Evaluating irrigation performance of sunflower in an irrigation scheme of Southern Spain

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ABSTRACT

Current water resource scarcity implies a change in the water management in the Spanish irrigation schemes. Assessment of irrigation performance over long time periods is a prerequisite for improving water use in the agricultural lands to respond to the water scarcity. We carried out a comprehensive assessment of the irrigation performance by documenting the water use of fields cultivated with sunflower at the Genil–Cabra Irrigation Scheme (GCIS), located in Andalusia, Southern Spain, from 1991 to 2007. We have used a model that simulates water balance for every field and three performance indicators to assess the performance of irrigation water use and management in the GCIS. Among the performance indicators, the average ratio of measured irrigation supply to the simulated optimum demand (ARIS) for sunflower ranged between 0.09 and 0.34, indicating that the crop was under water stress. The average Irrigation Water Productivity (IWP) provided low values for this crop, although in the last years it has reached higher values due to the recent increase of international market prices, with similar values to maize or wheat. Remote sensing techniques, based on using a satellite-based energy balance called METRIC, were used to obtain actual evapotranspiration maps during the 2004/05 irrigation season. Seasonal ET variability was found to be large between sunflower fields and also within sunflower fields in the GCIS. The current policies of subsidies in sunflower force the farmers to obtain a maximum profit from the irrigation water rather than a maximum yield, a scenario that must be considered when planning programs of water conservation.

Key words: deficit irrigation – evapotranspiration – irrigation management – water allocation – water supply.

INTRODUCTION

Sunflower occupies a large surface of the area cultivated in Andalusia. The high volume of crop water demand and a reduced water supply force farmers to use different strategies from irrigation water management. With the constant increase in water demand from other sectors of society, assessing water management is indispensable for proposing improvements in irrigation management and for quantifying water productivity (Molden and Sakthivadivel, 1999). There are different performance indicators for irrigation water use that require some information related with the irrigation applied by the farmers. However a detailed water-use record from each plot is often not available, which makes it impossible to carry out a good analysis of water management. Records of irrigation water use are required to obtain additional information, helping to estimate all water-balance components in fields, and which can be evaluated using a simulation model, hereafter named LORMOD, which can be employed to assess the actual performance and water management (Lorite et al., 2004a).

Most of the consumption of irrigation water corresponds to evapotranspiration (ET), the loss of water from the earth's surface through the combined processes of evaporation and transpiration. Therefore, the spatial and temporal quantification of ET is essential in agricultural water management. As a recent remote sensing technique, accurate ET estimations have been obtained using a satellite-based energy balance (Bastiaanssen et al., 1998; Allen et al., 2007). METRIC (*Mapping EvapoTranspiration with high Resolution and Internalized Calibration*) is an ET estimation model (Allen et al., 2007) based on the SEBAL (*Surface Energy Balance Algorithms for Land*) model of Bastiaanssen et al. (1998).

The objective of this work was to conduct a comprehensive assessment of the irrigation performance of sunflower, compared with maize and wheat, in an area using on-farm water-use information and a simulation model, as well as an ET estimation model (METRIC). The area selected was the Genil–Cabra Irrigation Scheme (GCIS) located in Andalusia, Southern Spain. This irrigation scheme was chosen because it disposes of accurate information on water use and on the cropping patterns of individual plots since the start of its operations (1990/1991) until present.

MATERIALS AND METHODS

The study area was located within the Genil-Cabra Irrigation Scheme (GCIS), in Cordoba province, Southern Spain (37º 31' N, 4º 51' W). The climate in this area is typically Mediterranean with an annual average precipitation of 606 mm and a rainless summer. The average air temperature ranges from 10 ºC for the coldest month to over 27 ºC for the warmest.

The study was carried out during 16 irrigation seasons (1991/1992 to 2006/2007). Daily meteorological data to estimate Penman–Monteith ASCE reference evapotranspiration (ET_0) and rainfall were obtained from a meteorological station located within the GCIS. Information about the cumulative water-meter for each plot was obtained by individual readings four/five times per irrigation season. Likewise, the information about irrigation practices, water supply and sowing dates was provided by the irrigation scheme manager or directly from farmers (Lorite et al., 2004a). Only the plots with a single crop were selected for this study.

A water-balance model was developed by Lorite et al. (2004a) to simulate water use in the GCIS. LORMOD is composed of sub-models that calculate the different water-balance components and estimate the effects of water stress on crop yield. It calculates the soil water balance components for each computation unit on a daily basis, generates optimum irrigation schedules and compares the optimum schedules for each field against the actual irrigation schedules, which were simulated by basing them on water-meter readings.

