Water Use and Productivity of Maize-based Cropping Systems in the Alqueva Region (Portugal)

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In intensive irrigated farming systems, the way to improve productive efficiency depends on the proper management of resources. With the implementation of the Alqueva global irrigation system in the southern Portugal region of Alentejo, agricultural intensification is a reality that imposes to farmers the challenge of producing more and more efficiently, ensuring the farming systems sustainability. This work resulted from an on-farm demonstration project carried out in two locations in the Alqueva region. Water use and water productivity were studied during 2012/2013 and 2013/2014, in three double cropping systems: a maize monoculture (MM) and two rotations, barley + maize-barley (BM-B) and sunflower-bar- ley + maize (S-BM). Maize yields were influenced by the length of the crop cycle. In the rotation BM-B, with a predominance of autumn-winter crops, water requirements were lower and the total volume of irrigation applied was approximately half of the monoculture (5930 m^3/ha and 13,230 m^3/ha, respectively). When the potential crop yield was reached, maize had the higher water productivity (the highest value achieved was of 2.7 kg/m^3). Overall, as a result of the lower yields achieved, the water productivity values indicate a less balanced performance of the S-BM rotation.

Keywords: Alqueva, monoculture, crop rotation, water extraction, water productivity

Introduction

The major challenge of the agricultural sector is to produce more with greater efficiency by reducing economic and environmental costs, strengthening itself against the risks associated with climate change, particularly in vulnerable areas such as the Mediterranean region where water scarcity is a key issue (Olesen and Bindi 2002; Zwart and Bastiaanssen 2004; Reidsma et al. 2009; Valverde et al. 2015; Li et al. 2016).

In the southern Portugal region of Alentejo, agriculture has been conditioned to the pace of a Mediterranean climate characterized by a large variability and irregularity in the distribution of annual and interannual rainfall and a hot and dry season in the summer months. The comparison of the key variables that characterize this climate with the development period and the productive potential of a large number of agricultural plant species implies that the success of the agricultural sector in Mediterranean regions - or other regions with water availability constraints - depends to a very large degree on proper water resources planning and management, as well as on the success of irrigation implementation (Pereira et al. 2012; Valipour 2013, 2014, 2015, 2016; Valipour and Singh 2016).

In recent years, with the development of the irrigation network of the Alqueva Multi-Purpose Development - EFMA (*Empreendimento para Fins Múltiplos de Alqueva*) - farmers in this region are increasingly resorting to the irrigation of their crops. The increase in the irrigated area is progressively changing the farming model in Alentejo. In addition, there is a growing pressure on farmers to increase the farming systems efficiency, and often doing it without the knowledge and the necessary assistance for the adoption of the best strategies and practices in a changing agriculture (Pereira et al. 2012; Levidow et al. 2014).

As a result of the implementation of the EFMA, the effort to provide support to farmers in a region that is witnessing a profound transformation of the agricultural landscape has been considerable. This support has been exercised with merit, mainly by agricultural extension centers and farmers associations. However, there is a perceived need to expand the technology and knowledge transfer process, and thus reduce the knowledge gap. This route of knowledge transfer should be joined by research institutions, with on-farm demonstration studies, evaluating the farming practices performance, and strengthening the links between all stakeholders in the region.

The use of crop rotations is included in the set of practices that farmers can adopt to improve the sustainability of the cropping systems. In addition to having other well- known advantages like the maintenance of soil fertility and the reduction of erosion, bal- anced rotations contribute to the enhance of the agro-ecosystems self-regulation mecha- nisms, disrupting the cycles of pests and diseases, controlling weeds and recycling nutri- ents, thereby helping to improve the resource-use efficiency of the systems (López-Fando and Almendros 1995; Sainju et al. 2011). There being no doubt that crop rotations have many advantages in rainfed systems, obtaining these benefits is also expected when crops develop under irrigation.

Maize (*Zea mays* L.) is a very common crop in Portugal, grown both in continuous cropping systems and in rotation with other crops, mainly winter cereals. Large irrigation volumes are normally applied during the maize growing season in order to maximize grain yields but the question remains if this practice is sustainable both economically, given the water tariff defined by the Portuguese Government (Ministério das Finanças e da Administração Pública 2010) and the global market fluctuations, and environmentally since these high water consumptions may not be compatible with adequate resource use efficiency.

