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Influence of irrigation water management on the quantity and quality of irrigation return flows

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SUMMARY

Irrigated agriculture is working towards environmental sustainability but more study is needed regarding the agro-systems' response to alterations imposed on them. This work analyzed the repercussions that alternative irrigation management can cause on water use and on the quality of irrigation return flows.

The case of Bardenas Canal Irrigation District no. V (ID-V) was studied, by analyzing the change of salinity and nitrate concentration in the drainage network through monthly samplings, before (2000) and after (2007) ID-V implanted alternative flood irrigation management.

The results showed that the electric conductivity (25 °C) and nitrate concentration in the drainage ditches increased in 2007 (0.99 dS/m and 62 mg/l) with respect to 2000 (0.86 dS/m and 57 mg/l). Nevertheless, the decrease in irrigation drainage in 2007 (88% lower in 2007 when compared to that of 2000) was a result of the decrease in water requirement (594 mm in 2007 against 752 mm in 2000) and of the increase in irrigation efficiency (93% in 2007 and 67% in 2000), causing the Riguel River to present a lower flow (13% inferior when compared with 2000), lower salinity (1.08 dS/m in 2007 and 1.18 dS/m in 2000), and lower nitrate concentration (29 mg/l in 2007 and 33 mg/l in 2000) when exiting ID-V in 2007.

In summary, simple alternatives in irrigation management achieved an increment of 26% in water use, decreasing by 20% and 24% the salt and nitrate masses exported, respectively, ameliorating the quality of the system receiving the irrigation return flows (Riguel River).

Introduction

Irrigation notably increases the yield of agricultural productions and allows stability in the supply of food and some raw materials. In fact, it has such an important impact that only 20% of the world's agrarian surface generates 40% of agricultural production, using at the same time 70% of water resources (FAO, 2003).

Although the water withdrawn to be used in agriculture is elevated, FAO (2003) estimates that at a global level, only half of the water applied is consumed by plants, and a considerable part of the initial water ends up in aquifers and rivers. As in the majority of water-requiring activities, return flows present inferior quality and therefore a control of the physicochemical characteristics of these return flows is necessary to assure possible posterior use.

There is a growing importance in establishing specific levels/ranks for the quality of water resources, a task developed by the World Health Organization (WHO, 2006), by the Food and Agriculture Organization of the United Nations (FAO; Ayers and Westcot, 1994), and also by governmental agencies (US Environmental Protection Agency, European Environment Agency-European Union), with rules and guidelines related to water use in function of the consumer sector (EU, 1998, 2000; EPA, 2000).

The main impacts of irrigation practice are the reduction or change in the natural water flows (Cai et al., 2003; Ji et al., 2006), soil and water salinization (Tanji and Kielen, 2002), and the contamination of water by nitrate derived from nitrogen fertilization (Lorite-Herrera and Jimenez-Espinosa, 2008), which in extreme cases can cause eutrophication (Kizuka et al., 2008) and hypoxia (Scavia and Bricker, 2006) of aquatic environments.

The great extension of the agrarian area (1500×10^6 ha; FAO, 2000) makes it one of the main sources of nonpoint water contamination, hindering quantification and control when compared with urban and industrial contamination which have a punctual source

Abbreviations: CAP, Common Agricultural Policy; CHE, Confederación Hidrográfica del Ebro-Ebro Basin Authority; D_I, Drainage proceeding from irrigation; EC, Electrical Conductivity at 25 °C; EMR, Evaluador Medioambiental de Regadíos-Irrigation Land Environmental Evaluation Tool; ET_0, Reference evapotranspiration; ET_C, Potential evapotranspiration; *I*, Irrigation; ID-V, Bardenas Canal Irrigation District no. V; IE, Irrigation efficiency; m.a.s.l., Meters above sea level; $[NO_3^-]$, Nitrate concentration; NF, Nitrogen fertilization needs; *P*, Precipitation; P_{ef}, Effective precipitation; *Q*, Flow; TDS, Total dissolved solids; VC, Variation coefficient; WHC, Water holding capacity; WR, Water requirement.

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(Ongley, 1996; ME, 2007). Therefore it is necessary to develop environmental studies to evaluate the use of agrarian supplies (mainly water and fertilizers) in relation to its management and the contamination induced to water resources.

The analysis of irrigation and fertilization tests in experimental conditions demonstrated that it is possible to maintain irrigation production by reducing the water volume applied and along with it, the water, salt, and nitrate leaching (Caballero et al., 2001; Spalding et al., 2001; Feng et al., 2005; Gehl et al., 2005; Li et al., 2007; Luo et al., 2008). From these tests, guidelines were developed, oriented to the maximization of water and nitrogen fertilizer use, minimizing the environmental impact generated by the agrarian sector.

Unfortunately, the results obtained from highly-controlled tests (lysimeters and experimental plots) have not been sufficiently evaluated and therefore further studies are necessary to consider greater surfaces and analyze the spatial–temporal evolution of agroenvironmental impact before implanting possible alternatives in "real" irrigated lands.

