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Assessment of the Irrigation Advisory Services' Recommendations and Farmers' Irrigation Management: A Case Study in Southern Spain

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Abstract The Local Irrigation Advisory Services (LIAS) carry out essential work to achieve an efficient use of irrigation water at field and irrigation scheme level, which is crucial in Mediterranean irrigation systems. However, it is unusual to find agronomic and economic assessments of LIAS advice. In this work, the LIAS operating in the Genil–Cabra Irrigation Scheme (southern Spain) was evaluated during the first 5 years of its advice. Acceptance by farmers of the LIAS recommendations was evaluated by using agronomic indicators, such as ARIS (Annual Relative Irrigation Supply). $ARIS_{LIAS}$ (actual irrigation applied v. recommendation of LIAS) with values ranging from about 0.23 for wheat and sunflower, and 0.94 for maize, also detecting a high variability between farmers, which indicated a scant acceptance of the LIAS recommendations. The economic evaluation of irrigation was made through two economic indicators, Irrigation Water Productivity (IWP) and Irrigation Water Benefit (IWB). IWP values varied significantly between different crops: around 0.23€ m^{-3} in wheat, sunflower and maize, about 0.53 € m^{-3} in cotton and sugar beet, and values higher than 2.0€ m^{-3} in garlic, for optimal irrigation schedules. For IWB, trends were similar, emphasizing the low IWB values in wheat and sunflower (average values of 0.06 and 0.13€ m^{-3}, respectively). Consideration of these economic indicators by LIAS could not only help to obtain more suitable and economically profitable irrigation schedules, but also contribute towards a greater acceptance of advisory services by farmers, by shifting the emphasis from maximizing production to maximizing irrigation profitability.

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1 Introduction

Irrigation is considered to be one of the most complex operations that a farmer can carry out due to the multiple factors that affect correct irrigation management. Lack of knowledge is usually substituted by previous experience, with the result, in many cases, of a wrong irrigation management, resulting in low water-use efficiency and adverse effects on the environment. That is why the Irrigation Advisory Services (IAS) can be considered as an essential tool for improving irrigation water management, using the irrigation scheme as an action framework. Crop water management and irrigation scheduling, design and installation of irrigation systems, water quality control, and certain agricultural advisory services (e.g. pest management, marketing, new alternative crops, etc.) have been some of the main activities of the IAS (Smith and Muñoz 2002).

The first experiences with IAS were carried out in USA (Eching 2002; English 2002). CIMIS (California Irrigation Management Information System) probably illustrates the potential and constraints of IAS best (http://www.cimis.water.ca.gov), and since its establishment (in the early 1980's) it has been a global reference. It provides information to assist California's irrigators in managing their water resources efficiently (CIMIS 2000; Eching 2002), encouraging ET-based irrigation scheduling, and providing information related to irrigation in particular and agricultural practices in general. Recently, the most advanced advisory services have included tools related to remote sensing and geographic information systems in order to improve irrigation management and water-use efficiency (Martín de Santa Olalla et al. 2003; Fortes et al. 2005), providing crop pattern information and accurate ET maps.

Focussing on Spain, in Castilla-La Mancha an important effort has been made in the last few years in relation to the IAS (e.g. Martín de Santa Olalla et al. 2003; Ortega et al. 2005; Córcoles et al. 2010; Montoro et al. 2011). Similarly, in Andalusia, the southernmost region of Spain, with about 80 % of the total water resources devoted to irrigation, the IAS should be a strategic tool for improving irrigation management performance. In 1998, the Regional Administration of Andalusia promoted the establishment of IAS in the main irrigation schemes in the region, in an effort to improve irrigation water management. Initially, three Local Irrigation Advisory Services (LIAS) were created, which started their advisory services in 2003. Currently, the LIASs are established in 16 irrigation districts located mainly in modern irrigation schemes, potentially providing assessment of more than 100,000 ha. The services provided by the LIAS in the region include: general irrigation schedules, irrigation performance assessment (irrigation system, equipment and infrastructure), irrigation training for technicians and farmers, dissemination of relevant information (monthly written bulletins about irrigation management, a website), and monitoring water quality. Meteorological information is also essential for carrying out the advisory services on irrigation water management. Thus, in recent years, and in parallel to the LIAS, national and regional public institutions have promoted and funded the establishment of the Agroclimatic Information Network of Andalusia (RIA, in Spanish). The RIA provides daily reference evapotranspiration (ET_o) estimations using the FAO Penman-Monteith equation on a daily basis (Allen et al. 1998), as well as daily rainfall and other climate variables, from more than 100 automatic weather stations deployed in the main irrigation schemes of Andalusia (Gavilán et al. 2006).

To achieve proper water management at the irrigation scheme level, a previous irrigation performance assessment is required, which must be taken as a starting point by the LIAS. The use of hydrological simulation models has been useful for this task. The definition of general recommendations and specific irrigation schedules using these models, and their extension to the farmers, has proved to be suitable in previous works (Lorite et al. 2004a, b, 2007; Shirsath and Singh 2010). These models allow the calculation of irrigation performance indicators based on average values for the whole irrigation area (Burt and Styles 1999). These indicators quantify water management by defining the inputs and outputs of irrigation, including amounts of water, yield and economics (Molden and Gates 1990; Burt et al. 1997; Bos et al. 2005). The irrigation performance indicators have been the basis of previous studies to evaluate irrigation performance in the irrigation districts with the support of the IAS (e.g. Quiñones et al. 1999; Giannini and Bagnoni 2002; Martín de Santa Olalla et al. 2003), obtaining acceptable results which permitted the identification of inefficiencies and an improvement in the sustainability of irrigation systems.

In this study, the LIAS operating in the irrigation district ‘Colectividad de Santaella’ located in the Genil–Cabra Irrigation Scheme (GCIS-CS) was evaluated, this LIAS being a good example of the advisory services in modern Spanish irrigation schemes. This area was chosen because it was possible to obtain accurate information on water use and cropping patterns of individualized field-plots for the first five irrigation seasons (from 2003 to 2007) since the establishment of the LIAS. The availability of water-use information at a field-plot level, including several measurements within each irrigation season, allowed a detailed analysis of the irrigation management carried out by individual farmers throughout the irrigation season. In this analysis, irrigation performance indicators have been used to assess the quality and acceptance of the LIAS advice on the irrigation management in the GCIS-CS irrigation district.

We present here the results of a performance assessment of LIAS in the GCIS-CS irrigation district, at field-plot scale, comparing the actual farmers’ behaviour with regard to irrigation recommendations provided by the LIAS and to irrigation requirements obtained by a water balance simulation model previously developed for the study area (Lorite et al. 2004a). Irrigation schedules provided by this simulation model allowed us to assess the suitability of the LIAS recommendations. The comparison between the irrigation schedules was complemented by the analysis of crop yields and profitability of irrigation water. Additionally, proposals for improving water management by farmers and a better functioning of the LIAS in the GCIS-CS irrigation district are also described. Furthermore, some aspects related to the level of acceptance of the service, determination of the causes of the variability in water-management between farmers, or the temporal evolution of the water-management within the irrigation season were analysed.

2 Methodologies

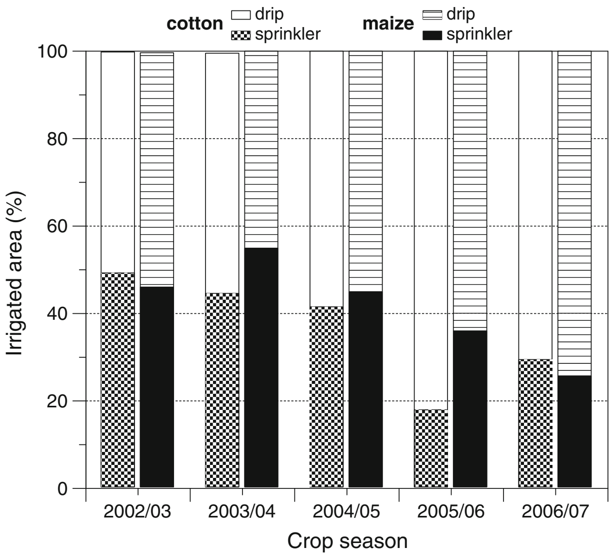
2.1 Study Area Description

The study area, the irrigation district “Colectividad de Santaella” (CS), is located within the Genil–Cabra Irrigation Scheme (GCIS), in the province of Córdoba (southern Spain). The GCIS-CS irrigation district started operating in the 1991 irrigation season on 2,660 ha. This area was expanded to 6,900 ha in 1994, remaining constant until now. The climate is Mediterranean with an annual average precipitation of 505 mm (over a 35 year span) and a rainless summer. The predominant soils according to the Soil Conservation Service classification (USDA-SCS 1975) are Chromic Haploxererts (35 %) and Typic Xerorthent (35 %), with average values of soil water content of 0.30 and 0.15 m^3 m^{-3} at field capacity and wilting point, respectively, for the whole area.

The area has an on-demand modern pressurized delivery system, which provides complete flexibility of frequency, rate and duration of irrigation water delivery. The irrigation method depends mainly on the crop. Thus, crops such as wheat or sunflower are irrigated using hand-move sprinkler systems, while horticultural crops and olive are mainly irrigated by drip systems, and in other crops such as cotton and maize there are combined drip and sprinkler systems with a tendency towards drip irrigation (Fig. 1). The values of water application uniformity (Merriam and Keller 1978), measured by the LIAS in 78 field-plots during the five irrigation seasons analysed, ranged from 40 % to 78 % (average 65 %) for fields with sprinkler systems, and from 58 % to 97 % (average 92 %) with drip systems. The causes of the low uniformities observed were mainly a combination of inadequate irrigation system design and poor irrigation management practices (e.g., slow farmer-response to repair leaks, or replace/reclaim clogged or malfunctioning emitters). The cost of irrigation water (amount paid) in GCIS is calculated using a dual water bill. Thus, one part of the cost is associated with the irrigated area, and the second part is uniquely associated with the volume of irrigation water applied. The first part comprises fixed costs and is based on the maintenance cost of water delivery (including water basin authority fees, amortization/maintenance of the irrigation scheme infrastructure, and personnel/administration costs of the irrigation scheme), and ranged between 50€ ha^{-1} and 158.42€ ha^{-1} in the period 2003–2007. These fixed costs must be paid even if the field-plot was not irrigated for one season. The second part is mainly constituted by the energy cost of water pumping, and increased from 1.75 to 2.98 euro-cents m^{-3} from the irrigation season 2003 to 2007. In contrast to fixed costs, this cost is only applicable when the field-plot is irrigated, and varies with the amount of water applied.

