International Journal of Agricultural Policy and Research Vol.2 (12), pp. 484-491, December 2014
Available online at http://www.journalissues.org/IJAPR/
http://dx.doi.org/10.15739/IJAPR.021

ISSN 2350-1561

Original Research Article

Water use efficiency and water productivity in the Spanish irrigation district "Río Adaja"

Accepted 20th November, 2014

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A study of the assessment of the irrigation water use has been carried out in the Spanish irrigation District "Río Adaja" that has analyzed the water use efficiency and the water productivity indicators for the main crops for three years: 2010-2011, 2011-2012 and 2012-2013. A soil water balance model was applied taking into account climatic data for the nearby weather station and soil properties. Crop water requirements were calculated by the FAO Penman-Monteith with the application of the dual crop coefficient and by considering the readily available soil water content (RAW) concept. Likewise, productivity was measured by the indexes: annual relative irrigation supply (ARIS), annual relative water supply (ARWS), relative rainfall supply (RRS), the water productivity (WP), the evapotranspiration water productivity (ETWP), and the irrigation water productivity (IWP).The results show that in most crops deficit irrigation was applied (ARIS<1) in the first two years however, the IWP improved. This was higher in 2010-2011which corresponded to the highest effective precipitation P_e. In general, the IWP (€.m^{-3}) varied among crops but crops such as: onion (4.14, 1.98 and 2.77 respectively for the three years), potato (2.79, 1.69 and 1.62 respectively for the three years), carrot (1.37, 1.70 and 1.80 respectively for the three years) and barley (1.21, 1.16 and 0.68 respectively for the three years) showed the higher values. Thus, it is highlighted they could be included into the cropping pattern which would maximize the famer's gross income in the irrigation district.

Key words: irrigation water use assessment, crops, productivity indicators.

INTRODUCTION

Intensive agricultural practices, the increase pressure of urban cities and the changes of lifestyle, have strengthened the concerns of competing users over a limited water resource in a fragile and already stressed environment. In Spain, 16118 hm^{3}of water was devoted for irrigation in 2010, accounting about 75% of the total water consumption (Instituto Nacional de Estadística, 2012). Within a water scarcity scenario, the irrigated agriculture economic sector would be affected by the reduction on water supply and this might have a negative impact on the National gross income. Therefore, the search for irrigation strategies dealing with sustainable irrigation by saving water and improving the environment quality is encouraged. Within this framework the assessment of water use in the irrigation districts to assist water stakeholder decisions is reinforced.

Water resources can be assessed at field, scheme or regional scale by analyzing the water use efficiency and the water productivity indicators (Kassam et al., 2007). These refer to the ratio between the crop water requirements and water supply (irrigation o irrigation plus rainfall), and the ratio between the production and the water supply or between the production and the crop evapotranspiration. Bos (1997) proposed several indicators for the irrigation and drainage performance assessment. Clemmens and Molden (2007) defined the indicators: annual relative water supply (ARWS) and the annual relative irrigation water supply (ARIS) to determine the water availability and the water supply quality in irrigation areas. Droogers and Kite (1999) proposed several water productivity indicators and their adequacy at field, irrigation scheme or basin conditions have been assessed in studies aimed at determining the water use in irrigation districts and suggesting criteria for irrigation management resulting in water saving and/or increased farmer's income. Likewise, Vazifedoust et al., (2008) determined the water productivity indicators to propose irrigation management strategies at field scale that increased farmer's revenues and water productivity. They concluded that deficit irrigation and the reduction of irrigated area could be a good strategy during the water scarcity periods. Lorite et al., (2004a, b) evaluated the irrigation performance of an irrigation scheme in southern Spain. Moreno-Pérez and Roldán-Cañas (2013), characterized the water use in the Genil-Cabra irrigation district (Cordoba, Spain) by determining the relative irrigation supply, the relative water supply and the relative rainfall supply indicators which were used to highlight the effect of crop, soil texture and irrigation method on irrigation management. Salvador et al., (2011) applied water use efficiency and water productivity indicators to evaluate the irrigation performance and its variability between irrigation systems and crops in the Ebro basin (Spain). Likewise, Andrés and Cuchí (2014) used water productivity indicators to analyze the water use and the quality of irrigation in their study area.