By means of monitoring and controlling water flows (drainage networks and rivers) that actuate as collectors of irrigation return flows, water quality can be associated with the climatic, hydrogeological, and agronomic characteristics of the territory it proceeds from, evaluating possible changes that improve irrigation management.

In this way, it is possible to advance in scientific research, going from very controlled punctual tests to conditions closer to the reality of agro-systems. The objective of this work is to analyze the repercussions that alternative irrigation management can cause on water use and on the quality of irrigation return flows.

Study area description

The study zone is Bardenas Canal Irrigation District no. V (ID-V), located on the left margin of the medium Ebro River Basin (Fig. 1). The zone extends itself for 15,500 ha and is supplied by good quality waters (Electrical Conductivity = 0.3 dS/m; nitrate concentration = 2 mg/l) from the Yesa reservoir.

SIGT (1985) classifies the climate of the study zone as Mediterranean warm weather, as the region presents historic reference evapotranspiration (ET_0) of 1068 mm/year and precipitation (P) of 460 mm/year (http://oficinaregante.aragon.es). The driest months correspond to Winter and Summer seasons, while the most humid months correspond to Spring and Fall.

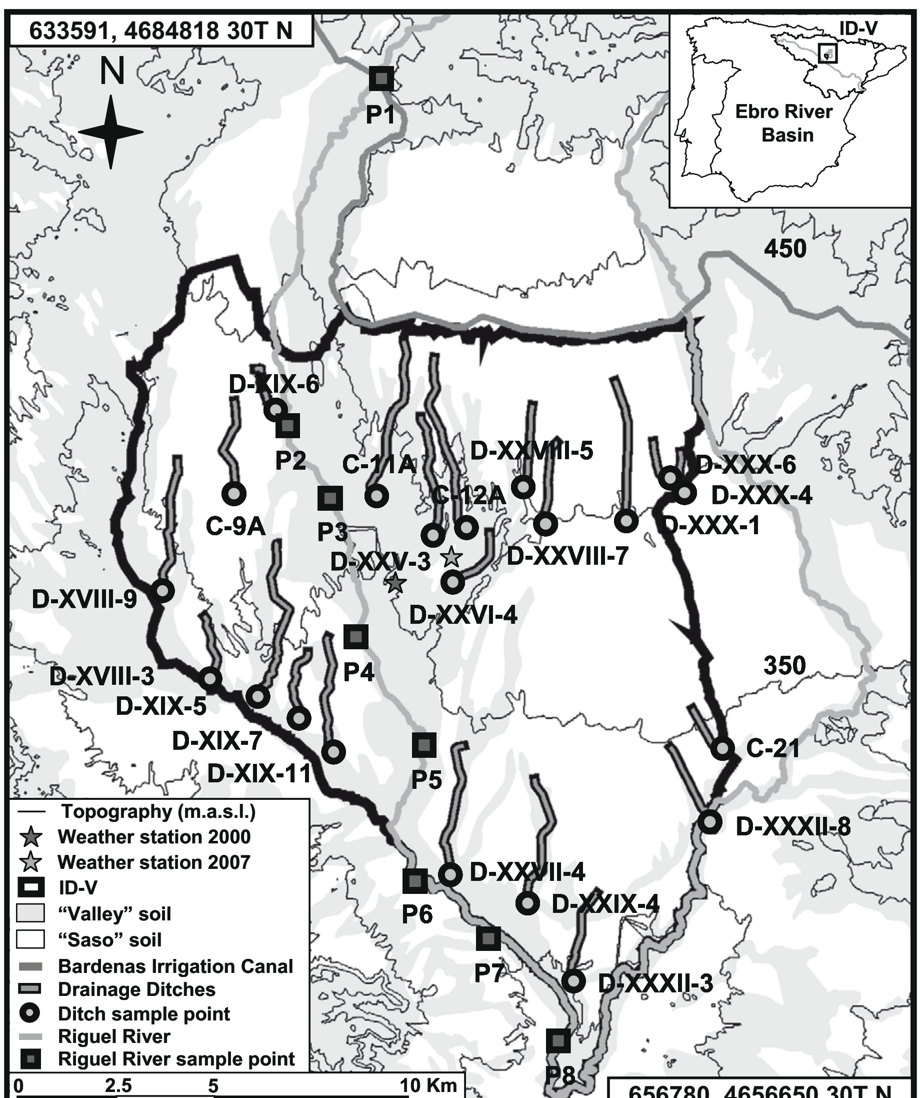

Fig. 1. Location of Bardenas Canal Irrigation District no. V (ID-V) in the Ebro River Basin. Location of the weather stations, soil cartography, Bardenas irrigation canal, sampling locations for the 21 drainage ditches and their belonging hydrological basins, and the eight sampling locations along the Riguel River (P1–P8).