Several indicators for the assessment of water use efficiency have been proposed and reviewed, both at an eco-physiological scale, based on the relationship between photosynthesis and transpiration of the leaf or canopy, as at an agronomic scale, relating crop yield with consumed or applied water (Burt et al. 1997; Katerji et al. 2008; Pereira et al. 2012; Medrano et al. 2015). The agronomic approach intends to obtain productive or resource-use efficiency indicators (Helweg 1991; Valero and Manas 1993; Howell 2001;

Zwart and Bastiaanssen 2004; Pereira et al. 2012; Sharma et al. 2015). The resource-use efficiency of field crops under different levels of irrigation has been thoroughly studied by many researchers, such as Di Paolo and Rinaldi (2008); Albrizio et al. (2010); Morell et al. (2011); Langeroodi et al. (2014) or Howell et al. (2015). These studies focused specifically on crops such as maize, cotton (*Gossypium hirsutum* L.), barley (*Hordeum vulgare* L.) or sunflower (*Helianthus annuus* L.) and not in rotations based upon them. Therefore, in this study, given the lack of data of resource-use indicators in irrigated cropping systems adopted in the Alqueva region, and based on the results of a demonstration project carried out in two farms located in this irrigation network, in close collaboration with farmers and with minimal intervention in their agronomic management options, it is intended to: (i) evaluate the productive responses to irrigation in a maize monoculture and two crop rotations that include, in addition to maize, barley and sunflower; (ii) analyze water use and productivity, and irrigation water productivity in each of the studied crops and cropping systems; (iii) evaluate the performance of the studied cropping systems based on these indicators.

Materials and Methods

The study was carried out during two seasons - 2012/2013 and 2013/2014 - on two types of cropping systems, maize monoculture and maize in rotation with other crops. Namely, the following cropping systems were studied: a continuous cropping of maize (MM), and two-year rotations, barley + maize-barley (BM-B) and sunflower-barley + maize (S-BM). The first two were installed in a private farm located in the municipality of Aljustrel and the last at a private farm located in the municipality of Serpa, both located in the Alqueva irrigation network (Alentejo, South of Portugal). In the maize monocultures were used cultivars with a FAO 600 cycle, in rotation BM-B and S-BM were sown cultivars with cycles FAO 300 and 200, respectively.

The soils of the studied plots are Cambisols, with a silt loam texture in the case of the MM and BM-B areas and clay loam texture in the S-BM area. Soil texture was obtained by mechanical analysis.

The climate in the areas of study is, according to Koppen classification, Mediterranean or temperate with hot and dry summer, Csa. Meteorological data were recorded in automatic weather stations located near the farms, belonging to the SAGRA agro-meteorological network support service to farmers in the Alentejo region (COTR 2016a).

Soils were conventionally tilled, as commonly performed by the farmers, with the exception of the maize crops in rotation as second crop that were directly seeded on the barley stubble.

All crops were irrigated by center-pivots. The applied irrigation volumes were recorded with automatic udometers. The soil water content was monitored hourly with non-calibrated *in situ* capacitance probes, with the main objective of defining irrigation opportunity. The access tubes had a 50 cm to 60 cm depth, with sensors distributed every 10 cm. With the udometers data, seasonal irrigation supplies were computed. With the registered soil water content values, daily soil water content was calculated throughout the different maize crops growing season.

Crop evapotranspiration *(ETc)* was estimated using the MOGRA model (COTR 2016b), developed as a support tool to farmers. This is a daily soil water balance calculation model that works online, using information from the SAGRA network and the specific informa- tion for each monitored crop, based on the FAO methodology for computing crop water requirements (Allen et al. 1998). From these data, seasonal ETc was determined.

The main details of the agronomic management carried in the different crops are described in Table 1.

To evaluate yield water use efficiency, the following indicators were used (Howell 2001; Zwart and Bastiaanssen 2004; Dagdelen et al. 2006; Albrizio et al. 2010; Pereira et al. 2012): (i) Water Productivity (WP) (kg/m^3), computed using the relation $WP = Y/ETc$, where Y is the grain yield (kg/ha) and ETc is the crop evapotranspiration (m^3/ha); (ii) Irrigation Water Productivity (IRRWP) estimated by $IRRWP = Y/IW$, where IW is the seasonal irrigation water applied (m^3/ha).

To analyze the effect of year and type of cropping system on maize yield, maize water productivity and maize irrigation water productivity, we considered the data from both years, 2013 and 2014, as well as from the two types of cropping system: (i) maize in monoculture (MNC) and (ii) maize in rotation after barley (RAB). An ANOVA for two factors (year and type of cropping system) was performed using the GLM procedures of the IBM SPSS Statistics 23 software (IBM®). Differences between means, when suitable, were compared using Tukey's test *($p < 0.05$)*.

