Agricultural Water Management 208 (2018) 163–175

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Hydrosaline Balance in and Nitrogen Loads from an irrigation district before and after modernization

M.T. Jiménez-Aguirre*, D. Isidoro

Centro de Investigación y Tecnología Agroalimentaria de Aragón, (CITA), Unidad de Suelos y Riegos (Unidad Asociada EEAD-CSIC), Avenida de Montañana 930, CP 50059, Zaragoza, Spain

ARTICLE INFO

Keywords:
Irrigation modernization
Irrigation return flows
Water quality
Water use
Nitrogen management
Soil salinization

ABSTRACT

The stress on water resources and the need to maintain water quality and to protect the environment push for an efficient use of natural resources: irrigation water and nutrients (particularly nitrogen). Traditional surface irrigation areas (frequently located on saline materials) use huge amounts of these resources, contributing to the degradation of water bodies by salts and nitrate loads in Irrigation Return Flows (IRF), and also to soil salinization when salt leaching is constrained. In this respect, 1.5 Mha of irrigated lands in Spain have been modernized recently to more efficient systems. Such is the case of the Violada Irrigation District (VID; 4880 ha; Northeast Spain) modernized from surface to sprinkler irrigation. The availability of historical data under both irrigation systems in VID offered an ideal scenario to analyze the impact of the modernization process on water consumption and nitrogen management. The analysis was based on the water and salt balances, which showed that irrigation modernization triggered an alteration of the hydrological regime of the VID controlled by the irrigation system. The transformation to sprinkler irrigation resulted in high quality non-diverted water savings of 5536 m^3/ha yr (19 h m^3/yr for the whole VID) available for other uses downstream, triggering a reduction of the IRF from the VID to the Ebro River. In general, the modernization has brought about a clear reduction of all flows in the water balance (except ET_a), together with a slight increase in salt and nitrate concentrations in IRF. Both changes entailed a reduction in salt and nitrate loads of 11.5 Mg/ha yr (44,889 Mg/yr; −60.4%) and 82.2 kg N/ha yr (301 Mg N/yr; −70.4%), respectively. The modernization also resulted in better water use and agronomic indices (drainage fraction, consumptive fraction and irrigation fraction). It was also concluded that at the moment, there is no risk of soil salinization in VID.

1. Introduction

Diffuse pollution and soil salinization are the main environmental problems linked to irrigation lands, especially in semi-arid areas because of water scarcity and the presence of salts. Irrigation may contribute to the salinization of water bodies (off-site effect) through the dissolution of saline materials (frequent in arid and semi-arid zones) and their transport by IRF. In that regard, Aragüés and Tanji (2003) estimated that salt loads to water bodies by Irrigation Return Flows (IRF) ranged between 2 and 20 Mg/ha per year in semi-arid zones. But irrigation may also induce soil salinization (in-situ effect) from the original salty minerals (primary salinization) or, more commonly, from the accumulation of salts provided by irrigation water under limited drainage (secondary salinization). The latter is associated to shallow water tables thus, an appropriate drainage system is the key to ensure the evacuation of the water and salts provided by irrigation (Rhoades, 2011), especially when low water quality is used (EC > 3 dS/m, Ayers and Westcot, 1985).

In addition, IRF drive huge amounts of nitrogen (in nitrate form) from the intensive, and sometimes excessive, fertilization practices (along with other pollutants, such as phosphorus or pesticides). Nitrate loads may reach 150 kg $N\text{-}NO_3^-$ per year, varying mainly due to the

Abbreviations: AEMET, Spanish Meteorological Agency; ANOVA, analysis of the variance; AW, soil water storage; AWUA, Almudévar Water User Association; CF, consumptive fraction; CHE, Ebro Basin Authority; CS, canal seepage; CU, consumptive use; DF, drainage fraction; EC, electrical conductivity; ET_0, reference evapotranspiration; ET_a, actual evapotranspiration; FC, field capacity; I, irrigation; IEf, irrigation efficiency; IRF, irrigation return flows; IS, irrigation season; K_s, daily stress coefficient; LSD, least significant difference test; N, nitrogen; N-FA, nitrate loads factor analysis; nIS, non-irrigation season; NL, nitrate loads; $N\text{-}NO_3^-$, nitrate-nitrogen; NO_3^-, nitrate; N_Q, mass of nitrate-nitrogen; P, precipitation; P_{ef}, effective precipitation; Q, drainage flow; RAW, readily available water; SB, salt balance; S-FA, salt balance factor analysis; SIAR, agroclimatic information system for irrigation; SL, salt loads; S_Q, mass of salts; TAW, total available water; TDS, total dissolved solids; VID, Violada irrigation district; WDEL, wind drift and evaporation losses; WFD, water frame directive; WP, wilting point