Geologically, ID-V is located in the Ebro basin domain, a Cenozoic and Quaternary basin. More specifically, it is located in the Quaternary glacis and alluvial levels that lie on a tertiary substratum that establishes the regional impervious boundary. Locally, the glacis and alluvial levels constitute detritic aquifers drained by a dense drainage network of ditches in charge of evacuating drainage water, mainly towards the Riguel River, which crosses ID-V from North to South (Fig. 1).

On the glacis (70% of ID-V surface) shallow-depth soils can be found with a large content of stones, with good internal drainage, low water holding capacity (WHC = 60 mm), and low salinity (Lecina et al., 2005), classified according to the Soil Survey Staff (1992) as Calcixerollic Xerochrept, locally denominated as "saso". The remaining 30% of ID-V presents deep soils on alluvial levels or on Tertiary lutites (main source of salts), and characterized by a higher WHC (182 mm; Lecina et al., 2005), classified as typic Xerofluvent (Soil Survey Staff, 1992).

A spatial–temporal analysis of the ID-V drainage water quality was accomplished by Causapé et al. (2004a), through monthly monitoring of Electrical Conductivity at 25 °C (EC) and nitrate concentration ($[NO_3^-]$) in the waters of the drainage network and Riguel River, between October 1999 and September 2000 (hydrological year: 2000). The results showed a low-moderate salinity (0.87 dS/m) and elevated nitrate content (55 mg/l) of the irrigation return flows, in such a way that the Riguel River waters presented minimal EC and $[NO_3^-]$ values at the beginning of ID-V during the irrigation period (0.45 dS/m and 2 mg/l), reaching maximal values when exiting ID-V during the less-irrigated period (1.55 dS/m and 50 mg/l).

The results of the study accomplished by Causapé et al. (2004a) led to a search for improvement alternatives through changes in irrigation water management. In the last few years there has been a greater water control, allocating maximum irrigation allowances at the beginning of each irrigation season, in function of the water reserves in the Yesa reservoir.

Also, the rotation flood irrigation system was replaced by an on-demand irrigation system, allowing the farmer to decide on the date and irrigation rate to apply according to the allocated water and to the crop distribution implanted, and not being "obligated" to irrigate in unnecessary periods so as not to lose his irrigation turn. Irrigation water control at a plot level also allowed the change from payment per surface area to an irrigation water consumption account.

The changes in irrigation management implemented by ID-V in the last few years may have influenced the quality and quantity of drainage waters. Building on the work of Causapé et al. (2004a), the objective of this study is to analyze the repercussions that the changes implemented in ID-V caused and on water use and on the quantity and quality of irrigation return flows by means of a new annual monitoring of the drainage network (hydrological year: 2007).

Methodology

Agroclimatic characterization

An agroclimatic characterization of ID-V was carried out for the hydrological years concerning the study (2000 and 2007). The execution of the Irrigation Land Environmental Evaluation Tool (EMR in spanish; Causapé, 2009) generated soil water balances for the entire ID-V; the application of EMR criteria to the balances allowed the estimation of effective precipitation (P_{ef}), water requirement (WR), drainage proceeding from irrigation (D_I), and irrigation efficiency (IE) for 2000 and 2007.

For the development of daily soil water balances, a WHC of 100 mm was introduced, obtained from the soil distribution (70% "saso" and 30% valley) and from their respective WHC ("saso": 60 mm, valley: 182 mm; Lecina et al., 2005). To perform the daily balance, initial soil water content was considered to be 1/2 WHC.

Daily data for precipitation (P) and reference evapotranspiration (ET_0) by Penman–Monteith (Allen et al., 1998) were obtained from two weather stations located in the geographical center of ID-V (Fig. 1; year 2000: Martinez-Cob, personal communication; year 2007: Network of the Ministry of Agriculture for Irrigation Support, http://oficinaregante.aragon.es).

Crops distribution for the year 2000 were facilitated by ID-V while in 2007 the data were collected from the annual declarations the farmers made to obtain subsidies related to the Common Agricultural Policy (CAP). Irrigation volumes were facilitated by the Ebro Basin Authority (CHE). The agronomic variables required for the estimation of the potential evapotranspiration (ET_C: crop coefficients and vegetative periods) and nitrogen fertilization needs (NF: crop nitrogen extraction and average crop production) for the two study years were the same as proposed by EMR for the agrarian district of Ejea (Zaragoza), which includes ID-V.

Spatial–temporal evolution of EC and $[NO_3^-]$ in drainage waters

The evolution of water quality in drainage waters of ID-V was analyzed for the hydrological years of 2000 and 2007. For such, the monthly sampling performed in 2000 (Causapé et al., 2004a) was repeated in 2007, maintaining the 8 sampling locations along the Riguel River (Fig. 1) but reducing the number of drainage ditches sampled, from 28 in 2000 to 21 in 2007, because of changes in the drainage network between the study years. Only the 21 remaining drainage ditches were utilized in the data analysis for both years.