Table 1. Crop management data

Cropping system	Crop	Sowing date (DOY)	Plant population (per ha)	Date of first irrigation	Date of last irrigation	Total irrigation supply	Seasonal crop evapotranspi- ration	Harvest date (DOY)
				in days of the year		(m^3/ha)		
MM	Maize	05/05/13 (125)	92000	126	269	6970	6696	15/10/13 (288)
	Maize	28/04/14 (118)	90000	120	256	6260	6531	20/10/14 (293)
BM-B	Barley	27/12/12 (362)	3750000	113	133	1000	3850	20/06/13 (171)
	Maize	09/07/13 (190)	82810	192	286	4270	3987	25/11/13 (329)
	Barley	20/12/13 (354)	3750000	355	130	660	3968	02/06/14 (153)
S-BM	Sun-flower	23/04/13 (113)	85000	115	234	4470	5348	25/09/13 (268)
	Barley	02/12/13 (336)	3750000	65	107	340	3362	11/06/14 (162)
	Maize	21/06/14 (172)	10900	173	276	4390	4577	17/12/14 (351)

MM - maize monoculture; BM-B - rotation barley + maize-barley; S-BM - rotation sunflower-barley + maize.

Results

Climate and phenology

During the years of the study, the average annual temperature values recorded ranged between 15.8 °C and 16.4 °C and between 16.6 °C and 17.1 °C in Aljustrel and Serpa wheather stations, respectively, with increasing values from 2012 to 2014 in both locations. The highest values of annual precipitation were observed in 2014: 634 mm in Aljustrel and 665 mm in Serpa. The driest year was 2013 when annual precipitation reached 499 mm in Aljustrel and 447 mm in Serpa. It must be noted that the 30-year-long period mean value of annual rainfall in the region is 558 mm (IPMA 2016).

Average daily temperature (T) values, accumulated rainfall (P_{cum}) and accumulated rainfall plus irrigation ($(P + I)_{cum}$) can be observed in Fig. 1.

Due to the availability of water provided by rainfall in the autumn-winter period, a smaller difference between P_{cum} and $(P + I)_{cum}$ was observed in the winter crops. However, in the 2013 barley crop in rotation B+MB, a low rainfall year, the addition of water by irrigation took place essentially in the period between stages of booting and ear emergence (Fig. 1c). As shown in Table S1*, in the period of the cycle that took place between these stages, that lasted about 50 days, rainfall amounted to only 10 mm, which strongly suggests that the addition of irrigation water was important to reach a guaran- teed yield.

In the final stages of the maize crop cycle in the BM-B rotation (Fig. 1d), the daily average temperature decreased approximately 5 °C between the milk stage (272 DOY) and physiological maturity (307 DOY) with an increased reduction of about 7 °C between the latter and harvest (329 DOY). Also, between milk stage and physiological maturity, rainfall was 75 mm, which lowered the irrigation water requirements in this period. During the maize development cycle in the S-BM rotation, rainfall totaled 366 mm, with 172 mm occurring between sowing and physiological maturity which on the one hand, greatly contributed to the decrease in irrigation requirements but, on the other, affected the harvest opportunity due to especially rainy autumn months (Fig. 1h).

Yield, water use and water productivity

Table 2 shows that grain yield values (kg/ha) reflect more the crop cycle length than the crop succession, especially in the case of maize, where the highest yields were observed in the monoculture. The low productivity of maize grown in rotation S-BM was the result of a strong attack of the Mediterranean corn borer (*Sesamia nonagrioides* Lefèvre). There were also problems in its implementation as a second crop after barley, related to post-emergence weed control (monocotyledenous), as well as to the harvest date due to the occurrence of a long rainy period following the physiological maturity stage. The sunflower yield could have been higher but an excessive plant population may have pro- moted competition between plants, translated into small capitula with few achenes.