The study was carried out during five successive crop seasons, from 2002/03, year of the beginning of LIAS activities, to 2006/07, with the irrigation district being under a similar irrigation/crop management up to the present. The most frequent crops were wheat, cotton,

Fig. 1 Evolution of the irrigated area by the irrigation method (%), in cotton and maize, during the five seasons analysed. (The total irrigated area of each crop in each season are shown in Table 1)



olive, sunflower and maize that occupied 70–72 % of the cultivated area during the 5 years analysed (Table 1). Other important crops were garlic, sugar beet, beans, and some other horticultural crops. The two first crop seasons analysed (2002/03 and 2003/04) were slightly above the average annual precipitation in the area, while, in the following three seasons, the precipitation was lower, with 2004/05, which was extremely dry with only 223 mm yr^{-1} (Table 2), standing out. Despite this, there were no irrigation water restrictions in 2005, and the farmers applied the highest annual irrigation depth, 428 mm on average, to compensate for the rainfall scarcity. However, in the following two irrigation seasons (2006 and 2007), there were restrictions in water allocation (2500 m^3 ha^{-1}; Table 2).

2.2 Local Irrigation Advisory Service

The LIAS in the GCIS-CS was originally established in 1999, performing at full capacity in the 2003 irrigation season. The tasks of this local advisory service are: to carry out the general irrigation schedules per crop, to determine application uniformity of irrigation systems under field conditions, to assess the new irrigation methods and crops introduced into the area, as well as the control of irrigation infrastructures, among others. The development of irrigation scheduling is the key point in the irrigation water management advisory service. The technician in charge of the LIAS provides weekly irrigation schedules for the main irrigated crops of the area (cotton, maize, garlic, sugar beet, etc.; Table 3). These schedules are communicated to the farmers by local bulletins and personal communication (via SMS or phone call). To obtain those schedules, the technician uses a simplified soil-water

Table 1 Total area (ha) and percentage (%, in parentheses) devoted to the main crops in the GCIS-CS irrigation district during the crop seasons from 2002/03 to 2006/07

Crop	Area									
	2002/03		2003/04		2004/05		2005/06		2006/07	
	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)
Wheat	1394	(20.3)	1804	(26.4)	1565	(23.1)	1765	(26.3)	2133	(30.9)
Cotton	1036	(15.1)	1217	(17.8)	1187	(17.5)	799	(11.9)	965	(14.0)
Olive	746	(10.9)	792	(11.6)	931	(13.7)	982	(14.7)	1185	(17.2)
Sunflower	915	(13.3)	428	(6.3)	279	(4.1)	807	(12.1)	475	(6.9)
Maize	785	(11.4)	618	(9.1)	773	(11.4)	354	(5.3)	231	(3.3)
Garlic	451	(6.6)	547	(8.0)	304	(4.5)	263	(3.9)	324	(4.7)
Sugar beet	445	(6.5)	386	(5.7)	423	(6.2)	413	(6.2)	42	(0.6)
Bean	400	(5.8)	217	(3.2)	317	(4.7)	194	(2.9)	104	(1.5)
Onion	31	(0.4)	119	(1.7)	138	(2.0)	203	(3.0)	136	(2.0)
Green pepper	78	(1.1)	89	(1.3)	160	(2.4)	162	(2.4)	20	(0.3)
Alfalfa	35	(0.5)	89	(1.3)	78	(1.2)	152	(2.3)	148	(2.1)
Potato	18	(0.3)	98	(1.4)	111	(1.6)	84	(1.2)	105	(1.5)
Asparagus	83	(1.2)	47	(0.7)	42	(0.6)	42	(0.6)	40	(0.6)
Other crops	257	(3.7)	223	(3.3)	294	(4.3)	311	(4.6)	736	(10.7)
No Crop	205	(3.0)	152	(2.2)	178	(2.6)	165	(2.5)	246	(3.6)
Total	6878		6827		6779		6697		6890	

Table 2 Rainfall (mm), average irrigation depth applied by farmers (mm), and irrigation water allocation (m^3 ha^{-1}) for each irrigation season in the GCIS-CS irrigation district

Irrigation season[a]	Rainfall (mm)	Irrigation water application (mm)	Irrigation water allocation[b] (m^3 ha^{-1})
2002/03	534	276	5000
2003/04	568	230	5000
2004/05	223	428	5000
2005/06	393	234	2500
2006/07	456	185	2500

[a] From 1st September to 31st August

[b] Average for Guadalquivir river basin (From *Confederación Hidrográfica del Guadalquivir*)

balance model. This simplified model only considers the effective rainfall and the crop evapotranspiration (ET_c), using average values for soil-water properties and considering a single sowing date for each crop. Rainfall and reference evapotranspiration (ET_o) are obtained from an agro-meteorological station belonging to the RIA located inside the irrigation scheme. Effective rainfall and crop coefficients (K_c) were obtained according to the methodology proposed by FAO (Allen et al. 1998), and modified locally following personal experience (Lorite 2002). Irrigation scheduling is based on the assumption that the crops are never water stressed. Thus, the LIAS provides a single irrigation schedule for each crop and irrigation system for the whole area, taking into account the corresponding averaged water application uniformity, previously measured in a large number of field-plots.

2.3 Water-balance Simulation Model

An advanced water-balance simulation model developed for the study area called LORMOD (Lorite et al. 2004a, 2007) was used to obtain the optimal irrigation schedules. The model was applied at field-plot level, providing a specific irrigation schedule for each crop-field plot. Also, the model was used to calculate actual evapotranspiration for current irrigation water applied by farmers and advised by LIAS, as well as the associated crop yields (Lorite et al. 2004a).

2.3.1 Data Collection

The field-plot map and the area of crops for each field-plot were obtained from the manager of the irrigation scheme. For each irrigation season, about 480 field-plots were evaluated. Soil-water properties of each field-plot were obtained from soil maps previously made for the GCIS-CS irrigation district (Lorite 2002). Daily rainfall and ET_o (obtained from the FAO Penman-Monteith method) for the 5 years of the study were obtained from an automatic weather station located within the irrigation scheme. The information about the irrigation systems was obtained by visiting every field-plot during each irrigation season. Christiansen's uniformity coefficient (Christiansen 1942) obtained from the evaluation of irrigation uniformity carried out by the LIAS were used to quantify the uniformity of water application, employing averaged values for each irrigation system. Information about irrigation practices (e.g. cut-off irrigation at the end of the crop cycle), and sowing dates were provided by the scheme manager or obtained directly from farmers through previous surveys (Lorite et al. 2004a). This information was used to calculate the distribution

Table 3 Annual irrigation depths (weighted-surface average; mm year^{-1}) applied by farmers, recommended by the LIAS, and demanded by crops using the model. Coefficients of variation among plots in parentheses

Crop[a]	Irrigation depth (mm year^{-1})														
	2002/03			2003/04			2004/05			2005/06			2006/07		
	Model	LIAS	Farmer	Model	LIAS	Farmer	Model	LIAS	Farmer	Model	LIAS	Farmer	Model	LIAS	Farmer
Wheat	110 (0.18)	nr[b]	18 (2.30)	73 (0.21)	nr	4 (3.59)	421 (0.05)	nr	136 (0.92)	254 (0.08)	166	30 (1.99)	124 (0.06)	119	30 (1.75)
Cotton	621 (0.08)	638 (0.01)	542 (0.43)	580 (0.09)	649 (0.08)	471 (0.39)	742 (0.04)	699 (0.09)	690 (0.34)	629 (0.12)	673 (0.13)	403 (0.48)	616 (0.06)	739 (0.07)	310 (0.43)
Olive	256 (0.18)	nr	129 (0.65)	182 (0.27)	nr	139 (0.51)	386 (0.13)	431	201 (0.64)	291 (0.20)	526	177 (0.59)	187 (0.24)	467	122 (0.62)
Sunflower	412 (0.08)	nr	137 (1.05)	294 (0.13)	nr	51 (2.28)	597 (0.03)	nr	124 (1.26)	457 (0.07)	506	120 (1.07)	336 (0.08)	nr	74 (1.36)
Maize	639 (0.07)	594 (0.13)	524 (0.51)	578 (0.07)	626 (0.06)	592 (0.36)	745 (0.04)	618 (0.08)	631 (0.53)	653 (0.06)	619 (0.05)	601 (0.50)	554 (0.08)	640 (0.05)	545 (0.50)
Garlic	337 (0.16)	320	292 (0.43)	205 (0.21)	301	170 (0.57)	500 (0.09)	447	349 (0.58)	330 (0.13)	438	298 (0.51)	175 (0.29)	318	247 (0.49)
Sugar beet	407 (0.13)	765	394 (0.48)	312 (0.16)	419	363 (0.33)	733 (0.05)	720	615 (0.43)	533 (0.09)	710	327 (0.78)	321 (0.13)	359	122 (0.51)
Bean	na[c]	na	na	na	na	na	301 (0.09)	349 (0.04)	243 (0.63)	109 (0.90)	182 (0.06)	38 (1.02)	90 (0.42)	195	88 (0.68)
Green pepper	520 (0.03)	655	563 (0.48)	596 (0.01)	718	677 (0.33)	na	na	na	513 (0.01)	850	559 (0.49)	na	na	na
Alfalfa	na	na	na	888 (0.03)	924	600 (0.59)	1275 (0.03)	1303	1086 (0.45)	1047 (0.04)	1191	845 (0.21)	903 (0.03)	1311	799 (0.47)
Potato	na	na	na	463 (0.11)	237	290 (0.78)	665 (0.06)	479	503 (0.60)	546 (0.03)	nr	497 (0.40)	397 (0.10)	307 (0.01)	208 (0.73)

[a] : actual consumption of onions not available (intercropping with other horticultural crops), and asparagus not shown (cropped area <100 ha all seasons; Table 1)

[b] : no recommendation (traditional rain-fed crops)

[c] : no available (the number of field-plots or the total crop area were very much reduced to carry out the analysis)

of sowing dates for each crop in the irrigation district, and to obtain a single sowing date for each crop used in the simplified model used by LIAS.