The water samples were taken to the laboratory where the EC was determined using an Orion five-star conductivity meter equipped with a DuraProbe, and nitrate concentration ($[NO_3^-]$) analysis was carried out using a colorimetric method (AutoAnalyzer 3).

The spatial evolution of the drainage water quality was obtained by a Cluster multivariate statistical analysis (Hair et al., 1999) taking as variables from 2007, the average EC and $[NO_3^-]$ of drainage waters, type of soil, percentages of alfalfa, rice, and corn, nitrogen fertilization needs, and irrigation volume applied to each one of the 21 drainage ditches' hydrological basins.

The hydrological basins were delimited starting from the Digital Terrain Model of the Ebro basin Mdt25 (ME, 2003) and from the Hydrotools tool of software ArcGIS 9.2.

The type of soil was quantified by the percentage of "saso" soils in each basin, obtained from the cartography facilitated by CHE (Fig. 1). The crop surface of each basin was obtained from the CAP 2007 farmers' declarations, extracting the percentages of alfalfa, rice, and corn, as well as the nitrogen fertilization needs of each basin.

As the irrigation volumes were unknown, they were estimated from their ET_c and IE, pondering the IE by plot estimated by Lecina et al. (2005) in 2000 for both types of soil (IE_{saso} = 53% and IE_{valley} = 62%) and correcting the values by the IE variation in 2007, quantified in the previous section.

The Cluster analyses were accomplished with the standardized data, the squared Euclidean distance, and the Ward method to obtain hierarchical conglomerates (Hair et al., 1999).

Pollutants loads exported and quality of the Riguel River

The salt and nitrate masses exported by the Riguel River (sampling location P8) were determined for 2000 and 2007, through the multiplication of the volume of water by its salt and nitrate concentration. The Total Dissolved Solids (TDS) was obtained from the EC by equation:

$$\mathrm{TDS}\ (\mathrm{mg/l}) = 682\ \mathrm{EC} + 89;\ n = 8;$$
$$R^2 = 0.98;\ (\text{Causapé et al., 2004a}).$$

The water flow of the Riguel River when exiting ID-V (sampling location P8) was obtained in 2000 (Causapé et al., 2004a) through the relation between daily flow data of the Arba river in Tauste ($Q_{\mathrm{Arba\ Tauste}}$, CHE) and the Riguel River at P8 ($Q_{\mathrm{Riguel\ P8}}$, CHE), for the periods both locations counted with operative gauging stations (1994–1997).

In 2007, the gauging station at P8 operated until May, and from then on data for the Arba River in Tauste was corrected by the equation obtained for the rest of the hydrological year:

$$Q_{\mathrm{Riguel\ P8}} = 0.56Q_{\mathrm{Arba\ Tauste}} - 0.32;\ n = 178;\ R^2 = 0.75;\ p < 0.001$$

Results

Agroclimatic characterization

Between 2000 and 2007 there were significant changes in crops distribution. While in 2000 alfalfa (31%) and corn (29%) were the major crops, in 2007 winter wheat was the major crop (33%). This was due to the fact that 2007 was preceded by low water reserves in the Yesa reservoir, and also influenced by the new conditions imposed by CAP (Atance et al., 2006) in such a way that, given the water shortage and the equality of subsidies, the farmers preferred crops with lower irrigation demands and production costs (mainly substituting corn for winter wheat; Table 1). The crops distribution changes led to a variation in NF; therefore, the fertilization needs of ID-V in 2007 (106 kg N/ha) were 5% lower than 2000 values (115 kg N/ha).

P (372 mm) and ET_0 (1260 mm) for 2007 were 15% higher (Table 1) than 2000 values (325 and 1099 mm, respectively), being both years dryer than the average year for the study zone (P = 460 mm and ET_0 = 1068 mm; www.oficinaregante.aragon.es).

Although the 2007 crops distribution was oriented towards a lower irrigation necessity, ET_C was 5% higher because ET_0 was also of a higher value. Nevertheless, according to EMR criteria, the P_{ef} of 2007 was double the 2000 values, causing the WR of 2007 to be 18% lower when compared with 2000 (Table 1).

The decrease in WR, along with the changes in irrigation management implemented by ID-V, caused the irrigation volume of 2007 to decrease by 42% when compared with the 2000 volume, decreasing the drainage proceeding from irrigation in 88% (Table 1).

Therefore, the irrigation management changes implemented by ID-V were positive regarding water use, in such a way that IE was incremented from 67% in 2000 to 93% in 2007, similar to the IE increase of 24% found by García-Garizábal et al. (2009) in a small irrigation basin belonging to ID-V. The decrease of WR along with an increase in IE caused a considerable decrease in the volume demand and irrigation return flows.

Evolution of EC and $[NO_3^-]$ in irrigation waters

Temporal evolution

Average EC for the water circulating in the ID-V drainage ditches in 2007 (0.99 dS/m) was 15% higher to that of 2000 (0.86 dS/m). While in 2000 38% of the samples did not present any restrictions for their irrigation use (EC < 0.70 dS/m, Ayers and Westcot, 1994), in 2007 this percentage decreased to 16% (Fig. 2).