Zwart and Bastiaanssen (2004), observed a broad interval in the average values of crop water productivity (wheat: 0.6 -1.7 kg/m^3; rice: 0.6-1.6 kg/m^3; cotton: 0.41-0.95 kg/m^3 and maize: 1.1-2.7 kg/m^3) and, pointed out its application to increase or maintain the same crop production reducing water supply about 20 to 40%. Qiu et al., (2008) determined the wheat water use efficiency in north China which varied within the interval 1.1 to 2.1 kg/m^3 decreasing as irrigation water increased. Sun et al., (2006), studied the effect of irrigation on water balance, yield and water use efficiency of winter wheat in north plan China during three years. They showed that non irrigation at the grain filling stage improved the water use efficiency and the grain yield. Garcia-Vila et al., (2008) studied the trends on irrigation management in the Genil-Cabra irrigation district for 15 years (including a couple of droughts periods). They showed that irrigation management followed a deficit irrigation scheme (60% of maximum crops water requirement), and that a proper crop selection minimized the risk by balancing stability and profitability. Thus, the strategies for irrigation management would adjust the irrigation depth to fulfill a proportion of crop water requirements. Likewise, Pereira et al., (2012) carried out deficit irrigation strategies by estimating economic water productivity indices and water use efficiency indicators that were based on a proper understanding of crop water requirements. Among the various methods and tools to determine crop water requirements, the soil water balance calculation is commonly used (Allen et al., 1998; Sun et al., 2006).

Objectives

Keeping in mind the water scarcity scenario for irrigation in the short and long term and the probably scenario of water allocation for different uses following criteria of efficiency and productivity, this work is aimed at assessing the water use efficiency and water productivity in a modernized Spanish irrigation district "Río Adaja" (Nava de Arevalo, Ávila) since it began in 2010. For that purpose, the following indicators: relative rainfall supply RRS, annual relative irrigation supply ARIS, annual relative water supply ARWS, water productivity WP, irrigation water productivity IWP and evapotranspiration water productivity ETWP were estimated for the three years of operation in the irrigation district. These indicators will be used to propose water management strategies, comprising water saving and/or farmer's income increase, that could assist water stakeholder decisions at the irrigation district. Moreover, the results could be references for benchmarking at regional, national or international level.

MATERIAL AND METHODS

The study area

The Spanish irrigation district "Río Adaja" is located at Nava de Arévalo in Avila province. The climate is generally Mediterranean with an annual rainfall average and reference evapotranspiration (ET_o) of 400 mm and 1200 mm, respectively, logged in the "Nava de Arevalo" weather station (Latitud: 40°58'42" N, Longitude: 4°46'34" W and Altitude: 864 m). Soils are sandy loam texture with an effective depth between 0.7 and 1 m.

This area has been irrigated with subsurface waters from single wells by pressure irrigation methods, since the beginning until the last decade of the XX century where the presence of arsenic concentration produced by the increase in the water table draw down reduced water extractions. The Spanish Government and Regional Agencies, funded the works required to build an automatic pressurized irrigation distribution network to convey surface water, contained in an open reservoir at the head of the irrigation system, to every hydrant in the branching network. In 2006 water users grouped in the Irrigation-District "Río Adaja" which irrigated 1220 ha in 2010, 5000 ha in 2012 and about 6000 ha in 2013. Sprinkler irrigation methods (center-pivot, moving lateral, solid set and guns) are predominant in the area. The farmers have increased their revenue since the first year of operation, and also, new agribusiness opportunities have arisen fostering the economic development of the rural area. It is highlighted that crops have changed from less water requirements (cereals) to more water demanding (horticultural crops).Table 1 presents the average values of water supply (irrigation and estimated effective precipitation, P_e) and harvested crop yield, sowing month and cycle span for the main crops although the area of sunflower decreased in

Table 1. Mean values of irrigation water supply and harvested yield, sowing month and cycle span for the main crops in the irrigation district "Rio Adaja"