For each field, to assess the evolution of irrigation management and benchmarking, the Annual Relative Irrigation Supply (ARIS) was chosen, defined by Malano and Burton (2001) as:

$$\text{ARIS} = \frac{\text{Annual volume of irrigation water inflow}}{\text{Annual volume of crop irrigation demand}} \quad (1)$$

Another indicator computed here was the Crop Yield Ratio (CYR; Bos et al. 1994), that relates the actual crop yield to the intended yield, defined as the attainable crop yield with optimum economic irrigation, defined as:

$$\text{CYR} = \frac{\text{Actual crop yield}}{\text{Intended crop yield}} \quad (2)$$

To evaluate the productivity of the water used in irrigation in this area, the indicator considered was the Irrigation Water Productivity (IWP; Lorite et al., 2004a), defined as:

$$\text{IWP} = \frac{\text{Increase in Annual Value of Agricultural Production due to Irrigation}}{\text{Annual Volume of Irrigation Water Inflow}} \ (\text{€/m}^3) \quad (3)$$

In this indicator, the numerator is computed as the difference between actual crop yields under irrigation minus rainfed yields. It is assumed that management does not change much as the grower shifts from rainfed to irrigated conditions, which is probably the case for the GCIS.

Satellite-based energy balance estimation of crop ET (METRIC)

Eleven Landsat 5 TM images were processed using the METRIC energy balance computation procedure of Allen et al. (2007) to obtain daily ET for each image date. The model METRIC estimates ET as a residual of the energy balance at the surface:

$$LE = R_n - G - H \quad (4)$$

where LE is the latent energy consumed by ET, R_n is net radiation, G is sensitive heat flux into the soil, and H is sensitive heat flux to the air. Details of the METRIC model are given in Allen et al. (2007) and Tasumi et al. (2005).

We define a crop coefficient, $K_{c\ act}$, as the ratio between actual ET estimated by METRIC, and the grass reference ET (ET_o) calculated following the ASCE standardized Penman-Monteith method (ASCE-EWRI, 2005). This $K_{c\ act}$ differs from the standard K_c (Allen et al., 1998) in that our actual ET estimate is usually below the maximum ET due to agronomic factors. Weather data for calculating ET_0 were provided by five automatic weather stations located close to the GCIS. These weather stations are part of the Agroclimatic Information Network of Andalusia (Gavilán et al., 2006).

RESULTS AND DISCUSSION

Throughout the period of study it was observed that the water applied to sunflower was different from year to year, due to variations in the precipitation and water availability (Fig. 1). Thus, the average annual rainfall in the periods 1991-1995 and 1999-2005 was smaller than 500 mm. Nevertheless, in the first period the water supply was very restricted (≈ 700 m^3 ha^{-1}), whereas in second the average water supply was three times bigger (≈ 2600 m^3 ha^{-1}) than in the first period. These policies importantly affected the volume of available water, that was little or null during the period 1992-1995 and increased significantly in the period from 1999 to 2005. In 1998/1999 irrigation season, the low precipitation forced all farmers, including those who did not usually apply water to sunflower, to increase the irrigation applied, favoured by the available water supply of that year, which was higher than average (Lorite et al., 2004a). For this reason, the variation between the fields in the annual volume of water applied, quantified by the coefficient of variation, diminished considerably in 1998/1999 irrigation season.