Minimal EC values coincided for both years with the EC values for irrigation water (0.3 dS/m); the maximal value for 2007 (2.34 dS/m for March in D-XVII-3) was 20% above that of 2000 (1.94 dS/m for May in C-11-A), although it did not exceed the severe restriction limit proposed by Ayers and Westcot (1994) for its agrarian use (EC > 3 dS/m).

The salinity of ID-V drainage waters was lower than other irrigated land with more saline soil and/or irrigation water. The differences between both study years can be justified by the increase in irrigation efficiency in 2007, which caused greater evapotranspiration and therefore higher drainage water salinity, as confirmed by other works (Caballero et al., 2001).

The irrigation return flows of the studied irrigated areas with saline soils and high irrigation efficiencies present EC between 7.5 d/Sm (Tedeschi et al., 2001) and 11.8 dS/m (Caballero et al., 2001), while the EC for other irrigated areas with lower irrigation efficiencies oscillates between 2.4 dS/m (Isidoro et al., 2006a) and 9.0 dS/m (Caballero et al., 2001).

Regarding nitrate, the average concentration in water during 2007 (62 mg/l) increased by 9% with respect to 2000 (57 mg/l). While in 2000, 51% of the collected samples exceeded the 50 mg/l limit established for waters intended for human consumption (EU, 1998), in 2007 this percentage increased to 64% (Fig. 2).

For both years there was a coincidence of minimal values of nitrate inferior to 10 mg/l and maximal values of approximately 150 mg/l, except for a sample collected in 2000 that presented 300 mg/l, for which Causapé et al. (2004a) attributed such high value to the direct disposal of pig slurry from a farm into the drainage ditch.

In spite of the lower NF, the increase in nitrate concentration from 57 to 63 mg/l is coherent with the increase of IE from 67% to 93%, as was confirmed in other irrigated zones. Therefore, irrigated lands such as Monegros II (Cavero et al., 2003) with high IE (90%) present higher nitrate concentrations (125 mg/l) than Monegros I irrigated lands (IE = 48% and $[NO_3^-] = 28$ mg/l; Isidoro et al., 2006b) with similar nitrogen fertilization needs.

Analyzing the monthly evolution for each study year it was observed that for both years, the greater monthly water contributions and lower irrigation water concentrations were produced in Summer months when irrigation application was maximal (Fig. 3). However, the highest concentrations occurred in the lowest irrigation period (from October to March) although the monthly maxi-

Table 1
Crops distribution, precipitation (P), effective precipitation (P_{ef}), reference evapotranspiration (ET_0) potential evapotranspiration (ET_C), water requirement (WR), irrigation (I), drainage proceeding from irrigation (D_I) and irrigation efficiency (IE) in Bardenas Canal Irrigation District no. V during the hydrological years of 2000 and 2007.

Year	Corn (%)	Winter wheat (%)	Alfalfa (%)	Grass (%)	Sunflower (%)	Rice (%)	Other (%)	Fallow (%)
2000	29	13	31	5	8	4	7	3
2007	18	33	23	10	1	4	4	6
	P (mm)	P_{ef} (mm)	ET_0 (mm)	ET_C (mm)	WR (mm)	I (mm)	D_I (mm)	IE[1] (%)
2000	325	175	1099	857	732	1094	362	67
2007	372	360	1260	904	594	639	45	93

[1] $IE = [1 - (D_I/I)] \cdot 100$.

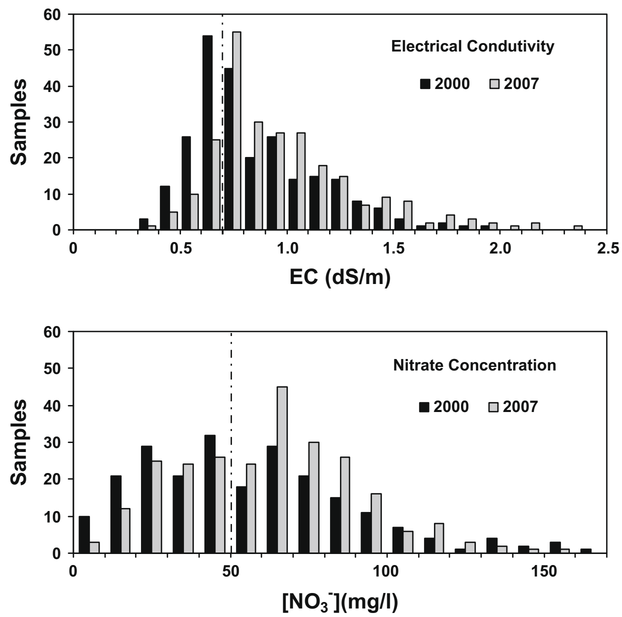

Fig. 2. Histograms for Electrical Conductivity at 25 °C (EC) and nitrate concentration ($[NO_3^-]$) for the 21 drainage ditches sampled during the hydrological years of 2000 and 2007. The discontinuous lines mark the first degree of restriction on irrigation use (0.70 dS/m; Ayers and Westcot, 1994) and the $[NO_3^-]$ quality of water intended for human consumption (50 mg/l; EU, 1998).