* Corresponding author.
E-mail addresses: mtjimeneza@cita-aragon.es (M.T. Jiménez-Aguirre), disidoro@aragon.es (D. Isidoro).

https://doi.org/10.1016/j.agwat.2018.06.008
Received 17 January 2018; Received in revised form 5 May 2018; Accepted 7 June 2018
0378-3774/

dominant crop, fertilizer practices, and especially, irrigation management (Quemada et al., 2013) and also due to soil type and climatology (Li et al., 2007). The IRF may be reused downstream for irrigation or human consumption, posing a risk for human health (Weisenburger, 1993) as well as for environment: eutrophication of the water bodies (Carpenter et al., 1998) and salinization of irrigated areas (Gómez-Ferrer et al., 1983; Tanji and Kielen, 2002).

On the other hand, irrigation is the backbone of rural development in arid and semi-arid areas, launching the economy (raising crop productivity), ensuring yields and enhancing rural population (FAO, 2002). Thus, the mitigation of pollution is essential, to maintain the balance between fulfillment of human needs and respect for the environment by the correct crop management and the good status of irrigation infrastructures (Thayalakumaran et al., 2007).

To this ends, the irrigation modernization programs contribute to a better use of water and reduce environmental impacts (Lecina et al., 2010b). On the contrary, better water use efficiency is linked to higher water consumptions at basin level that leads to the so-called "irrigation paradox" based on the Jevons or rebound paradox (Berbel et al., 2015; Rodríguez-Díaz et al., 2011).

In Europe, the Water Framework Directive (WFD; UE - European Union, 2000) established the frame for the protection, regulation and management of the aquatic ecosystems, pointing to an efficient and sustainable water use, water withdrawals limitations and reduction of the point and non-point source pollutant loads. As part of the water policy, 1.5 Mha of Spanish irrigated lands have been modernized since 2002 under several governmental national plans (MARM, 2002, 2006; MARM, 2010) with the same objectives as the WFD of water use efficiency, rural development and conservation of the environmental and natural resources. After all the resources invested on it, the environmental and socio-economic effects of this irrigation modernization process should be analyzed with actual and detailed data from modernized and not-modernized irrigated areas with similar characteristics (Alarcón et al., 2016; Fernández-García et al., 2014).

The availability of historical data since the 80 s in regard to crop, fertilizer, irrigation and land management at La Violada Irrigation District (VID; Fig. 1), modernized from traditional surface irrigation to sprinkler irrigation; allows for a reliable evaluation of modernization with pre and post modernization data from the same irrigation district and crop management.

Water balance for a given time period (year) is recognized as a fundamental tool for hydrologic characterization and system evaluation, especially if it is influenced by anthropic actions as irrigation. Thus, on irrigation districts, the proper definition of the main water balance flows is essential for the system characterization, along with establishing hydrological indicators and irrigation quality indices (Burt et al., 1997; Perry, 2011). Moreover, the monitoring of salt and nitrate concentrations in those flows will allow setting up the salt balance (SB) and the nitrate loads (NL) at irrigation district level. SB, will provide the key to assess the potential salinization risk in a given irrigation district (Scofield, 1940).

The main objectives of this paper are (i) to quantify the hydrosaline balance and nitrate loads in the irrigation return flows and (ii) to establish the hydrological and irrigation quality indices in VID, before and after the modernization of the irrigation system from surface to sprinkler. The results will allow comparing the IRF from both systems and establishing the impact of the modernization process upon the hydrological regime and pollutant loads.