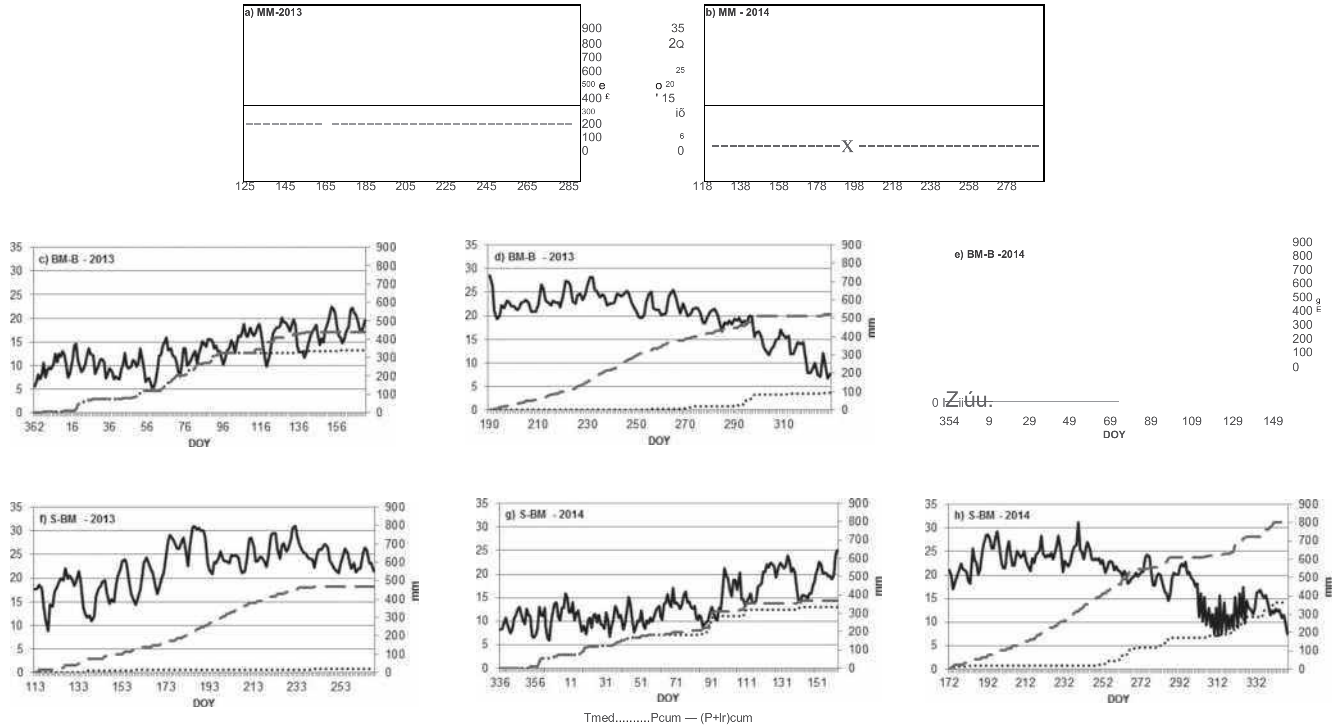

Figure 1. Daily average air temperatura (T_{med}), cumulative rainfall (P_{cum}) and cumulative precipitation plus irrigation ($(P+R)_{cum}$) during the growing season of each crop in each cropping system. a) maize; b) maize; c) barley; d) maize; e) barley; f) sunflower; g) barley; h) maize. MM - maize monocultura; BM-B - rotation barley+maize-barley; S-BM - rotation sunflower-barley+maize

Table 2. Grain yield, water productivity (WP) and irrigation water productivity (IRRWP) in the different crops

Cropping system	Crop (year)	Grain yield (kg/ha)	WP (kg/m^3)	IRRWP (kg/m^3)
MM	Maize (2013)	15000	2.2	2.2
	Maize (2014)	17000	2.6	2.7
BM-B	Barley (2013)	5078	1.3	5.1
	Maize (2013)	10700	2.7	2.5
	Barley (2014)	4900	1.2	7.4
S-BM	Sunflower (2013)	2544	0.5	0.6
	Barley (2014)	4265	1.3	12.4
	Maize (2014)	4370	1.0	1.0

MM - maize monoculture; BM-B - rotation barley + maize-barley; S-BM - rotation sunflower-barley+maize.

Barley yields in the different rotations and years were similar, with the lowest value observed in the S-BM rotation, probably due to a lowest water supply.

In Table 2 it is also possible to observe that maize had the highest values of water productivity (WP, in kg/m^3) and sunflower the lowest. As for irrigation water productivity (IRRWP, in kg/m^3), barley presented the highest values due to low irrigation water inputs in this autumn-winter crop. In contrast, the lowest values were found in maize and in sunflower, both spring-summer, thus dry season, crops.

From the analysis of water consumption and applied irrigation amounts it was observed that maize was the most demanding crop and, as expected, there was a higher water demand in the longer cycle varieties grown in monoculture (Fig. S1).

The statistical analysis performed (Table S2) showed non-significant effect of year and of type of cropping system on maize grain yield, water productivity and irrigation water productivity. These results are most likely due to the amount of available data than a true reflection of the influence of these factors on the variables analyzed.

Discussion

More than the crop succession it was the duration of the growing season that contributed to differentiate maize yield. In fact, the highest yields were observed in the monoculture, MM, where maize crop development cycles were longer.