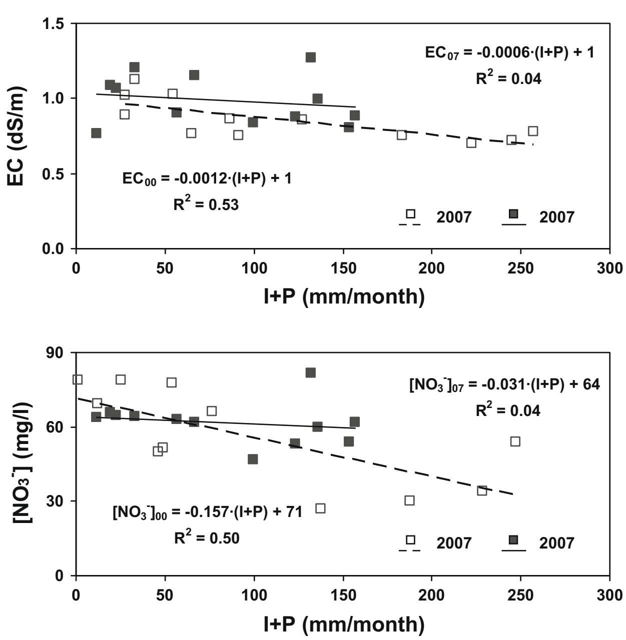

Fig. 3. Relationship between average monthly Electrical Conductivity at 25 °C (EC) and nitrate concentration ($[NO_3^-]$) for the 21 drainage ditches sampled versus monthly hydric supplies as Irrigation (I) and Precipitation (P) in Bardenas Canal Irrigation District no. V for the hydrological years of 2000 (open squares) and 2007 (filled squares).

mal EC (1.27 dS/m) and $[NO_3^-]$ (82 mg/l) was produced in April after the highest precipitation event of the year.

In this regard Klocke et al. (1999) already confirmed that, in semiarid climate the leaching in non-irrigated periods depends on the nitrate present in the soil and on precipitation. The absence of crops that take the nitrate available in the soil and decrease soil water content is a contribution to leaching. However, Caballero et al. (2001) are in favor of making use of the high precipitation events that occur in this type of climate as a method to leach the accumulated salts from the soil profile.

In 2000, both EC and $[NO_3^-]$ monthly averages for the 21 sampled drainage ditches presented significant relationships ($p < 0.01$) with the hydric monthly contributions ($I + P$) in such a way that, with greater contributions by irrigation and precipitation, the drainage waters presented lower concentration (Fig. 3). This was also observed in previous studies of other irrigated lands (Tedeschi et al., 2001; Isidoro et al., 2003), where the flow increase (conditioned by the contributions of irrigation and precipitation) was related to the lower salinity of the drainage waters. Nitrate also complies with this relationship (Isidoro et al., 2003), although it is affected by the rates and dates of fertilizer application (Isidoro et al., 2006b). The relationships between EC-$[NO_3^-]$ and $I + P$ were not maintained in 2007 (Fig. 3), when the higher irrigation efficiency ($IE_{00} = 67\%$ against $IE_{07} = 93\%$) granted a smaller variability in water quality, particularly for nitrate concentration ($VC_{00} = 60\%$ against $VC_{07} = 46\%$). Nitrate concentration variability was greater to the EC variability ($VC_{00-07} = 35\%$), not influenced by the variability associated with nitrogen fertilization.

The variability of nitrate concentration in 2000 was of the same order as obtained in other traditional irrigation systems (Causapé et al., 2004b; Isidoro et al., 2006b), while the variability in 2007 was approximately that of the lowest variability registered for modern pressurized irrigation systems ($VC_{\text{Monegros II}} = 26\%$; Cavero et al., 2003). The inclinations of the regression lines between EC-$[NO_3^-]$ and $I + P$ were reduced in 2007, by half for the EC and to one-fifth for nitrate (Fig. 3).

This was due to the fact that irrigation management in 2007 was more adequate, decreasing the irrigation water directly diverted to the drainage network (as confirmed by Causapé et al., 2004a), and in consequence, reducing the number of samples with lower salt and nitrate concentration (Fig. 2). It is worthwhile to note that the number of samples with higher EC values increased in 2007, while for $[NO_3^-]$ there was a decrease (Fig. 2) as a consequence of lower fertilization needs.

The results indicate that the lower nitrogen fertilization needs and possible higher efficiency in the application of fertilizers obtained in systems with higher irrigation efficiency was not sufficient to compensate higher evapoconcentration, and therefore there was an increase in salinity and nitrate concentration in the drainage water, resulting in more uniformity in these values throughout the year.