Accumulated water applied in each field-plot was determined three/four times in each irrigation season from water meters, allowing one to analyse irrigation management within the irrigation season. All the weekly irrigation schedules recommended by the LIAS during the period under study were provided by the district manager.

2.3.2 Model Description

A daily water-balance model (LORMOD; Lorite et al. 2004a) was used to simulate water management at field-plot level. The components of the water balance model were: rainfall, irrigation, soil evaporation, transpiration, run-off and drainage. Surface run-off was predicted from daily precipitation using Soil Conservation Service curve number method (USDA-SCS 1972), adjusted to consider the effect on run-off of slope and soil moisture conditions (Williams 1991). Soil water-retention properties were considered, with three soil water thresholds for each soil layer: the saturated water content (SAT), the drained upper limit or field capacity (FC), and the lower limit of plant extractable water or wilting point (WP). Infiltrated water was distributed following a cascade approach along the 20 layers of the soil profile. The amount of water above FC of a given layer was assumed to be immediately transferred to the layer just below. This procedure was repeated for subsequent layers until drainage from a layer was less than the soil water deficit, referred to FC, of the layer below. Drainage below the profile occurs when the soil water content of the deeper layer is above FC. Maximum crop evapotranspiration (ET_c) was calculated from ET_o and dual crop coefficients (Allen et al. 1998). The basal crop coefficients were obtained from the methodology proposed by FAO (Allen et al. 1998) modified locally following local experience (Lorite 2002). Thus, the crop cycle and the duration of the crop growth stages were obtained from data collected locally. Soil evaporation was considered calculating the amount of energy available at the wet soil surface (Allen et al. 1998).

Actual plant transpiration under water stress conditions was obtained by linearly reducing the maximum plant transpiration from soil water content at which transpiration starts to be restricted down to the wilting point, both soil water contents being calculated for the whole root zone. Crop transpiration was distributed in the soil layers as a function of root density and water content in each layer (Coelho et al. 2003). The computed seasonal actual crop evapotranspiration was then divided by the seasonal maximum crop evapotranspiration (ET_c) to estimate yield reduction using a production function approach (Doorenbos and Kassam 1979). Seasonal crop response factors proposed by Doorenbos and Kassam (1979) were adjusted according to our local experience (Lorite et al. 2005). These crop response factors were used to determine the slope of the production functions up to 40 % of the seasonal ET_c deficit. In order to account for situations of severe water stress, yield was reduced linearly from the actual yield for 40 % of ET_c deficit to zero for 80 % of ET_c deficit (Lorite et al. 2004a). A general review of these types of functions is in Geerts and Raes (2009).

2.4 Performance Indicators

To assess the quality and acceptance of the LIAS in the GCIS-CS irrigation district, the following irrigation performance indicators were chosen: Annual Relative Irrigation Supply (ARIS), considering the optimal irrigation demand obtained using LORMOD ($ARIS_{opt}$) and the irrigation recommended by LIAS ($ARIS_{LIAS}$); and Crop Yield Ratio (CYR), considering the estimated crop yields for the irrigation water applied by farmers (CYR_{act}) and for irrigation recommended by the LIAS (CYR_{LIAS}).

$$ARIS_{opt} = \frac{Annual\ volume\ of\ irrigation\ water\ inflow}{Annual\ volume\ of\ crop\ irrigation\ demand}$$

$$ARIS_{LIAS} = \frac{Annual\ volume\ of\ irrigation\ water\ inflow}{Annual\ volume\ of\ crop\ irrigation\ recommended}$$

$$CYR_{act} = \frac{Actual\ crop\ yield}{Intended\ crop\ yield}$$

$$CYR_{LIAS} = \frac{Estimated\ crop\ yield\ using\ LIAS\ scheduling}{Intended\ crop\ yield}$$

where *Intended crop yield* is defined as the maximum field-level yield obtained in the area with optimal irrigation and the best crop management practices. These values were supplied by the manager of the irrigation scheme. The methodology used for CYR estimation was satisfactorily validated in previous studies in the same area (Santos et al. 2010).

Additionally, two new performance indicators (Irrigation Water Productivity, IWP; and resulting Irrigation Water Benefit, IWB, Bos et al. 2005) were calculated to evaluate profitability of irrigation water in the area, considering the optimal irrigation demand obtained using the model, the irrigation recommended by LIAS and the irrigation water applied by farmers, as:

$$IWP\ \left(Euro\ m^{-3}\right) = \frac{Increase\ in\ annual\ value\ of\ agricultural\ production\ due\ to\ irrigation}{Annual\ volume\ of\ irrigation\ water\ inflow}$$

where the numerator was calculated as the difference between the crop yield under irrigation and under rain-fed conditions (using the LORMOD model with local rainfall data), times the actual price of each product in local markets for each season. When the irrigation costs are considered, the profitability of irrigation can be determined from the IWP:

$$IWB\ \left(Euro\ m^{-3}\right) = IWP - \frac{Annual\ cost\ of\ irrigation\ water\ application}{Annual\ volume\ of\ irrigation\ water\ inflow}$$

where the cost of irrigation was calculated including only the costs incurred when irrigation water was applied, such as the energy costs of water pumping, labour costs associated with irrigation, and amortization/maintenance of irrigation system used in each field-plot. Irrigation costs to be paid even if the crop was not irrigated (i.e. water basin authority and irrigation scheme costs) were not considered.

Previously, some of these performance indicators have been used successfully in the same area (Lorite et al. 2004a; García-Vila et al. 2008; Santos et al. 2010), providing an excellent tool for comparing different irrigation schemes and determining possible irrigation improvements (Lorite et al. 2004b).

3 Results and Discussion

3.1 Assessment of the Irrigation Performance in GCIS-CS Irrigation District

The actual volume of irrigation applied by farmers, the optimal volume of irrigation estimated by the LORMOD model, and the volume of irrigation recommended by the LIAS are presented in Table 3. In general, irrigation recommendations provided by the LIAS and by the LORMOD model were higher than actual water consumptions. In addition, there were substantial differences between the recommendations of the LIAS and the model for some crops, such as olive and some horticultural crops (e.g. green pepper or potato). The annual volume of irrigation recommended by the LIAS was higher for olive (65 %, considering the three seasons advised) compared to irrigation demand estimated by the model, indicating that irrigation recommendations by the LIAS exceed crop requirements. In horticultural crops, the trend between the LIAS and model schedules varied among crops. Thus, the irrigation amounts recommended by the LIAS were higher than those by the model in green pepper and bean, but lower in potato, and without a clear trend in garlic (Table 3). The simplified methodology used by the LIAS for irrigation schedules for the whole area could explain most of these differences. In addition, horticultural crops have been introduced recently in the area, and, therefore, it is necessary to adjust crop coefficients to local conditions and farmers' agricultural practices (i.e. crop cycles and sowing dates). Some new tools such as remote sensing could be useful in this task, because they seem capable of providing crop coefficients locally adjusted with sufficient accuracy (Allen et al. 2007a, b; Santos et al. 2008, 2010). In major irrigated crops, such as cotton or maize, these two schedules generated similar consumptions.

$ARIS_{LIAS}$ values varied for different crops and seasons analysed (Table 4a). During the first three irrigation seasons (2003 to 2005), in general, a trend towards improving $ARIS_{LIAS}$ to values close to 1 was found for the irrigation-advised crops. However, this trend changed for the next two seasons (Table 4a). Thus, cotton in 2005 had an $ARIS_{LIAS}$ value equal to 1, implying that the averaged annual irrigation applied by farmers was equal to the irrigation advised by the LIAS; although the variability (coefficient of variation, CV, equal to 0.37) suggests that the recommendations were not followed by all farmers. However, in 2006 and 2007 (with water restrictions; Table 2), $ARIS_{LIAS}$ decreased to 0.61 and 0.43, respectively, i.e. farmers applied average irrigation depths below those recommended. On the contrary, maize had $ARIS_{LIAS}$ values close to 1 during the five seasons, with a high variability between farmers (CV around 0.50; Table 4a), but the maize area was significantly reduced in the last 2 years (over 50 %; Table 1). These changes in irrigation strategy and crop pattern observed in the last 2 years were associated with the restrictions in water allocation, and the onset in 2006 of the implementation of the reform of the Common Agricultural Policy (CAP) of the European Union (i.e. CAP subsidies are now calculated on the basis of cropped area; http://europa.eu.int/comm/agriculture/capreform/index_en.htm). Thus, in the CAP-crops, those supported by CAP-subsidies (e.g. cotton, maize and sugar beet), the strategy followed by farmers in situations of water-allocation restrictions varied depending on the crop. Thus, farmers preferred to maintain the cotton area, but applying deficit irrigation strategies (García-Vila et al. 2008), while they reduced the maize area, maintaining the irrigation strategy. This strategy was linked to an increased area of rain-fed crops, wheat and sunflower (Tables 1 and 4a). This different behaviour of farmers depending on the crop was caused by the good results obtained in deficit irrigation strategies for cotton (Fereres and Soriano 2007; García-Vila et al. 2009) but not for maize (Farré and Faci 2006; Fereres and Soriano 2007). Sugar beet was very seriously affected by the implementation of the CAP-reform, reducing the $ARIS_{LIAS}$ significantly (Table 4a) and virtually disappearing from the area (Table 1). In garlic (not a CAP-crop; high profit crop) its irrigation strategy and acreage were not affected by water restrictions in the last 2 years (Tables 1 and 4a).

