of irrigated area, but also in an increase in the amount of water applied annually per hectare, mainly due to double cropping practices (Table 1). Finally, the salinity of the irrigation water, 0.3 dS/m, does not pose any limitations on to the type of cultivated crops.

3. Methodology

3.1. Water balances

Annual water balances were calculated for the irrigable area of the Lerma basin for 2004 through 2008 using EMR 2.0 (Irrigation Land Environmental Evaluation Tool – in Spanish, EMR: Causapé, 2009).

3.1.1. Soil water balance

Data on precipitation (P), irrigation (I), combined losses by both evaporation and wind drift (EWDL), and potential evapotranspiration (ET_0) were utilized by EMR to develop daily water soil balances to estimate actual evapotranspiration (ET_a), soil drainage (D_s) and soil water storage (ΔS) in each of the 55 irrigated fields in the Lerma basin:

$$(P + I) - (ET_a + D_S + EWDL) = \Delta S \quad (1)$$

The daily weather data necessary to calculate the water balances was obtained from two agro-climatic stations of the SIAR Network (Tauste and Ejea). EMR software interpolates the climatic variables of the different stations to obtain a daily value for Lerma using the inverse square distance technique (Isaaks and Srivastava, 1989). Irrigation volumes were measured daily with flow meters installed by the Irrigation District Authority in the 55 irrigated fields of the basin.

The percentage of losses, calculated by EMR in accordance with Playán et al. (2005), was applied to the volume of irrigation to quantify the combined losses by both evaporation and wind drift of sprinkler irrigation, using the following equation:

$$EWDL = 20.34 + 0.214 WS^2 - 2.29 \times 10^{-3} RH^2 \quad (2)$$

The wind speed 2 m above the surface (WS, m/s) and relative humidity 1.5 m above ground level (RH, %) were also provided by the SIAR Network. The last dataset obtained from the SIAR Network was the reference evapotranspiration (ET_0), which was derived according to Penman–Monteith (Allen et al., 1998). With ET_0 and the monthly crop coefficients (k_c) obtained from Martínez-Cob (2004) for the study zone, the daily crop evapotranspiration (ET_C) was calculated according to the methodology proposed by Allen et al. (1998):

$$ET_C = ET_0 \times k_c \quad (3)$$

The water holding capacity in the soil (WHC, mm) available for plants was estimated from the average apparent electrical conductivity of the soil (EC_a, dS/m) of each field, which depends on soil water content. EC_a was derived from 43,433 measurements taken in about two weeks, after rainfall (soil at field capacity). A mobile geo-referenced electromagnetic sensing system (Urdanoz et al., 2008) was used for these measurements and the WHC of 10 soil samples (representative of the EC_a range of Lerma soils) was analyzed in the laboratory according to the methodology of the Soil Survey Laboratory (1995) (WHC = field capacity at 0.33 bar minus