4.2.2. Spatial evolution

The Cluster analysis classified the hydrological basins of the 21 drainage ditches into three groups (Table 2). The first group included 67% of the sampled drainage ditches, whose basins presented an elevated percentage of low-salinity soils and low WHC ("saso" = 72%) that conditioned the lower efficiencies of the flood irrigation system (Lecina et al., 2005) and therefore low EC of the drainage waters (0.95 dS/m). However, the highest fertilization needs were observed (115 kg N/ha) because of the greater cultivation of corn ($NF_{corn} = 243$ kg N/ha), inducing high nitrate concentrations in the drainage waters (61 mg/l).

The second group was constituted of 24% of the sampled drainage ditches, whose basins presented the highest percentage of "saso" soils (86%), the lowest EC (0.94 dS/m), and highest $[NO_3^-]$ (73 mg/l). This highest $[NO_3^-]$ factor was a surprise when considering that the lowest NF (71 kg N/ha) was estimated for this group, because of the extension dedicated to alfalfa (44%) when compared to other groups.

Alfalfa does not require nitrogen fertilization because it is a leguminous plant (Malhi et al., 2002), although Delgado and Muñoz (2005) estimated by surveying the farmers that 50 kg N/

Table 2
Number of drainage ditches and percentage over the total, average yearly Electrical Conductivity at 25 °C (EC) and average yearly nitrate concentration ($[NO_3^-]$) in the drainage waters, saso soils percentage, Irrigation water, alfalfa percentage, rice percentage, corn percentage and nitrogen fertilization needs (NF) in each group classified by Cluster analyses of the 21 ditches and their respective hydrological basins during the hydrological year of 2007.

Group		1	2	3
Drainage ditches	no. (%)	14 (67%)	5 (24%)	2 (9%)
EC	dS/m	0.95	0.94	1.39
$[NO_3^-]$	mg/l	61	73	36
Soil	% saso	72	86	54
Irrigation	mm	910	962	1010
Alfalfa	%	18	44	12
Rice	%	1	1	17
Corn	%	15	6	6
NF	kg N/ha	115	71	103

ha year are applied in the study area, which could justify the higher nitrate concentrations found in the second group (Table 2).

Lastly, the third group comprises only two drainage ditches (9% of the basins), which presented the lowest percentage of "saso" soils (54%) and therefore an elevated percentage of soils developed on Tertiary lutites of higher salinity, conditioning a higher EC of drainage waters (1.39 dS/m). Saline soils only allow the cultivation of rice, which is the major crop in this group, leading to higher irrigation volume and lower $[NO_3^-]$ (36 mg/l).

Summarizing, the soil is a key factor in controlling not only the quantity of salts available for leaching but also the type of crops and the irrigation and fertilizer rate applied (mainly in flood irrigation systems), conditioning the quality of the irrigation return flows. Therefore, very permeable soils with low WHC led to a higher nitrate concentration and lower drainage water salinity, while soils with opposite characteristics inverted such a trend.

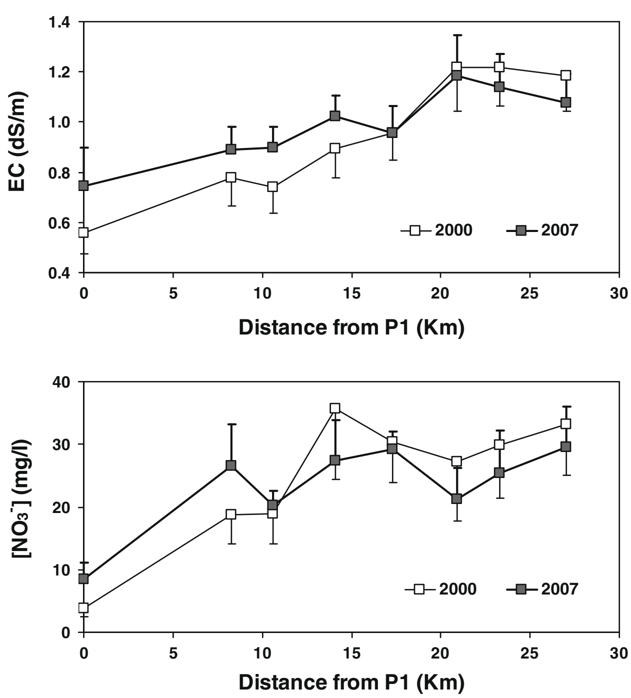

Fig. 4. Average yearly Electrical Conductivity at 25 °C (EC) and average yearly nitrate concentration ($[NO_3^-]$) for the eight sample locations along the Riguel River (P1–P8) during the hydrological years of 2000 (open squares) and 2007 (filled squares). Vertical bars indicate 1/2 standard deviation.