In the traditional rain-fed crops, wheat or sunflower, annual irrigation volumes applied by the farmers were generally well below that proposed by the LIAS ($ARIS_{LIAS}$ values were around 0.20; Table 4a). Additionally, variability in $ARIS_{LIAS}$ was very high in these crops (CV higher than 1; Table 4a) due to large relative differences in the irrigation applied by farmers (most of the fields were cultivated under rain-fed conditions; Fig. 2). Also, in olive, a tree crop with a steady increase in the area (Table 1), farmers applied average annual irrigation below that recommended by the LIAS ($ARIS_{LIAS}$ lower than 0.50).

Table 4 Annual Relative Irrigation Supply (ARIS), considering a) the irrigation recommended by LIAS ($ARIS_{LIAS}$), and b) irrigation requirements obtained by simulation model ($ARIS_{opt}$). Weighted-surface average and coefficient of variation (in parentheses)

a)

Crop	$ARIS_{LIAS}$				
	2002/03	2003/04	2004/05	2005/06	2006/07
Wheat	–	–	–	0.18 (1.99)	0.25 (1.75)
Cotton	0.85 (0.43)	0.73 (0.40)	1.00 (0.37)	0.61 (0.47)	0.43 (0.43)
Olive	–	–	0.47 (0.64)	0.34 (0.59)	0.26 (0.62)
Sunflower	–	–	–	0.24 (1.07)	–
Maize	0.90 (0.53)	0.95 (0.37)	1.02 (0.53)	0.97 (0.53)	0.86 (0.51)
Garlic	0.91 (0.43)	0.56 (0.57)	0.78 (0.58)	0.68 (0.51)	0.78 (0.49)
Sugar beet	0.52 (0.48)	0.87 (0.33)	0.85 (0.43)	0.46 (0.78)	0.34 (0.51)
Bean	–	–	0.70 (0.63)	0.20 (0.97)	0.45 (0.68)
Green pepper	0.86 (0.48)	0.94 (0.57)	–	0.66 (0.49)	–
Alfalfa	–	0.59 (0.59)	0.83 (0.45)	0.71 (0.21)	0.61 (0.47)
Potato	–	1.22 (0.78)	1.05 (0.60)	–	0.68 (0.72)

b)

Crop	$ARIS_{opt}$				
	2002/03	2003/04	2004/05	2005/06	2006/07
Wheat	0.16 (2.27)	0.05 (3.87)	0.32 (0.92)	0.12 (1.95)	0.24 (1.72)
Cotton	0.87 (0.43)	0.82 (0.40)	0.93 (0.35)	0.65 (0.44)	0.51 (0.44)
Olive	0.52 (0.69)	0.80 (0.49)	0.52 (0.60)	0.62 (0.59)	0.68 (0.56)
Sunflower	0.33 (1.04)	0.16 (2.20)	0.21 (1.28)	0.26 (1.05)	0.23 (1.31)
Maize	0.82 (0.52)	1.03 (0.37)	0.85 (0.53)	0.92 (0.53)	1.00 (0.49)
Garlic	0.87 (0.43)	0.84 (0.52)	0.70 (0.56)	0.90 (0.52)	1.00 (0.50)
Sugar beet	0.96 (0.42)	1.19 (0.32)	0.85 (0.43)	0.64 (0.83)	0.36 (0.45)
Bean	–	–	0.81 (0.62)	0.33 (0.89)	1.22 (0.49)
Green pepper	1.08 (0.47)	1.14 (0.33)	–	1.09 (0.50)	–
Alfalfa	–	0.67 (0.58)	0.85 (0.47)	0.81 (0.23)	0.88 (0.43)
Potato	–	0.64 (0.74)	0.77 (0.63)	0.92 (0.44)	0.54 (0.84)
GCIS-CS	0.58 (0.85)	0.63 (0.82)	0.65 (0.69)	0.49 (0.97)	0.49 (0.95)

Global annual values of $ARIS_{opt}$ indicated that the farmers apply irrigation below crop water requirements in the area (0.49–0.65 for the whole analysed period; Table 4b). However, different groups of crops could be identified from an analysis of the $ARIS_{opt}$ values. Crops like maize and garlic, and cotton and sugar beet until the CAP-reform was applied, could be considered, on average, to be correctly irrigated, while wheat and sunflower were clearly under-irrigated (22 and 24 % of crop irrigation demand, respectively, for the five seasons analysed), (Tables 3 and 4b). In wheat and sunflower, supplemental irrigation was commonly used due to their very low water productivity and prior rain-fed practices in an area recently converted to irrigation (rain-fed conditions before 1991). In olive, several reasons (such as lack of knowledge and some disease problems associated with excess soil water) are related to the irrigation below crop water requirements observed (Tables 3 and 4b). In horticultural crops, the irrigation strategy (i.e. $ARIS_{opt}$) differed significantly between crops and years, reflecting the lack of local knowledge about these newly introduced crops in

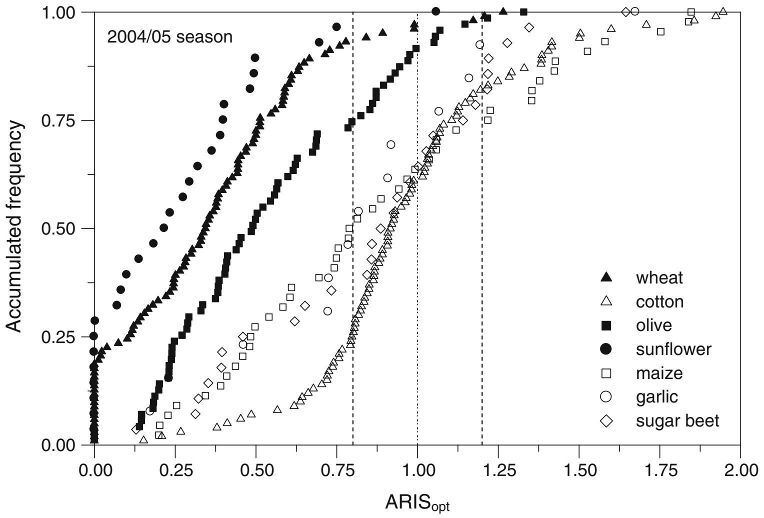


Fig. 2 Cumulative frequency distribution curves of $ARIS_{opt}$ for individual farmers for the main crops in the GCIS-CS irrigation district in the 2004/05 crop season. (External dashed lines separate ARIS values between 0.8 and 1.2)

the area. Similar differences in irrigation management among these crops had been found in other irrigation schemes in Spain (Faci et al. 2000; Montoro and López-Fuster 2005).

Although the crop groups in relation to irrigation management by farmers have persisted in the area at least since the 1996/97 season (Lorite et al. 2004b; García-Vila et al. 2008), the implementation in 2006 of the CAP-reform has significantly affected the crop group composition. Thus, the irrigation strategy in cotton and sugar beet was clearly affected by the decoupling of subsidies and subsequent reduction in the producers' selling price, making the extensification of farming practices more economically attractive (Arriaza and Gómez-Limón 2006, 2007); so farmers have turned towards applying irrigation below crop water requirements, especially in the years of water-allocation restrictions (Tables 2 and 4b). A similar behaviour in the reduction in input used by farmers was previously described in other European areas for pesticide use (Serra et al. 2005) and fertilization (Schmid and Sinabell 2007), when policy reforms consisting of decoupled income-support payments were carried out.

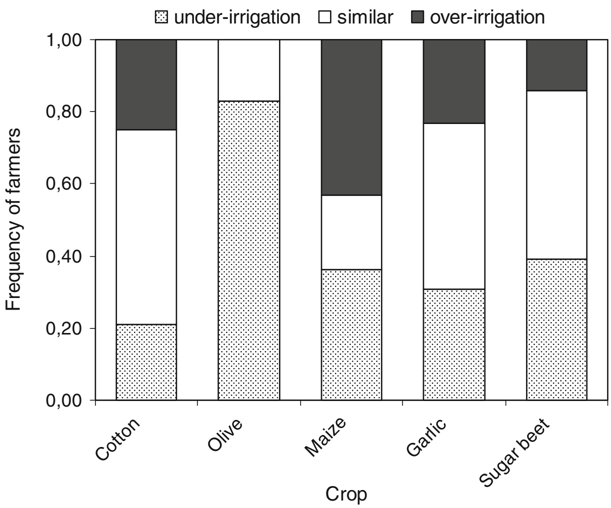
The different behaviour of farmers in the irrigation of major irrigated CAP-crops (i.e. cotton, maize and sugar beet) was caused by the coming together of different factors, such as restrictions in irrigation supply (Table 2), the different response of crops to deficit irrigation (Fereres and Soriano 2007), and the reform of the CAP subsidies ('decoupled' single farm payment). Thus, new decision support systems that include irrigation restrictions and changes in CAP-subsidies, considering dynamic crop simulation models such as that used by García-Vila and Fereres (2012), must be considered by the LIAS in order to obtain suitable irrigation schedules and even to consider changes in the cropping pattern.