Cropping systems where spring-summer crops prevailed were the most demanding in water. In BM-B rotation, with predominance of autumn-winter barley, the sum of seasonal irrigation volumes was approximately half of the maize monoculture. Given the distinct dry season prevailing in Mediterranean climates, the balance of total water used by the different cropping systems shows that those dominated by spring-summer crops are the most water demanding. The maize monoculture and the S-BM rotation had similar total water requirements (1322.7 mm and 1328.7 mm, respectively), with the BM-B rota- tion having the lower total water demand (1180.5 mm). When we analyze the total amount of irrigation applied the differences are clearer as a result of the rainfall events occurred during the autumn-winter barley cycle. In fact, in this crop, irrigation is essentially complementary, on one hand to regulate production by bridging the interannual variability of rainfall, typical of Mediterranean climates, and on the other hand to prevent water shortages in some key stages of the crop cycle as it happened in 2013 in BM-B rotation when barley was irrigated mainly between the states of booting and ear emergence. Overall, and as a consequence of the above aspects, the two-year irrigation water supply to the MM and S-BM cropping systems was 13,230 m^3/ha and 9200 m^3/ha, respectively, while the rotation with the two winter-autumn barley crops (BM-B) received a total amount of ir- rigation of approximately half of the monoculture, with 5930 m^3 applied per hectare.

The values of WP and IRRWP in maize, barley and sunflower were close, or higher in the case of maize, to those referred in other studies (Abdel-Wahab et al. 2005; Dagdelen et al. 2006; Di Paolo and Rinaldi 2008; Albrizio et al. 2010; Morell et al. 2011; Langeroodi et al. 2014; Howell et al. 2015), indicating high crop productivity per each drop of water used. The exception occurred in the maize of S-BM rotation whose low WP (1.0 kg/m^3) was due to the low grain yield, merely 4370 kg/ha and very far from the crop potential yield. From the IRRWP values found for the various crops, the following aspects stand out: given the low contribution of rainfall to meet the water requirements of spring-summer crops, the IRRWP values found for maize and sunflower did not differ from the WP values; the considerable differences between the IRRWP and WP values found for the barley crops were due to low irrigation water inputs in a crop whose cycle takes place in the rainy season. When the potential yield of the crop was reached, maize presented higher WP values compared to barley and sunflower. In fact, considering all the studied cropping systems, the average WP value found for the different crops was 2.1 in maize, 1.3 in barley, and 0.5 in sunflower. This can be explained relating agronomic and eco- physiological resource-use efficiencies. Different crops have necessarily different effi- ciencies in terms of the relationship between biomass or grain produced and water use, also as a result of their carbon assimilation mechanisms: C3 species such as barley or sunflower are less efficient in using water than C4 species as maize (Hay and Walker 1989; Sharma et al. 2015).

Although it was not observed significant effect of year and of type of cropping system on maize grain yield, WP and IRRWP, results suggest that the productive response and the yield water use efficiency indicators were lower in 2014, probably as a result of the very poor maize yield obtained in the S-BM rotation. This is also the possible explanation for the lower values of yield, WP and IRRWP verified in the maize crops in rotation after barley.

While WP values obtained in the S-BM rotation are the lowest, barley had the highest IRRWP observed for this crop not due to its yield but to the low volumes of irrigation water. In fact, as defended by Pereira et al. (2012), the significance of these indicators must not be confounded because crop yields depend not only on the amount of irrigation water applied but also on the effective rainfall which in turn is dependent on the rainfall distribution during the crop development cycle.

In overall terms, and considering the referred aspects, the water productivity indicators used point to a good yield water use efficiency of the MM and BM-B crops and a less balanced performance of the S-BM rotation.

Seeing as traditional rainfed systems are being progressively replaced with intensive irrigated cropping systems, not only in the Mediterranean regions but also in other climate change affected areas, the findings in this study can contribute to enhance environmental and economical sustainability of irrigated farming systems.

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Electronic Supplementary Material (ESM)

Electronic Supplementary Material (ESM) associated with this article can be found at the website of CRC at http://www.akademiai.com/content/120427/

Electronic Supplementary *Table S1*. Crop phenology

Electronic Supplementary *Table S2*. Effect of year and of cropping system on maize grain yield, water productivity (WP) and irrigation water productivity (IRRWP)

Electronic Supplementary *Figure S1*. Seasonal water requirements and irrigation supplies of each crop in each cropping system. MM - maize monoculture; BM-B - rotation barley+maize-barley; S-BM - rotation sunflower-barley + maize

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