Pollutants loads exported and quality of the Riguel River

EC and $[NO_3^-]$ for the Riguel River when exiting ID-V in 2007 (1.08 dS/m and 29 mg/l) were 9% and 11% lower, respectively, to those values of 2000 (1.18 dS/m and 33 mg/l), although the quality of the waters of the Riguel River evolved differently for the first and last stretch of the river (Fig. 4). In the first stretch, EC and $[NO_3^-]$ were higher in 2007 as a consequence of a higher concentration of the irrigation return flows of ID-V, which constituted almost the total water flow of the Riguel River.

In 2007, due to a decrease in the volume of drainage proceeding from irrigation from ID-V, the last stretch of the Riguel River presented an improvement in water quality, and therefore, presented a lower capacity to vary the water quality of the river. At this final stretch, the river presents significant flows originating from outside the Irrigation District.

All this implies that the average increases of EC and $[NO_3^-]$ in 2007 (0.012 dS/m km and 0.77 mg/l km) were half that of 2000 (0.023 dS/m km and 1.09 mg/l km), confirming a smaller spatial variability of the river's water quality.

For both study years, EC and $[NO_3^-]$ of the drainage ditches network was greater to that of the Riguel River at P1, decreasing the quality of its waters (Fig. 4), which is the same occurrence in other rivers under the influence of an irrigated area (Mhlanga et al., 2006; Ventura et al., 2008; Kato et al., 2009). Although salt and nitrate concentrations increased in the drainage ditches of ID-V in 2007, the decrease in the irrigation drainage volume caused a decrease of 13%, 20%, and 24%, respectively, in the flow and salt and nitrate masses exported by the Riguel River when exiting ID-V (Table 3).

Based on information from the year 2000, a previous geochemical modeling of the Bardenas irrigated land (Causape et al., 2004c), simulated the consequences of an increase in the irrigation efficiencies with values similar to those of 2007. This simulation predicted that the flow and salinity of the Riguel River could decrease by 30%, a value close to what was measured in this study, and reachable if the remaining irrigation communities that dispose of their irrigation return flows into the Riguel River also increased their irrigation efficiency.

Luo et al. (2008), for an irrigation district in China (73,300 ha), also proposed that by reducing irrigation by 10% and controlling the fertilizer rates, the contaminant concentrations would increase in the drainage ditches network, but would reduce irrigation drainage volume up to 60%, decreasing the salt and nitrate masses exported by the irrigated land.

Table 3
River flow at the end of Bardenas Canal Irrigation District no. V (P8), average yearly Electrical Conductivity at 25 °C (EC) and nitrate concentration ($[NO_3^-]$) in drainage ditches and Riguel River (P8), and yearly salt and nitrate masses exported by the Riguel River during the hydrological years of 2000 and 2007.

Year	Flow	Salt			Nitrate		
	Riguel P8	Drainage ditches	Riguel River P8		Drainage ditches	Riguel River P8	
	Hm^3	dS/m	dS/m	$Mg \times 10^3$	mg NO_3^-/l	mg NO_3^-/l	$MgNO_3^-N$
2000	133	0.86	1.19	115	56	33	892
2007	116	0.99	1.08	92	62	29	674

Therefore, although EC and $[NO_3^-]$ increased in 2007 for the drainage ditches network of ID-V, the decrease in irrigation drainage (consequence of the reduction of water requirement and increase of irrigation efficiency) produced a lower flow and lower concentration in the Riguel River waters when exiting ID-V.

Conclusions

The shortage of irrigation water along with the new conditions imposed by CAP caused an expansion of winter wheat at the expense mainly of corn and alfalfa, with higher water requirement and production costs.

The changes in irrigation management implemented by ID-V (i: allocating of irrigation allowances, ii: on-demand irrigation, and iii: water consumption account) increased irrigation efficiency by 26% (from 67% to 93%) which along with the decrease in water requirement (from 732 mm to 594 mm) propitiated that the irrigation volume in 2007 (639 mm) decreased by 42% that of 2000 (1094 mm), decreasing in turn drainage proceeding from irrigation by 88% (from 362 mm to 45 mm).

The increase in irrigation efficiency was associated with an increase in salinity (from 0.86 dS/m to 0.99 dS/m) and nitrate concentration (from 56 mg/l to 62 mg/l) of the drainage ditches network, granting a lower temporal variability. The spatial variability was conditioned by the type of soil in such a way that more permeable soils with lower water holding capacity presented the highest nitrate concentration and lowest salinity in drainage waters.

Although salinity and nitrate concentration increased in the drainage ditches of ID-V, the reduction in the volume of drainage proceeding from irrigation (consequence of the decrease in the water requirement and increase of irrigation efficiency) caused a decrease of 13%, 20%, and 24%, respectively, in the water flow and salt and nitrate masses of the Riguel River, increasing in turn water quality (EC from 1.19 dS/m to 1.08 dS/m and $[NO_3^-]$ from 33 mg/l to 29 mg/l).

Therefore, simple alternatives in irrigation management allowed the increase in irrigation water use efficiency and improvement of water quality of the river receiving the irrigation return flows. These are the objectives which must be attained when managing irrigated areas to reach environmental sustainability.

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