3.2 Variability in Irrigation Management among Farmers

The variability in the actual amount of irrigation water applied by farmers was high (average CV higher than 0.40 for all crops), as was concluded by Santos et al. (2008, 2010) for the same area using remote sensing techniques. This variability was especially high for wheat and sunflower in all the seasons analysed (Table 3). A more detailed analysis of the variation in applied irrigation to different crops by farmers is presented in Fig. 2, which shows the cumulative frequency distribution curves of $ARIS_{opt}$ for individual farmers for the main crops in the area (Table 1) during the 2004/05 crop season. In this season, there were no restrictions in water allocation, and the average irrigation depth applied was the highest due to the very limited rainfall (Table 2). Analysing Fig. 2, only a fraction of the farmers applied similar irrigation to that proposed by the model. Moreover, this behaviour showed important differences between crops. Thus, in the most under-irrigated ones, wheat and sunflower, the curves are located to the left of $ARIS_{opt}$ value equal to 1, implying that most farmers applied irrigation well below crop requirements (93 % and 96 % of farmers, respectively, in $ARIS_{opt}$ lower than 0.8). Additionally, a significant number of farmers (19 % and 25 % respectively) had not applied irrigation (Fig. 2). It was the opposite in the case of cotton, with a limited number of farmers applying deficit irrigation strategies (25 % of farmers had $ARIS_{opt}$ values lower than 0.8), and with 57 % of farmers with $ARIS_{opt}$ values of between 0.8 and 1.2 (Fig. 2). Similarly, in garlic and sugar beet, 46 % and 43 %, respectively, of farmers had $ARIS_{opt}$ values between of 0.8–1.2, but with 46 % and 36 % of farmers with $ARIS_{opt}$ values lower than 0.8. An intermediate case was the olive, in which factors mentioned above led to irrigation substantially below crop water requirements (over 50 % of farmers had $ARIS_{opt}$ values lower than 0.5). Among the major irrigated crops, under-irrigation was more common in maize (50 % of the $ARIS_{opt}$ values were lower than 0.8), but there was also over-irrigation (27 % of the $ARIS_{opt}$ values were higher than 1.2). Thus, maize was the crop with the highest variability in irrigation applied by farmers (Fig. 2). The behaviour of these farmers in the irrigation of maize is particularly mistaken because maize yield is especially sensitive to water stress compared to other crops in the irrigation district, such as cotton (Fereres and Soriano 2007).

The analysis made for $ARIS_{LIAS}$ for major irrigated crops in the GCIS-CS irrigation district gave similar results. The percentage of farmers who applied under-irrigation ($ARIS_{LIAS}$ lower than 0.8), similar irrigation ($ARIS_{LIAS}$ between 0.8 and 1.2) and over-irrigation ($ARIS_{LIAS}$ higher than 1.2), compared to that recommended, was determined in each crop for the 2004/05 irrigation season (Fig. 3). Considering these criteria, 37 % of the farmers in

Fig. 3 Percentage of farmers who applied under-irrigation ($ARIS_{LIAS}$ lower than 0.8), similar ($ARIS_{LIAS}$ between 0.8 and 1.2) and over-irrigation ($ARIS_{LIAS}$ higher than 1.2), in relation to the recommendations of the LIAS in the 2004/05 crop season



the GCIS-CS applied the irrigation advised by the LIAS (with 43 % applying deficit-irrigation, and 20 % over-irrigation; Fig. 3). However, the percentage of farmers who followed the recommendations of the LIAS would be even lower considering the farmers who applied the advised irrigation schedules, but based on local experience or small irrigation tools, such as tensiometers. Analysed per crop, for cotton, 54 % of the farmers applied similar irrigation to that proposed by the LIAS, while 21 % applied deficit irrigation strategies, and 25 % applied over-irrigation. Similar results were obtained for garlic and sugar beet, with 46 % of farmers applying similar irrigation, and 23 % and 14 % respectively, over-irrigation; while in maize, only 20 % of farmers applied the advised irrigation, but with 43 % applying over-irrigation (Fig. 3). In the opposite case is the olive, in which 83 % of the farmers applied irrigation below crop water requirements, and the remaining 17 % applied irrigation similar to that advised.

Additionally to crop type and management practices, their irrigation method is an important factor to explain the farmers' behaviour in relation to their irrigation management. Thus, analysing the crops in the area irrigated by sprinkler or drip systems (i.e. cotton and maize; Fig. 1), $ARIS_{opt}$ was higher (i.e. irrigation applied by farmers was more similar to optimal irrigation estimated by the model) in field-plots with drip irrigation than with the sprinkler system, for the five seasons analysed. Averaged values of $ARIS_{opt}$ were 0.64 for maize and cotton with sprinkler irrigation, and 1.0 for maize and 0.82 for cotton with drip irrigation system. Additionally, variability in $ARIS_{opt}$ was lower for the field-plots irrigated by the drip system (average CV of 0.52 and 0.41 for maize, and 0.37 and 0.34 for cotton, with sprinkler and drip irrigation, respectively), this also being the sign of a better irrigation management using this irrigation system. The reasons for this could be a better technology and increased qualification of farmers with drip irrigation systems, as opposed to the more traditional irrigation carried out in the field-plots with hand-moved sprinkler irrigation systems. Farmers with old-irrigation systems are usually less receptive to advice, and their irrigation scheduling (correct or not) is not based on any agronomic/technical foundation, but on traditional and non-homogeneous irrigation rules.

A high variability in $ARIS_{LIAS}$, or $ARIS_{opt}$ when the actual irrigation applied in an irrigation scheme is analysed, indicates large differences in the water applied by farmers for the same crop, implying errors in irrigation management by farmers. However, these differences in the irrigation applied by farmers could also be due to differences in the sowing date or duration of the crop cycle, and, in some specific crops, to differences in the irrigation practices carried out in the last period of the crop cycle. Thus, the lack of consideration of these specific crop and irrigation management practices (e.g. reduction or cut-off of irrigation at the end of the crop cycle, particularly in cotton and sugar beet) may result in erroneous irrigation schedules recommended by the LIAS for some specific crops and seasons. Therefore, it is recommended to adapt the parameters involved in water balance (e.g. crop coefficients) to the variability in the irrigation/crop practices.

Any analysis of variability in irrigation among farmers, based on performance indicators such as $ARIS_{opt}$ or $ARIS_{LIAS}$ can be considered as a measurement of the quality of the irrigation management in an irrigation scheme. Performance variability has also been used as an indicator of the irrigation quality at an irrigation scheme scale (Lorite et al. 2004b; Fernández et al. 2007). Thus, an initial analysis of the variability in irrigation (e.g. using performance indicators) is required in order to characterize the irrigation scheme performance, and should be considered a priority in the implementation of the new LIAS. In this study, the high variability observed in the irrigation applied by farmers, and, hence, the scant acceptance of the advisory services, requires new ways of making contact with farmers especially with those with clearly wrong irrigation schedules, in an attempt to adjust the irrigation schedules recommended to the particular conditions of these field-plots, and crop and irrigation management practices.

3.3 Intra-seasonal Analysis of the Irrigation Management

In previous sections, spatial irrigation management was analysed. However, the moment of water application is also an important component of irrigation practice. Thus, if this fact is considered, the number of farmers who follow the irrigation recommendations provided by the LIAS would be even lower. Using actual water consumption, measured 3–4 times within the irrigation season in each individual field-plot, it was possible to analyse the way in which farmers followed the recommendations advised by the LIAS throughout the season.

Considering the $ARIS_{LIAS}$ for the two main irrigated crops in the area (cotton and maize) (Tables 1 and 3), a consistent trend was found in the values of $ARIS_{LIAS}$ as the season progressed during four irrigation seasons analysed (in the last irrigation season, 2006/07, it was not possible to obtain enough data) and in both crops. Thus, at the beginning of the irrigation season, $ARIS_{LIAS}$ values were high (maximum values of the season) and, in general, higher than 1. However, as the irrigation season progressed, $ARIS_{LIAS}$ values decreased to deficit values (lower than 0.8), (Fig. 4). Thus, during 2004/05 irrigation season (the year with the highest average irrigation depth; Table 3), the value of $ARIS_{LIAS}$ for cotton was equal to 1.93 for the first period of the crop cycle (until mid-June), and reduced its value throughout the season to 0.83 for the last period of the crop cycle (from early-August to harvest). Similarly, the corresponding values of $ARIS_{LIAS}$ for maize were 1.32 and 0.70, respectively (Fig. 4). This behaviour was repeated similarly for the two crops and the other irrigation seasons. However, there was a high variability in the irrigation applied by farmers in each of the three periods of the crop cycle analysed for each irrigation season (CV higher than 0.4 for cotton, and 0.5 for maize). For horticultural crops, the same trends throughout the crop cycle in $ARIS_{LIAS}$ values were also observed. Similar reductions in ARIS values as the irrigation season progressed were also obtained by Molden and Gates (1990), analysing two irrigation areas in Sri Lanka.

These results confirm previous surveys (Lorite et al. 2004b) reporting that farmers at the beginning of the crop cycle meticulously monitor the crop irrigation in order to avoid water stress, exceeding even the irrigation requirements. However, when the crop is correctly established, this monitoring is relaxed and farmers tend to apply less water than that recommended, and then the LIAS schedule is not strictly followed. This was caused by the general irrigation management carried out by the farmers and not by district irrigation network deficiencies or restrictions. Moreover, these irrigation practices carried out by farmers are not based on any technical approach, but are implemented drawing on previous experience (García-Vila et al. 2008).