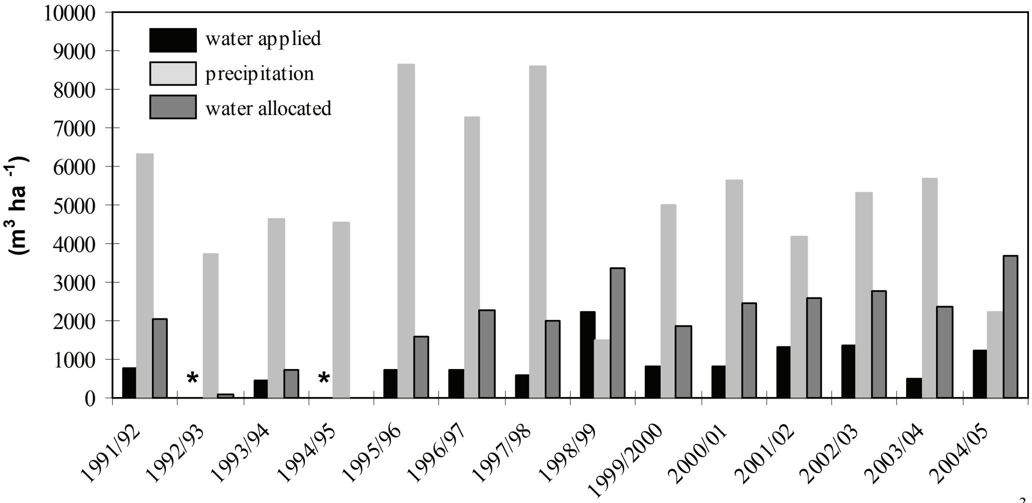

Fig. 1. Evolution of average irrigation water use, irrigation water allocation, and precipitation (m^3 ha^{-1}) from 1991/1992 until 2004/2005 irrigation seasons. * During 1992/1993 and 1994/1995 irrigation depth applied was practically null.

The limited water supply available during the period 1991-1995 caused an increase in sunflower and wheat areas (Fig. 2). However, during the following years the absence of restrictions caused a reduction in those areas, whereas there was a continuous increase in the one devoted to maize.

Performance indicators of irrigation water use

The average ARIS for sunflower and for wheat was very low during the whole period (0.23 and 0.26 respectively; Fig. 3A) with respect to maize, where the ARIS experimented a constant increase up to values close to 1, which represented an optimum irrigation. The low values of ARIS for sunflower and wheat suggest that these crops received below 30% of the maximum potential evapotranspiration. In dry seasons (e.g. 1998/1999), the values of ARIS increased for sunflower and wheat, although this increase does not signify a linear relation between ARIS and the amount of precipitation, as shown by García-Vila et al. (2008). However, these authors observed that an increase in precipitation caused a clear decreasing of ARIS in cotton, sugar beet and garlic. Low values of the ARIS in sunflower show that most of the farmers consider that this crop could be cultivated as a rainfed crop, or with a small irrigation supply. On the other hand, the low ARIS values observed in the 16 seasons of study (smaller than 0.25; Fig. 3A) suggest that the crop remained under a constant water stress. One of the reasons for this water management is that the current policies of subsidies in sunflower are based on the cultivated area and not on yield. Therefore, for farmers it is more beneficial to obtain a maximum profit from the irrigation water rather than at maximum yield (Lorite et al., 2004b). The ARIS for sunflower showed a high variability, with an average variation coefficient of 1.25, although in the driest year of the period (1998/1999) it descended to 0.88 (Fig. 3B).

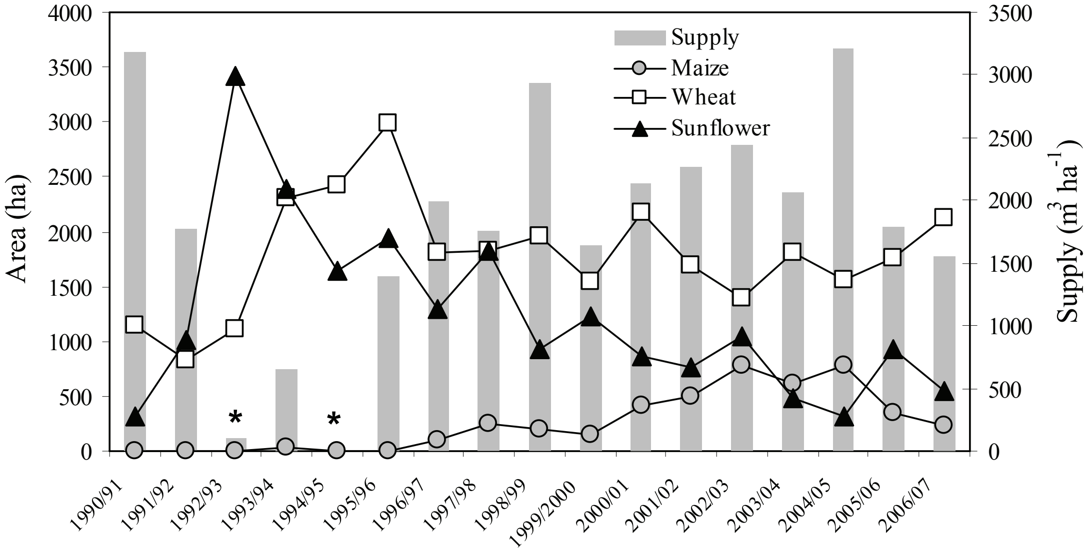

Fig. 2. Evolution of the area cultivated with maize, wheat and sunflower (ha) and irrigation water allocated (m^3 ha^{-1}) in GCIS from 1991/1992 until 2006/2007 irrigation season. *During 1992/1993 and 1994/1995 irrigation depth applied was practically null.