Crop	Irrigation water supply (mm)			P_e (mm)			Harvested yield (t.ha^{-1})			Sowing month	Crop cycle span
	2010-2011	2011-2012	2012-2013	2010-2011	2011-2012	2012-2013	2010-2011	2011-2012	2012-2013		
Alfalfa	568.40	493.26	530.99	184.38	138.65	143.07	14.5	11.09	14.72	Marsh	180
Barley	115.36	76.48	160.87	191.70	177.14	170.49	6.14	3.9	4.81	November	200
Bean	357.81	405.36	394.86	83.52	38.97	53.41	3.3	1.27	2.77	May	110
Carrot	874.94	607.26	631.00	142.86	134.21	132.11	83.88	72.17	79.26	Marsh	140
Maize	612.03	582.53	560.98	110.30	38.97	78.23	12.84	13.22	11.96	May	150
Onion	515.27	580.59	575.27	142.86	134.21	132.11	71.31	38.44	53.37	Marsh	150
Potato	190.83	518.94	554.26	138.52	123.10	79.27	30.8	50.82	51.96	April	120
Sorghum	170.00	332.89	219.31	107.07	38.97	53.41	7.5	4.75	7.49	May	120
Sugar beet	593.85	616.70	645.00	142.57	123.10	92.32	102.12	105.76	99.22	April	150
Sunflower	282.97	109.06		115.78	122.50	68.31	3.31	1.2		April	130
Winter wheat	164.41	140.62	209.01	247.36	185.01	192.01	5.56	4.95	5.81	November	240

the third year.

Irrigation policy in the irrigation district

InfoRiego is the Castilla and Leon regional advisory platform which supports farmers in irrigation management. It contains the climatic data of several weather stations throughout the Castilla and León Community. Thus, farmers can determine the gross crop irrigation requirements by knowing information such as: crop and its development stage, irrigation method and, the period of time for which the crop water requirement will be determined. However, it is observed that farmers did not determine the crop water requirement properly, causing underestimation of water requirements in some cases and overestimation in others. Hence, it would be interesting to assess the water use efficiency in the irrigation district.

Crop water requirement to maintain the optimal soil water content

Before irrigation, it is necessary to check the soil moisture in the root zone at several locations of the agricultural land. Estimation of the amount of water needed to bring the soil to field capacity is very important in order to bring the soil to field capacity.

Table 1 shows the sowing month and the crop cycle span corresponding to farmer's current practice. The crop water requirements were simulated by a soil water balance based on the environmental conditions (weather data), soil and crop characteristics. The soil water content within the crop root zone can be expressed as water depletion (D_e) which means the remaining water quantity to reach the soil field capacity (Allen et al., 1998). Thus, the water depletion equals to zero at the soil field capacity. In this context the soil water balance can be described as follows:

$$D_e = D_b + ET_c + D_p - I - P_e - U_f \qquad [1]$$

Where: D_e and D_b (mm) are the soil water depletion between the end of one day and the beginning of the following day, respectively, which was estimated taking into account the soil properties (field capacity and the wilting point) and the effective crop root depth; ET_c (mm) is the crop evapotranspiration; D_p (mm) is the deep percolation; I (mm) is the net irrigation requirement; P_e (mm) is the effective precipitation (the daily precipitation minus runoff); U_f (mm) is the uprising flow from water table which was considered negligible (water table was deeper). Runoff was calculated from the daily precipitation values by the curve number method of the Soil Conservation Service (1972) adapted by MOPU (1990) for the Spanish conditions.

If no rain, the initial depletion equaled the readily available soil water (RAW) (mm) that was calculated as defined by Allen et al. (1998):

$$RAW = p * TAW \qquad [2]$$

Where: p is the fraction of the total available water (TAW) (mm) that can be depleted from the root zone before moisture stress. The p values were adjusted according to crop and the daily ET_{max} as described by Allen et al., (1998). TAW (mm) is defined like follows:

$$TAW = 1000(\theta_{FC} - \theta_{WP})Z_r \qquad [3]$$

Where: θ_{FC} and θ_{WP} ($m^3\ m^{-3}$) are the field capacity and the wilting point, respectively and Z_r is the rooting depth (m).

The maximum evapotranspiration (ET_{max}) was calculated from the reference evapotranspiration (ET_o) for all crops with the dual crop coefficient approach (Allen et al., 1998; Allen, 2000; Lorite et al., 2004a; García-Vila et al. 2008):

$$ET_{max} = ET_o * K_c \text{ and } K_c = K_e + K_{cb} \qquad [4]$$

Where: K_c, K_{cb} and K_e were the crop coefficient, the basal crop coefficient and the soil evaporation coefficient, respectively. The K_{cb} values proposed by FAO for different crops were adjusted according to the climate of the irrigation district. The daily K_e values were determined by the topsoil water balance.

The ET_o (mm) was calculated with de Penman-Monteith equation, as proposed by Allen et, al. (1998).