When the actual water consumption is compared with the optimal irrigation schedule obtained by the simulation model ($ARIS_{opt}$), the results were similar to those obtained comparing with LIAS scheduling, although the trend towards reducing the values of ARIS as the irrigation season progressed was less clear than with the LIAS recommendations. Some differences in cotton were caused by the LIAS-schedule consideration of an irrigation reduction or cut-off (a common irrigation practice for cotton in the area) too late (around mid-October), while the optimal-schedule considered it to be earlier (around mid-September), resulting in lower values of $ARIS_{LIAS}$ as compared with $ARIS_{opt}$ for the last period of the cotton crop cycle. This demonstrates the importance of the LIAS consider all the facts related to the crop management in its advice, in order to avoid mistakes in the irrigation recommendations caused by the omission of management practices that affect crop development.

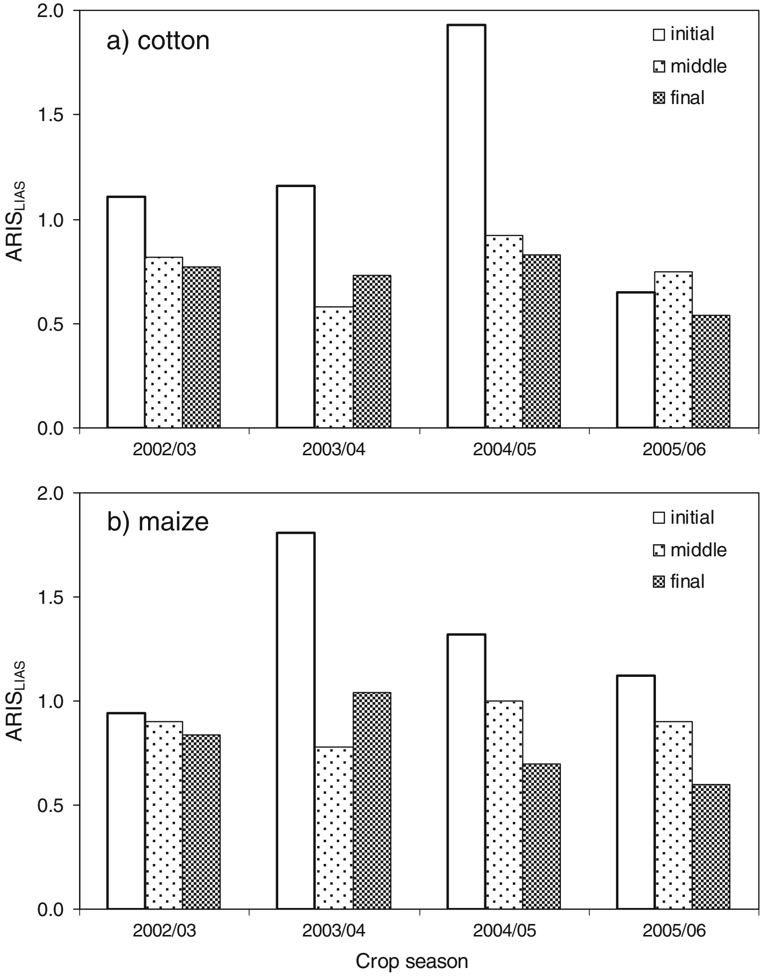


Fig. 4 Evolution of the values of $ARIS_{LIAS}$ throughout each irrigation season (for the initial, middle and final crop cycle periods) for the two major irrigated crops in the GCIS-CS irrigation district, **a** cotton and **b** maize

Therefore, in the future, the LIAS must consider the inclusion of deficit irrigation strategies in irrigation scheduling, advising farmers about the possible benefits of deficit irrigation and the most sensitive periods to water stress of specific crop. An example of simple methodology for the generation of deficit irrigation schedules is described in Geerts et al. (2010).

3.4 Assessment of Agronomic and Economic Irrigation Performance

The crop yield ratio for the actual irrigation applied by farmers (CYR_{act}) and for the irrigation schedule recommended by the LIAS (CYR_{LIAS}) was calculated for the major irrigated crops in the GCIS-CS irrigation district in the five crop seasons analysed (Table 5). Average values of CYR_{LIAS} ranged between 0.74 and 1, while CYR_{act} average values varied between 0.63 and 0.98, for all crops and years analysed. The very high values of CYR_{LIAS},

Table 5 Crop Yield Ratio (CYR) for major irrigated crops in GCIS-CS irrigation district from 2002/03 to 2006/07 crop seasons, for the irrigation water applied by farmers (CYR_{act}) and for recommendations by the LIAS (CYR_{LIAS}). Weighted-surface average and coefficient of variation (in parentheses)

Crop season	Cotton		Maize		Garlic		Sugar beet	
	CYR_{act}	CYR_{LIAS}	CYR_{act}	CYR_{LIAS}	CYR_{act}	CYR_{LIAS}	CYR_{act}	CYR_{LIAS}
2002/03	0.88 (0.10)	0.97 (0.03)	0.81 (0.36)	0.89 (0.12)	0.94 (0.13)	0.99 (0.03)	0.94 (0.09)	1.00 (−)
2003/04	0.90 (0.09)	1.00 (0.01)	0.94 (0.20)	1.00 (0.01)	0.94 (0.09)	1.00 (0.02)	0.98 (0.05)	1.00 (−)
2004/05	0.89 (0.20)	0.93 (0.06)	0.71 (0.44)	0.74 (0.11)	0.79 (0.27)	0.93 (0.04)	0.82 (0.13)	0.99 (0.01)
2005/06	0.73 (0.27)	0.96 (0.11)	0.85 (0.33)	0.87 (0.06)	0.94 (0.09)	1.00 (0.01)	0.73 (0.27)	1.00 (−)
2006/07	0.67 (0.21)	1.00 (−)	0.87 (0.30)	1.00 (0.01)	0.96 (0.06)	1.00 (0.01)	0.63 (0.10)	1.00 (0.01)

very close or equal to 1 (e.g. sugar beet, or 2003/04 and 2006/07 seasons for the four crops), indicate adequate LIAS irrigation schedules for maximum crop yields in the area, and only in the case of maize were significant under-optimal irrigation schedules recommended in some years (e.g. CYR_{LIAS} of 0.74 in 2005), (Table 5). CYR_{act} averaged values lower than 1 indicate that, in general, farmers applied irrigation below crop water requirements. There was also a high variability between farmers, which resulted in a high variability in the values of CYR_{act}, particularly in maize (CV between 0.20 and 0.44). The coefficient of variation for CYR_{act} could be greatly reduced for all crops and seasons if the irrigation schedules recommended by the LIAS were used by all farmers in the GCIS-CS irrigation district (Table 5); implying similar crop yields in all field-plots, and an increase in the average yields for the whole area. However, due to over-irrigation recommended by the LIAS for some crops and seasons (Table 3), these irrigation schedules cannot be considered as being an optimal irrigation management.

In the previous sections, irrigation assessment has been approached from an agronomic point of view. In addition, the irrigation assessment in the GCIS-CS irrigation district has been dealt with from an economic perspective. Thus the increased irrigation costs (e.g. energy and labour), restrictions in irrigation water delivery, and the effect of CAP reform on input use in recent years have been addressed using economic performance indicators, in order to improve the irrigation assessment in the area. Moreover, economic performance indicators of irrigation are essential in assessing the sustainability of irrigated agricultural systems (Bazzani et al. 2005).

Following the recommendations of LIAS (Table 3) and in order to increase crop yields (Table 5), water consumption in the GCIS-CS irrigation district should be increased, although this fact would also reduce the irrigation water profitability (IWP and IWB; € m^{-3}). Thus, when the LIAS irrigation schedule was considered, the IWP was reduced compared with the actual schedule applied by farmers in the main crops in the area, especially in olive and garlic (Fig. 5a). Thus, the IWP values for LIAS schedules decreased, on average, by between 55 % (82.0 euro-cents m^{-3}) and 2 % (0.4 euro-cents m^{-3}), in olive and maize, respectively, compared with the IWP for actual irrigation management. The IWP values were also reduced, in general, if farmers implemented the optimal irrigation schedule proposed by the simulation model, although to a much lesser extent (Fig. 5a). This is due to increased annual irrigation depths in irrigation schedules proposed by the LIAS and the model (Table 3), with small increases in crop yields for the increase in the irrigation applied, i.e. marginal irrigation water productivity decreases with increasing irrigation (Zhang 2003; Zwart and Bastiaanssen 2004). Irrigation recommended by the LIAS was higher than that demanded by the crops, as estimated by the model, in most cases