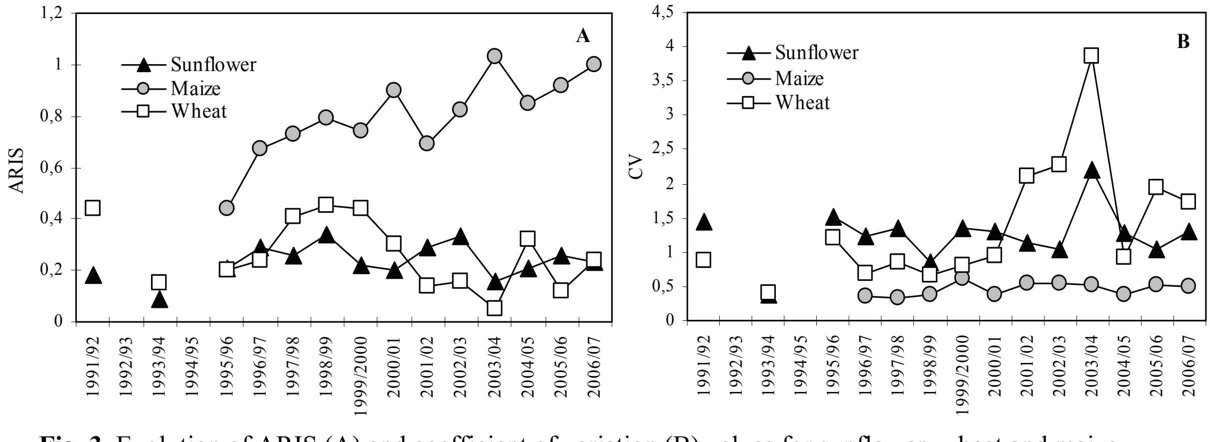

Fig. 3. Evolution of ARIS (A) and coefficient of variation (B) values for sunflower, wheat and maize from 1991/1992 to 2006/2007 irrigation season.

CYR values for sunflower ranged between 20% and 70% depending on the annual rainfall, although the average was 40%, evidencing that the production obtained during the whole irrigation season was smaller than 50% of that attainable, as observed by Lorite et al. (2004b). This confirms that the farmers are not interested in obtaining the maximum yield, and prefer to allocate the available water to other crops such as cotton or maize.

The IWP for sunflower, wheat and maize is presented in Fig. 4A. The average values were low in the three crops (sunflower, 0.19 €/m^3; wheat, 0.26 €/m^3; maize, 0.24 €/m^3), indicating that the application of irrigation here did not generate an increment in gross income, compared with rainfed production. However, in the last few years sunflower values have reached higher values due to its increase in international market prices. Comparing Fig. 3A and 4A, sunflower obtained similar values of IWP compared with maize, but with a significantly lower irrigation consumption. Thus, a deficit in irrigation for sunflower could be considered as a correct alternative compared with other crops such as maize.