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,U_2)} \qquad [5]$$

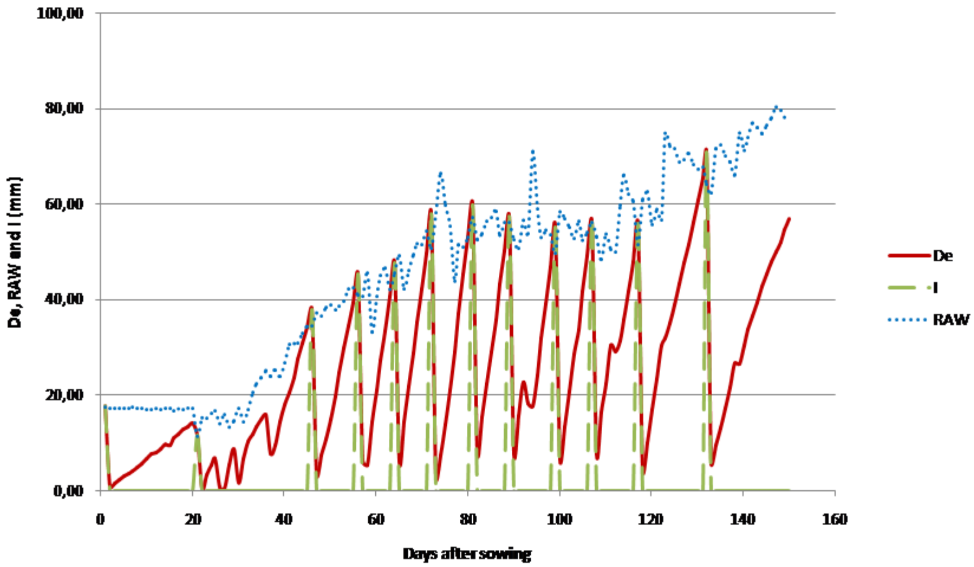

Figure 1: Simulation of irrigation management to maintain optimal soil water content for maize during 2010-2011.

Where: R_n is the net radiation at the crop surface, (MJ m^{-2} day^{-1}), G is the soil heat flow density (MJ $m^{-2}day^{-1}$), T is the average of the daily air temperature measured at 2 m height(°C), U_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), e_s-e_a is the saturation vapor pressure deficit, (kPa), Δ is the slope vapor pressure curve (kPa°C^{-1}) and γ is the psychrometric constant (kPa°C^{-1}).

The soil water balance was computed in the Excel spread sheet and the daily optimum net irrigation requirement was estimated for all crops. In such as way, irrigation is considered if the soil depletion was equal or higher than the RAW value, although at this point ET_c slightly reduced, because of the water deficit within the crop root zone, but it is close to ET_{max}. Thus, this irrigation scheduling would be adequate to obtain the maximum crop yield. Then, ET_c can be expressed as follows:

$$ET_c = (K_e + K_{cb} * K_s) * ET_o \quad [6]$$

Where: K_s is the soil water deficit coefficient calculated with the soil water balance like described by Allen et al., (1998). Figure 1 shows an example of this irrigation scheduling for maize corresponding to the 2010-2011 irrigation season .

The soil water balance was simulated considering the whole climatic data set available in the weather station which corresponded to the last eleven years. Crop water requirements were estimated considering a typical wet, normal and dry average year. These were calculated by the normal distribution of the results of the simulated eleven years climatic data set and, by assuming a P_e probability exceedance of 20, 50 and 80% (for wet, normal and dry year, respectively). The gross irrigation requirement was determined by setting a target irrigation application performance of 0.85 which corresponded to the mean value calculated in the field evaluations of the irrigation systems in the study area; these values varied from 0.80 to 0.90 and it shows a good uniformity water application (Naroua et al. 2012). The linear crop-yield function (Doorenbos and Kassam, 1979) was used to estimate the actual evapotranspiraton (ET_a) by adjusting ET_{max} according to the harvested yield. The regional potential crop yield and the proposed FAO crop reduction coefficient (K_y) by water deficit was also considered.

$$1 - \frac{Y_a}{Y_{max}} = K_y\left(1 - \frac{ET_a}{ET_{max}}\right) \quad [7]$$

Where Y_a and Y_{max} (t/ha) are the actual harvested yield and the potential yield respectively, K_y is the crop reduction coefficient by water deficit, ET_a and ET_{max} are the actual and the maximum evapotranspiration, respectively.