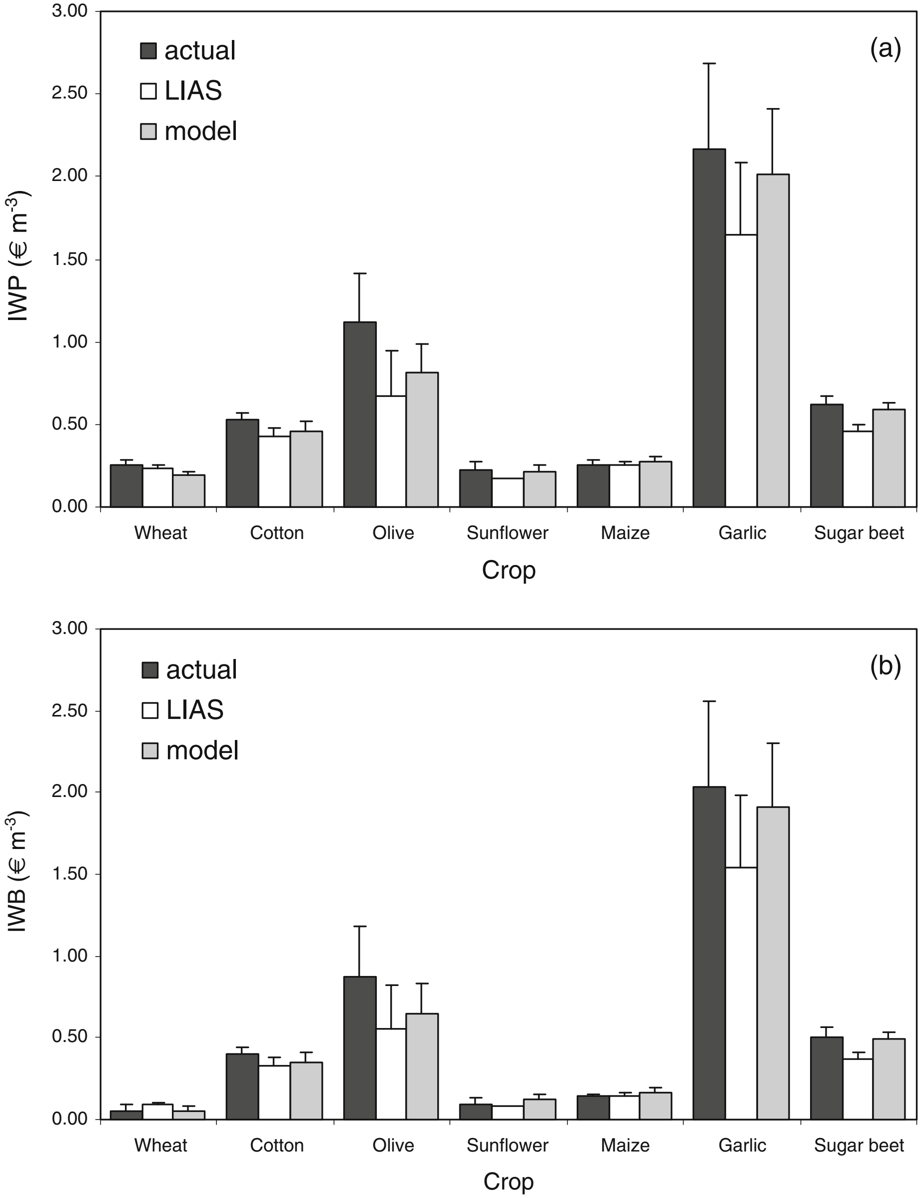


Fig. 5 **a** Irrigation water productivity (IWP; € m^{-3}), and **b** irrigation water benefit (IWB; € m^{-3}) for the main crops in the GCIS-CS irrigation district, for the irrigation schedules applied by farmers, recommended by the LIAS and estimated by the model. Average values for the crop seasons 2002/03 to 2006/07. The error bars represent the standard error of the mean. (IWP and IWB values for LIAS schedules in wheat, olive, and sunflower only for the seasons advised; see Table 3)

(except for wheat and maize; Table 3), resulting in lower IWP values for these LIAS schedules (Fig. 5a). The average IWP values for crop seasons 2002/03 to 2006/07 ranged from 2.16 € m^{-3} in garlic to 0.23 € m^{-3} in sunflower for actual irrigation schedules applied by farmers (Fig. 5a).

In addition to the IWP, the analysis of the IWB allowed one to determine the economic benefits (or losses) of irrigation, to deduct the costs of applying water. Figure 5b shows the average IWB values for the main crops in the area, considering the five irrigation seasons analysed. When the IWB values are close to zero, the irrigation practice is close to the profitability threshold, and it might be desirable to discourage the irrigation of these crops in certain irrigation seasons (i.e. in those with water allocation restrictions or low crop irrigation requirements). This could be the case of wheat and sunflower, with average IWB values of 5.4 and 9.2 euro-cents m^{-3}, respectively, for actual irrigation management, and 5.6 and 12.6 euro-cents m^{-3} for model schedules, for the five irrigation seasons analysed (Fig. 5b). However, these IWB values were negative in wheat in the 2003/04 season (−8.0 and −0.1 euro-cents m^{-3}, for actual and model schedules, respectively), indicating that the costs originated by supplementary irrigation (Tables 2 and 3) were higher than the incomes generated. In the opposite case, garlic and olive were the crops with the highest benefit per unit of irrigation water (average IWB values of 2.03 and 0.87 € m^{-3} for actual irrigation, and 1.91 and 0.65 € m^{-3} for model schedules, respectively; Fig. 5b).

Similarly to the IWP, the lowest values of the IWB corresponded to increased irrigation schedules recommended by the LIAS, compared with the scheduling carried out by farmers and that estimated by the simulation model (Fig. 5b). The irrigation unit costs (IWP-IWB; € m^{-3}), however, increased when the amount of applied irrigation was reduced (e.g. IWP-IWB average for olive was of 0.120€ m^{-3} and 0.243€ m^{-3}, for the irrigation schedules by the LIAS and farmers, respectively; Figs. 5a and b). However, the lower irrigation unit costs for the recommended LIAS schedules (highest average irrigation depth; Table 3) did not balance the higher values of the IWP for the actual irrigation applied by farmers (lower average irrigation depth; Table 3). Only when a very small volume of water was applied by farmers, increasing significantly the irrigation unit costs, in crops with low IWP (e.g. wheat and sunflower; Table 3 and Fig. 5a), were the IWB values similar for the LIAS and actual applied schedules (Fig. 5b).

However, if the annual amount of irrigation water applied or recommended (m^3 ha^{-1}; Table 3) for each crop was considered, the irrigation benefit per unit area (€ ha^{-1}) was higher when applying the irrigation schedules recommended by the LIAS, compared with actual irrigation schedules. Thus, considering the crop seasons analysed, the averaged annual irrigation benefits of shifting to LIAS schedules ranged from 350€ ha^{-1} to 300€ ha^{-1} in sugar beet and olive, to about 90 € ha^{-1} in maize. These differences became even higher when changing to the model schedules, ranging from 460€ ha^{-1} to 410€ ha^{-1} in sugar beet, garlic, sunflower and olive, to about 100 € ha^{-1} in wheat.

When comparing the LIAS and model irrigation schedules, the greater differences in average annual irrigation benefit per unit area of irrigated crop corresponded to garlic and olive (270 and 220 € ha^{-1}, respectively), the highest-profit crops, and also showed more annual divergences between the two proposed irrigation schedules (Table 3). In contrast, no differences were observed in wheat and sunflower in the irrigation benefit per unit area between the LIAS and model irrigation schedules. Therefore, the LIAS should improve irrigation scheduling in olive and garlic, and in other horticultural crops, as previously discussed in section 3.1.

Results from the irrigation performance analysis using agronomic and economic indicators suggest that LIAS advice should include the economic assessment of recommended irrigation schedules. Also, the inclusion of the irrigation economic assessment could undoubtedly contribute towards the greater acceptance of advisory services by farmers, to shift the focus from maximizing their crop yields to maximizing irrigation profitability. In this context, irrigation schedules recommended by the LIAS should be adjusted year-to-year according to changes affecting irrigation management in the area. Thus, the changes in the costs associated with irrigation or in the prices of each harvested product, or changes in CAP subsidies, should be considered in the LIAS irrigation schedules, together with annual irrigation water allocation. In this scenario, the use of economic performance indicators, such as IWP or IWB, and agronomic performance indicators, such as ARIS or CYR, constitutes a useful tool for adjusting irrigation schedules for each crop, each year. Thus, in years with water allocation restrictions, the recommendations of the LIAS must prioritize the irrigation of crops with a higher economic profitability (i.e. higher IWP_{opt} or IWB_{opt}), such as garlic and olive, but without exceeding its irrigation requirements (i.e. $ARIS_{opt} \leq 1$), and allocate supplemental irrigation to the crops with lower values of the IWB_{opt} (Fig. 5). However, the years in which there are no water allocation restrictions, the irrigation schedules recommended by the LIAS should maximize the irrigation benefit per unit area of each irrigated crop, i.e. they must meet the irrigation water requirements of each crop, as estimated by the model (or $ARIS_{LIAS} \equiv ARIS_{opt} = 1$; $CYR_{act} \equiv CYR_{LIAS} = 1$).

4 Conclusions

The Local Irrigation Advisory Services (LIAS) have an important role in improving irrigation water management at an irrigation scheme scale. In the case of GCIS-CS irrigation district, the LIAS generally provided adequate irrigation schedules to meet the water requirements of traditional field crops, but these should be improved in order to adapt irrigation schedules to local irrigation/crop practices (i.e. irrigation cut-off in crops such as cotton, various sowing dates), modifying the crop coefficients. Therefore, knowledge of crop coefficients locally adapted should be promoted, especially in the new horticultural crops, like garlic, and olive. In addition, the advice must be adapted to new factors affecting irrigation (such as water delivery restrictions and CAP-subsidies).

The irrigation management in the GCIS-CS irrigation district showed a general irrigation application below crop water requirements (average $ARIS_{opt}$ ranged from 0.58 to 0.65, in years without restrictions in water delivery). Thus, considering the major irrigated crops, in only around one third of the fields similar irrigation depths were applied to those recommended by the LIAS. However, the acceptance of the advice service depended clearly on the crop, so the highest level of acceptance was for cotton (over 50 % of farmers followed the recommendations), while in traditional rain-fed crops, wheat and sunflower, farmers did not follow the irrigation recommendations (less than 10 %), applying in general uniquely a supplemental irrigation. Among the causes of the high variability in the irrigation applied by farmers to the same crop and the low acceptance of the advisory services are: the lower IWP with the increase in irrigation, the previous traditional rain-fed crop-management in the area, the scant introduction of new technology in some farms, or the ignorance of the services provided by the LIAS. Thus, for a higher acceptance of advisory services by farmers, and better irrigation management, the irrigation recommendations of LIAS should be adjusted to local conditions and farmers' agricultural practices, particularly in horticultural crops (i.e. adapting the K_c curves to sowing dates and crop cycles) and olive. For this task, new ways of communicating with farmers should be explored by the LIAS for a more efficient transfer of irrigation information. Thus, the development of new alternatives for communication between the LIAS and farmers, using new technologies such as last generation cell phones or Internet would contribute to a better knowledge of the services and an improved and fast response of the LIAS to farmers concerns.