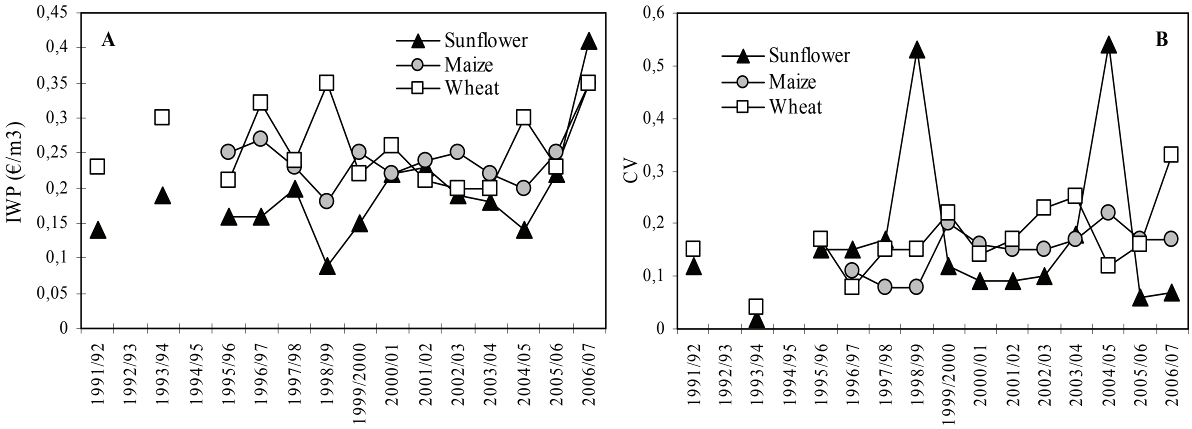

Fig. 4 Evolution of IWP values and coefficient of variation for sunflower, wheat and maize from 1991/1992 to 2006/2007 irrigation seasons.

Seasonal ET variability and crop coefficients for sunflower in the GCIS

The seasonal ET estimated with METRIC for all the plots in the GCIS for the 2004/05 irrigation season ranged from more than 1000 mm for well-irrigated fields, to almost zero for non-agricultural areas (Santos et al., 2008). Crop coefficients for individual fields were estimated as the ratio between METRIC ET and ET_0. Fig. 5A shows real crop coefficient values for different sunflower fields within GCIS, obtained with ET estimated by METRIC.

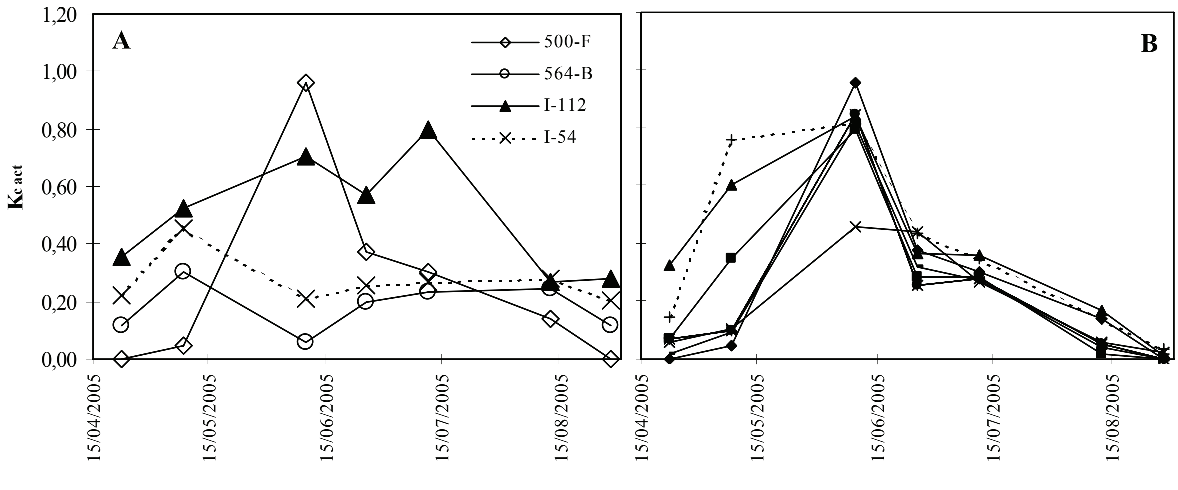

Fig. 5. Real crop coefficient curves for four sunflower fields within GCIS (A) and for one sunflower field having enough size to contain more than one thermal pixel with valid METRIC ET estimates (B).

ET variability was high in sunflower, with a variation coefficient of 0.28, while average ET was low (378 mm). This high variability in actual ET can be explained by the plot to plot variability in irrigation and crop management in the GCIS, as characterized previously by Lorite et al. (2004b).

In the plots with enough size to contain more than one thermal pixel with valid METRIC ET estimates, the ET variability within fields was assessed (Fig. 5B). The variation coefficient within fields for sunflower was 0.13, which means higher variations than 160 mm (44% of seasonal ET) within a sunflower field, caused by emergence problems, very limited irrigation applied, etc.

In conclusion, the study of performance indicators for sunflower at the GCIS showed that this crop is frequently under a clear water stress, and this irrigation management has an impact on yield, which is usually lower than expected. The performance indicators analysed indicated a high variability during the irrigation seasons and between different sunflower fields. The high variability was confirmed with remote sensing techniques using the METRIC model to obtain actual ET measures.

In spite of the low level of inputs provided to the crop, irrigation productivity for sunflower in the last few years has provided similar values than for other crops such as maize, but with very low irrigation requirements.

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