The harvested crop yield and the irrigation water supply by irrigation season were determined by a farmer's survey. Then, the water use efficiency (ARIS, RRS, ARWS) and the water productivity indicators (WP, IWP and the ETWP expressed as $Kg.m^{-3}$ and €.m^{-3}) were calculated to evaluate the irrigation management and the water productivity at the irrigation district level. In addition, the results of the current water use (water productivity) were compared to the ones considering the scenario of no irrigation water restriction that would allow to reach the maximum crop production for the average wet, normal and dry years.

Water use and water productivity indicators

Water use efficiency is simply the ratio of the water

Table 2. Values of the water use efficiency indices among crops and irrigation seasons

	ARIS			ARWS			RRS		
Crop	2010-2011	2011-2012	2012-2013	2010-2011	2011-2012	2012-2013	2010-2011	2011-2012	2012-2013
Alfalfa	0.79	0.59	0.93						
Barley	0.61	0.39	1.81						
Beans	0.73	0.72	0.97	1.18	2.32	1.75	0.22	0.20	0.21
Carrot	1.57	0.99	1.49						
Maize	0.91	0.81	1.06	1.13	0.95	1.38	0.17	0.06	0.17
Onion	0.84	0.90	1.35	1.16	2.15	2.18	0.25	0.40	0.41
Potato	0.30	0.69	1.06	0.88	1.05	1.41	0.37	0.20	0.18
Sorghum	0.31	0.53	0.57	0.79	1.90	1.04	0.31	0.20	0.20
Sugar beet	0.76	0.68	1.02	1.05	0.95	1.43	0.20	0.16	0.18
Sunflower	0.50	0.17		1.05	1.80		0.31	0.95	
Winter wheat	0.42	0.30	0.83	0.97	0.91	1.27	0.58	0.52	0.61
Average	0.70	0.62	1.11						

beneficially used and the quantity of water delivered. Basically, the term water use efficiency originates from the economic concept of productivity. Thus, water productivity might be measured by the volume of water taken into a plant to produce a unit of the output. In general, the lower the resource input requirement per unit, the higher will be the efficiency. Performance indicators for water use efficiency and water productivity assessed the actual water and its availability in the irrigation district for the three irrigation seasons. The water use efficiency indicators used in this study were as follows:

Annual relative irrigation supply ARIS

$$ARIS = \frac{\text{Annual volume of irrigation water supply}}{\text{Annual volume of crop irrigation requirement}} \quad [8]$$

Annual relative water supply ARWS

$$ARWS = \frac{\text{Irrigation Supply} + \text{Effective Precipitation}}{ET_a} \quad [9]$$

Relative rainfall supply RRS

$$RRS = \frac{P_e}{ET_a} \quad [10]$$

On the one hand, ARIS assessed the irrigation water use and its availability in the irrigation scheme. On the other hand, ARWS highlights if water supply (irrigation plus precipitation) covers the ET_a which, was estimated by adjusting the ET_{max} considering the actual harvested yield and, RRS quantifies the part of ET_a that could be cover by P_e. Likewise, the water productivity indices were the following:

Water productivity WP

$$WP = \frac{\text{Actual yield}\left(\frac{Kg}{ha}\right)}{(\text{Irrigation supply} + \text{Effective precipitation})\left(\frac{m^3}{ha}\right)} \quad [11]$$

Irrigation water productivity IWP

$$IWP = \frac{\text{Actual yield}\left(\frac{Kg}{ha}\right)}{\text{Irrigation supply}\left(\frac{m^3}{ha}\right)} \quad [12]$$

Evapotranspiration water productivity

$$ETWP = \frac{\text{Actual yield}\left(\frac{Kg}{ha}\right)}{ET_a\left(\frac{m^3}{ha}\right)} \quad [13]$$

The water productivity indicators, expressed as €.m^{-3}, were determined taking into account the price of the harvested products published by the ITACYL (Agriculture Technical Institute of Castilla and León).

RESULTS AND DISCUSSIONS

As in other resources, the management of irrigation water is vitally needed for its conservation and efficient use. Inefficient use of irrigation water is directly proportional to the loss of the resources conserved. The present research study was carried out for assessing the water use efficiency and water productivity in a modernized Spanish irrigation district "Río Adaja" (Nava de Arevalo, Ávila). For this purpose different water use and productivity indicators were studied and estimated for the three years of operation in the subject irrigation district. The data analysis and statistical analysis were done through ANOVA procedure accordingly.