2. Material and methods

2.1. Site description

The VID (Ebro River Basin, in northeast Spain; Fig. 1) covers 5234 ha, of which 92% (4808 ha) belong to Almudévar Water User Association (AWUA) and the rest to Tardienta and Gurrea de Gállego Water User Associations (7% and 1% respectively). The VID defines a fairly closed hydrological system, contoured by three concrete irrigation canals (Monegros, La Violada and Santa Quiteria), at higher elevation than the VID. The relief is quite flat (ranging from 345 to 414 m above sea level) except for some hills within. The soils are mainly characterized by the presence of calcite and gypsum and predominant silty texture all over the VID (Jiménez-Aguirre et al., 2018a,b).

Four gullies flow into the district from the drylands to the northeast and join the drainage network of the VID (Valenticosa, Las Pilas, Azud and Valdepozos Gullies), while the two main drainage ditches collecting the IRF join upstream the gauging station nº EA-9230 of the Ebro River Authority (CHE; Fig. 1). Due to an impervious clay layer underlying the district (Faci et al., 1985; ITGE, 1995a,b), deep percolation can be neglected and the only significant water outflows take place through the gauging station. This station allows for quantifying and monitoring the IRF pollutant loads (salts and nitrate) from VID.

Climate is dry, subhumid and mesothermic. Precipitations are concentrated in spring and autumn with an annual average of 458 mm (data from 1964 to 2014; Jiménez-Aguirre et al., 2018a). The mean temperature was 13.5 °C for the same period; the hottest month was July with mean temperature of 22.8 °C and the coldest was January (5.0 °C). Reference evapotranspiration (ET_0; Penman-Monteith) was 1166 mm for the period of 1995–2008 (Barros et al., 2011a).

2.2. Irrigation systems

Irrigation water is diverted from the Gállego River (Ebro River tributary) and distributed through the Monegros Canal (from the Sotonera Reservoir; Fig. 1). It presents excellent quality for irrigation [EC ~0.4 dS/m, [NO_3^-] < 1 mg/l and SAR < 1 $(mmol_c/l)^{0.5}$; Barros et al., 2012a] Since irrigation started in the 1930 s, border irrigation prevailed in VID before the modernization. The irrigation system was designed for crops with low-water-needs (winter grains), with low capacity ditches and leveled basins of small size. The gradual introduction of crops with higher needs (corn and alfalfa) resulted in longer irrigation intervals (around 13 days) and therefore, in low irrigation efficiencies (Faci et al., 2000; Playán et al., 2000). Also, huge water loses took place through canal seepage from the three main irrigation canals (Barros et al., 2011a; Isidoro et al., 2006a). The huge irrigation volumes used along with the seepage and the hydrologic characteristics of VID forced farmers to install sub-surface drainage systems since the 1940′s (De los Ríos, 1966), underlining along time the need for a modernization of irrigation infrastructures.

Modernization works to pressurized irrigation at AWUA, took place in 2008-09, although some infrastructure improvements were made during the 2000 s as the new elevated Violada Canal (in 2003) and the five in-line irrigation reservoirs (1999 to 2005) (Barros et al., 2011a). The modernized sprinkler system in AWUA consists of a pressurized pipe network with 298 hydrants supplied from the reservoirs and scheduled through a remote control system, resulting almost in on-demand irrigation. The works took place after a process of land consolidation to facilitate tillage and cropping operations: the existing land leveling was eliminated and some of the older open drainage lines were buried to increase crop area. This process resulted in a much lower number of plots of greater size (Jiménez-Aguirre, 2017; Stambouli et al., 2014). But, the installation of the buried irrigation lines affected the existing tile-drains, and some farmers have begun the installation of new tile-drains as needed in their plots after 2011 (Gómez-Lanuza, 2016).

Previous studies in VID on water and pollutants and crop management (Barros et al., 2011a,b, 2012a,b; Isidoro et al., 2004, 2006a,b) set up a wide database from 1995–98 and from 2005–08, completed in this work for the years 2009–15. The actual information on crops, water and fertilization management in the VID was provided by the AWUA and Tardienta and Gurrea de Gállego Water User Associations, and their farmers. Those data allow for comparison between surface and