Additionally, the promotion of deficit irrigation schedules by the LIAS, advising the farmers of the most sensitive crop periods to water stress, would contribute towards improving the functioning of these advisory services, increasing irrigation water productivity and saving water, especially under limited available water scenarios. Finally, the LIAS should include among its functions, the economic assessment (cost-income ratio) of irrigation schedules for each crop. In this context, consideration of performance indicators, such as IWP or IWB, water allocation restrictions, and changes in CAP subventions, should help to obtain more adequate and economically profitable irrigation schedules, compared with traditional irrigation scheduling based on maximizing crop yields.

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References

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration: guidelines for computing crop water requirements. Irrigation and Drainage Paper 56. FAO, Rome, Italy

Allen RG, Tasumi M, Trezza R (2007a) Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)-Model. J Irrigat Drain Eng 133:380–394

Allen RG, Tasumi M, Morse A, Trezza R, Wright JL, Bastiaanssen W, Kramber W, Lorite IJ, Robison CW (2007b) Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)-Applications. J Irrigat Drain Eng 133:395–406

Arriaza M, Gómez-Limón JA (2006) How decoupling could mean dismantling of the cotton sector in Spain. New Medit 1:4–14

Arriaza M, Gómez-Limón JA (2007) Policy implications of the decoupling of the EU cotton subsidies. J Int Agr Trade Dev 3:87–103

Bazzani G, Di Pasquale S, Gallerani V, Morganti S, Raggi M, Viaggi D (2005) The sustainability of irrigated agricultural systems under the Water Framework Directive: first results. Environ Model Software 20:165–175

Bos MG, Burton MA, Molden DJ (2005) Irrigation and drainage performance assessment. Practical guidelines. CABI Publishing, Wallingford, UK

Burt CM, Styles SW (1999) Modern water control and management practices in irrigation: impact on performance. Water Reports 19. FAO, Rome, Italy

Burt CM, Clemmens AJ, Strelkoff TS, Solomon KH, Bliesner RD, Hardy LA, Howell TA, Eisenhauer DE (1997) Irrigation performance measures: efficiency and uniformity. J Irrigat Drain Eng 123:423–442

Christiansen JE (1942) Irrigation by Sprinkling. California Agricultural Experiment Station, Bull. 670. University of California, Berkley, USA

CIMIS (2000) CIMIS (California Irrigation Management Information System). Agriculture Resource Book. Department of Water Resources, CA, USA

Coelho MB, Villalobos FJ, Mateos L (2003) Modelling root growth and the soil-plant-atmosphere continuum of cotton crops. Agr Water Manag 60:99–118

Córcoles JI, de Juan JA, Ortega JF, Tarjuelo JM, Moreno MA (2010) Management evaluation of Water Users Associations using benchmarking techniques. Agr Water Manag 98:1–11

Doorenbos J, Kassam AH (1979) Yield response to water. Irrigation and Drainage Paper 33. FAO, Rome, Italy

Eching S (2002) Role of technology in irrigation advisory services: The CIMIS experience. 18th Congress and 53rd IEC meeting of the International Commission on Irrigation and Drainage (ICID). FAO/ICID International workshop on Irrigation Advisory Services and Participatory Extension Management. 24 July 2002. Montreal, Canada

English M (2002) Irrigation advisory services for optimum use of limited water. 18th Congress and 53rd IEC meeting of the International Commission on Irrigation and Drainage (ICID). FAO/ICID International workshop on Irrigation Advisory Services and Participatory Extension Management. 24 July 2002. Montreal, Canada

Faci JM, Bensaci A, Slatni A, Playán E (2000) A case study for irrigation modernisation. I. Characterisation of the district and analysis of water delivery records. Agr Water Manag 42:313–334

Farré I, Faci JM (2006) Comparative response of maize (Zea mays L.) and sorghum (Sorghum bicolour L. Moench) to deficit irrigation in a Mediterranean environment. Agr Water Manag 83:135–143
Fereres E, Soriano MA (2007) Deficit irrigation for reducing agricultural water use. J Exp Bot 58:147–159
Fernández MD, González AM, Carreño J, Pérez C, Bonachela S (2007) Analysis of on-farm irrigation performance in Mediterranean greenhouses. Agr Water Manag 89:251–260
Fortes PS, Platonor AR, Pereira LS (2005) GISARED–A GIS based irrigation scheduling simulation model to support improved water use. Agr Water Manag 77:159–179
García-Vila M, Fereres E (2012) Combining the simulation crop model AquaCrop with an economic model for the optimization of irrigation management at farm level. Eur J Agron 36:21–31
García-Vila M, Lorite IJ, Soriano MA, Fereres E (2008) Management trends and responses to water scarcity in an irrigation scheme of Southern Spain. Agr Water Manag 95:458–468
García-Vila M, Fereres E, Mateos L, Orgaz F, Steduto P (2009) Deficit irrigation optimization of cotton with AquaCrop. Agron J 101:477–487
Gavilán P, Lorite IJ, Tornero S, Berengena J (2006) Regional calibration of Hargreaves equation for estimating reference ET in a semiarid environment. Agr Water Manag 81:257–281
Geerts S, Raes D (2009) Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agr Water Manag 96:1275–1284
Geerts S, Raes D, García M (2010) Using AquaCrop to derive deficit irrigation schedules. Agr Water Manag 98:213–216
Giannini A, Bagnoni V (2002) Evolution of irrigation support services in Tuscani. 18th Congress and 53rd IEC meeting of the International Commission on Irrigation and Drainage (ICID). FAO/ICID International workshop on Irrigation Advisory Services and Participatory Extension Management. 24 July 2002. Montreal, Canada
Lorite IJ (2002) Modelo para el análisis de la gestión del agua en zonas regables. Ph.D. Dissertation. University of Córdoba, Córdoba, Spain. In Spanish
Lorite IJ, Mateos L, Fereres E (2004a) Evaluating irrigation performance in a Mediterranean environment. I. Model and general assessment of an irrigation scheme. Irrigat Sci 23:77–84
Lorite IJ, Mateos L, Fereres E (2004b) Evaluating irrigation performance in a Mediterranean environment. II. Variability among crops and farmers. Irrigat Sci 23:85–92
Lorite IJ, Mateos L, Fereres E (2005) Impact of spatial and temporal aggregation of input parameters on the assessment of irrigation scheme performance. J Hydrol 300:286–299
Lorite IJ, Mateos L, Orgaz F, Fereres E (2007) Assessing deficit irrigation strategies at the level of an irrigation district. Agr Water Manag 91:51–60
Martín de Santa Olalla F, Calera A, Domínguez A (2003) Monitoring irrigation water use by combining Irrigation Advisory Service, and remotely sensed data with a geographic information system. Agr Water Manag 61:111–124
Merriam JL, Keller J (1978) Farm irrigation system evaluation: a guide for management. Department of Agricultural and Irrigation Engineering, Utah State University, Logan, Utah
Molden DJ, Gates TK (1990) Performance measures for evaluation of irrigation/water delivery systems. J Irrigat Drain Eng 116:804–823
Montoro A, López-Fuster P (2005) Los Servicios de asesoramiento de riegos: el ejemplo del SAR de Albacete. In: Martín de Santa Olalla F, López-Fuster P, Calera A (eds) Agua y Agronomía. Mundi-Prensa, Madrid, Spain, pp 433–466, In Spanish
Montoro A, López-Fuster P, Fereres E (2011) Improving on-farm water management through an irrigation scheduling service. Irrigat Sci 29:311–319
Ortega JF, de Juan JA, Tarjuelo JM (2005) Improving water management: The irrigation advisory service of Castilla-La Mancha (Spain). Agr Water Manag 77:37–58
Quiñones PH, Unland H, Ojeda W, Sifuentes E (1999) Transfer of irrigation scheduling technology in Mexico. Agr Water Manag 40:333–339
Santos C, Lorite IJ, Tasumi M, Allen RG, Fereres E (2008) Integrating satellite-based evapotranspiration with simulation models for irrigation management at the scheme level. Irrigat Sci 26:277–288
Santos C, Lorite IJ, Tasumi M, Allen RG, Fereres E (2010) Performance assessment of an irrigation scheme using indicators determined with remote sensing techniques. Irrigat Sci 28:461–477
Schmid E, Sinabell F (2007) On the choice of farm management practices after the reform of the Common Agricultural Policy in 2003. J Environ Manage 82:332–340
Serra T, Zilberman D, Goodwin BK, Hyvonen K (2005) Replacement of agricultural price supports by area payments in the European Union and the effects on pesticide use. Am J Agr Econ 87:870–884
Shirsath PB, Singh AK (2010) A comparative study of daily pan evaporation estimation using ANN, regression and climate based models. Water Resour Manag 24:1571–1581

Smith M, Muñoz G (2002) Irrigation advisory services for effective water use: a review of experiences. 18th Congress and 53rd IEC meeting of the International Commission on Irrigation and Drainage (ICID). FAO/ICID International workshop on Irrigation Advisory Services and Participatory Extension Management. 24 July 2002. Montreal, Canada

USDA-SCS (1972) National engineering handbook. USDA-Soil Conservation Service, Washington DC, USA

USDA-SCS (1975) Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Handbook 436. Soil Survey Staff, USDA, Washington DC, USA

Williams JR (1991) Runoff and water erosion. In: Hanks J, Ritchie JT (eds) Modelling plant and soil systems. ASA/CSSA/SSSA, Madison, WI, pp 439–455

Zhang H (2003) Improving water productivity through deficit irrigation: examples from Syria, the North China Plain and Oregon, USA. In: Kijne JW, Barker R, Molden D (eds) Water productivity in agriculture: limits and opportunities for improvement. CAB International, Wallingford, Oxon, UK, pp 301–309

Zwart SJ, Bastiaanssen WGM (2004) Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agr Water Manag 69:115–133