Water Use Efficiency Indicators

Table 2, presents the results for the water use efficiency indicators: ARIS, ARWS and RRS calculated with Eqs [8], [9] and [10], respectively. It is observed; they varied among crops and year. Irrigation did not fulfill the simulated crop water requirements for the optimal soil water content within the root zone (ARIS<1), for most crops in 2010-2011 and 2011-2012 and, the contrary was observed in 2012-2013. In this year most crops were irrigated in excess (ARIS>1). Attending to their ARIS values, crops were classified into three groups: the first with ARIS>0.80 (the maximum crop production was attained); the second within the interval 0.50<ARIS<0.80 and the third with ARIS≤0.5. During these years, crop production could have been affected by water stress and crop yield could have been reduced by an inadequate irrigation management in the last group.

Considering the above classification, the maximum cop production (first group) was reached in carrot, maize,

Table 3.Values of productivity indicators, expressed as $Kg.m^{-3}$, among crops and irrigation season

	IWP($Kg.m^{-3}$)			WP ($Kg.m^{-3}$)			ETWP($Kg.m^{-3}$)		
Crop	2010-2011	2011-2012	2012-2013	2010-2011	2011-2012	2012-2013	2010-2011	2011-2012	2012-2013
Alfalfa	2.55	2.25	2.77	1.93	1.75	2.18			
Barley	5.32	5.10	2.99	2.00	1.54	1.45			
Beans	0.92	0.31	0.70	0.75	0.29	0.62	0.88	0.66	1.08
Carrot	9.59	11.88	12.56	8.24	9.73	10.39			
Maize	2.10	2.27	2.13	1.78	2.13	1.87	2.01	2.03	2.59
Onion	13.84	6.62	9.28	10.84	5.38	7.54	12.60	11.56	16.46
Potato	16.14	9.79	9.37	9.35	7.92	8.20	8.23	8.29	11.54
Sorghum	4.41	1.43	3.42	2.71	1.28	2.75	2.14	2.43	2.84
Sugar beet	17.20	17.15	15.38	13.87	14.30	13.46	14.56	13.64	19.31
Sunflower	1.17	1.10		0.83	0.52		0.88	0.93	
Winter wheat	3.38	3.52	2.78	1.35	1.52	1.45	1.30	1.38	1.84

onion for 2010-2011 and 2011-2012, and in all crops, except sorghum, in 2012-2013. The second group was composed by alfalfa, bean and sugar beet in the first two years, by sorghum in 2011-2012 and 2012-2013, barley in 2010-2011 and potato in 2011-2012. The third group was composed by sunflower and winter wheat in the first two years, potato and sorghum in 2010-2011 and barley in 2011-2012. These results are similar to the ones reported in the literature by Lorite et al., (2004b) for wheat, barley and sunflower (ARIS<0.5) and for sugar beet and maize (ARIS>0.5) in southern Spain. The mean ARIS value at the irrigation district level was 0.70, 0.62 and 1.11 respectively for the three irrigation seasons. The ANOVA test (Least Significant Difference, LSD) for these values showed statistically significant difference at the 95% probability level between the third and the other two irrigation seasons. This highlights that it was an under-application of water during 2010-2011 and 2011-2012 caused either by the strategies followed by the farmers or by a limitation on water resources for irrigation in the watershed. The irrigation district reported water scarcity for irrigation in 2010-2011 and an increase in water resources in 2011-2012 although this not fulfilled the crop water requirements corresponding to the increment of 3800 ha in the irrigated area.

The ARWS and RRS values depend on the estimated ET_a which in turn depends on the availability of the regional potential crop yield and the K_y values. It is observed that irrigation plus precipitation covered the estimated ET_a ($0.9 \leq$ ARWS ≤ 1.2) considering the current yield for bean, maize, onion, sugar beet, sunflower and winter wheat in 2010-2011; maize, potato, sugar beet and winter wheat in 2011-2011 and sorghum in 2012-2013. These results indicate a proper irrigation management for these crops in the irrigation district as it was shown by other authors (Moreno-Perez and Roldan-Cañas, 2013). However, ET_a was not fulfilled in sorghum in 2010-2011 (ARIS=0.31). This could be explained by the criteria of deficit irrigation followed by farmers. Conversely, bean, onion, sorghum and sunflower presented an excess of water to fulfill the ET_a, for the corresponding yield, in 2011-2012 and, bean, maize, onion, potato, sugar beet and winter wheat in 2012-2013. This might be explained either by an inadequate irrigation management or by other factors, independent to water supply, which reduced crop yield.

According to RRS values, P_e covered more than 50% of the estimated ET_a, considering the harvested yield, for winter wheat highlighting an opportunity to save water by planning a proper irrigation management taking into consideration the rainfall. The highest RRS value corresponded to sunflower in 2011-2012 as a result of its low estimated ET_a, calculated with the low harvested yield, which might have been caused by an inadequate deficit irrigation management (ARIS=0.17).

Water Productivity Indicators

Table 3 presents the water productivity indicators: WP ($kg.m^{-3}$), IWP ($kg.m^{-3}$) and ETWP ($kg.m^{-3}$) for different crops during the three years calculated by Eqs. [11], [12] and [13], respectively. They varied among crops; the highest values corresponded to potato, sugar beet, onion and carrots because of the characteristics of the harvested products. The results of ETWP ($kg.m^{-3}$) values for winter wheat and maize are similar to the values proposed by Zwart and Bastiaanssen (2004) (maize: 1.1-2.27 $kg.m^{-3}$ and wheat: 0.6-1.7 $kg.m^{-3}$). However, Salvador et al., (2011) reported lower IWP values ($kg.m^{-3}$) for alfalfa, barley, maize, sunflower and wheat (1.8; 2.5; 1.6; 0.68 and 1.6, respectively) at the Ebro basin (Spain). Likewise, Andrés and Cuchí (2014) reported WP, IWP and ETWP ($kg.m^{-3}$) values for barley (2.47; 1.01 and 1.20, respectively), maize (1.55; 1.01 and 1.19, respectively) and alfalfa (1.53; 1.04 and 1.21, respectively) lower than the ones observed in this study. It is noted that the indices for the same crops were different between years by example, the harvested yield in beans and onion decreased in the second year although water supply (irrigation plus P_e) was similar. Thus again, an inadequate irrigation management in the second year could have caused these results. WP and IWP indices in carrot (2010-2011) reduced by the excess of irrigation. In addition, they were lower in sunflower in the second year

Table 4. Values of productivity indicators in term of €.m^{-3} among crops and irrigation season, and scenarios of non-irrigation water restriction for the typical wet, normal and dry years

	IWP (€.m^{-3})						WP(€.m^{-3})					
Crop	Wet	Normal	Dry	2010-2011	2011-2012	2012-2013	Wet	Normal	Dry	2010-2011	2011-2012	2012-2013
Alfalfa				0.48	0.42	0.52				0.36	0.33	0.41
Barley	1.03	0.89	0.78	1.21	1.16	0.68	0.44	0.46	0.48	0.45	0.35	0.33
Bean	1.03	0.93	0.85	0.93	0.31	0.70	0.85	0.82	0.79	0.75	0.29	0.62
Carrot	3.02	2.58	2.25	1.37	1.70	1.80	2.22	2.08	1.96	1.18	1.39	1.49
Maize	0.52	0.48	0.45	0.48	0.52	0.49	0.43	0.43	0.42	0.41	0.49	0.43
Onion	4.72	4.08	3.59	4.14	1.98	2.77	3.53	3.33	3.15	3.24	1.61	2.26
Potato	1.68	1.53	1.40	2.79	1.69	1.62	1.35	1.31	1.27	1.62	1.37	1.42
Sorghum	0.44	0.41	0.37	0.88	0.29	0.68	0.36	0.36	0.35	0.54	0.26	0.55
Sugar Beet	0.49	0.43	0.38	0.51	0.51	0.46	0.40	0.37	0.35	0.41	0.43	0.40
Sunflower	0.51	0.43	0.38	0.57	0.54		0.39	0.36	0.34	0.40	0.25	
Winter Wheat	0.57	0.46	0.39	0.81	0.84	0.66	0.30	0.30	0.29	0.32	0.36	0.35
Average	1.40	1.22	1.09	1.29	0.91	1.04	1.03	0.98	0.94	0.88	0.65	0.82

since the reduction of water devoted for irrigation in the watershed (inadequate deficit irrigation application). The yield in alfalfa, barley and potato decreased as water for irrigation decreased however, WP and IWP indices improved.

Water Productivity Indicators in term of (€.m^{-3})

Table 4 shows the IWP and WP (€.m^{-3}) values among crops during the years of operation in the irrigation district, and the scenarios of no irrigation water restriction for the typical wet, normal and dry years. The scenario of no water restriction for irrigation maintained the optimal soil water content within the crop root zone and, considering a maximum crop yield production (potential yield). IWP and WP (€.m^{-3}) depend on crop yield and the market price of the harvested product. It can be useful not only to compare the water productivity among crops in the irrigation district but also to determine a cropping pattern for farmer's income optimization. According the three studied years, the results varied between 4.14 and 0.29 for IWP (€.m^{-3}) and, between 3.24 and 0.25 for WP (€.m^{-3}).The highest values corresponded to onion, potato, carrot and barley which suggests that these crops would be a proper cropping pattern for the irrigation district. These results are lower than those presented by Lorite et al., (2004a) for sugar beet, maize sunflower and winter cereals at the Genil-Cabra Spanish irrigation district but they are higher than those reported by Salvador et al., (2011) for barley, wheat, alfalfa, corn and sunflower in the Ebro basin (Spain).The indicators for the same crops varied during the tree years. It is noted that the effect of P_e, in general, produced the highest values of IWP and WP (€.m^{-3}). During the three years, the highest value corresponded to 2010-2011 (1.29 €.m^{-3}); although the ANOVA test (LSD) did not show significant difference for the average values among years.

When comparing the actual water use with the scenario of non irrigation water restriction for the typical wet, normal and dry years, it is observed that deficit irrigation improved irrigation water productivity indicators in barley (2010-2011 and 2011-2012), beans (2010-2011), potato (2010-2011 and 2011-2012), sorghum (2010-2011), sugar beet (2010-2011 and 2011-2012), sunflower (2010-2011 and 2011-2012) and winter wheat(2010-2011 and 2011-2012) but, it reduced in bean (2011-2012 and 2012-2013), onion (2011-2012) and sorghum (2011-2012). Meanwhile, the achievement of maximum crop production in maize (during the three years), onion (2010-2011) and sugar beet (2012-2013) reached similar IWP values than those no water restriction scenarios however, they were lower in carrot (during the three years) and onion (2011-2012 and 2013-2013).

Conclusions

The modernized irrigation district "Río Adaja" began its operation in 2010 so; it is interesting to assess the water use and water productivity during these first years. The results could aid the water stakeholders in their decisions regarding the seasonal water planning and the improvement of the water use efficiency in the irrigation district, and the planning of water allocation in the basin.

The results of the three first years of irrigation (2010-2011, 2011-2012 and 2012-2013) showed that the irrigation district followed a deficit irrigation strategy with ARIS values of 0.70 and 0.62, respectively for the first two years and, a full irrigation application in the third year (ARIS = 1.11) although there is a trend of maximum crop production for carrot, maize and onion (ARIS>0.80). Likewise the deficit irrigation application has improved the water productivity indicators for most of the crops and has been higher for onion, potato, carrot and barley. Thus, it is suggested that these crops should be included in the proper cropping pattern for maximizing farmer´s gross income.

Although there was a good irrigation management (ARIS≤1, 0.90≤ARWS≤1.20 and the IWP increased in all years with high P_e) in many cases, a deficient management was observed in other cases. Since the estimated evapotranspiration for the actual harvested yield did not correspond to the water supply (irrigation + P_e) for bean (2011-2012 and 2012-2013), maize (2012-2013), onion (2011-2012 and 2012-2013), potato (2012-2013), sorghum (2011-2012), sugar beet (2012-2013), sunflower (2011-2012) and winter wheat (2012-2013), and since irrigation water was in excess for carrot in 2010-2011 and 2012-2013, it is recommended to modify the irrigation management criteria for these crops.

Suggestions

In the light of study carried out it is suggested that good management practice right from the beginning of the project is essential; otherwise, farmers once accustomed to irrigate with plenty of water find it difficult to change their practice during periods of scarcity. Proper and efficient management ensures not only the conservation of water, but also helps in increasing the crop productivity and preservation of soil fertility. As the productivity of agriculture mainly depends on efficient use of irrigation water therefore; any effort in this regard should be beneficial in minimizing the growing water scarcity issue up to some extent.

Acknowledgement

We would like to thank the Commission of Science and Technology (CICYT) for the funding received for this research through project AGL2004-01689.

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