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Water and land productivities of wheat and food legumes with deficit supplemental irrigation in a Mediterranean environment

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ABSTRACT

Selecting appropriate crops and applying deficit irrigation can help increase water productivity in water-limited regions such as the Mediterranean. The objective of this study was to develop water production functions of major cereal and legume crops under the same environmental and management conditions. Bread and durum wheat, faba bean, chickpea, and lentil were grown under full supplemental irrigation (FSI), two deficit irrigations levels of 2/3 of FSI (2/3SI) and 1/3 of FSI (1/3SI), and under rainfed conditions (no irrigation). In average, the actual evapotranspirations (ETs) under FSI were 549, 552, 365, 451 and 297 mm, for bread wheat, durum wheat, faba bean, chickpea and lentil, respectively. For the same crops, they were 463, 458, 330, 393 and 277 mm for the treatment 2/3SI and 357, 351, 265, 318 and 244 mm for the treatment 1/3SI, respectively. In the case of the rainfed treatment, ETs for the mentioned crops were 250, 251, 227, 237 and 215 mm, respectively. The experiment was conducted at the ICARDA experimental station at Tel Hadya, near Aleppo, Syria, over three growing seasons from 2007 to 2010.

Results showed that, in general, the treatment with 1/3 of FSI gave the highest rate of increase in grain yield and water productivity. The mean grain yield from rainfed, 1/3SI, 2/3SI, and FSI were 1.36, 3.82, 5.18, and 5.70 t/ha for bread wheat; 1.24, 3.80, 5.10, and 5.75 t/ha for durum wheat; 1.57, 2.35, 2.86, and 3.54 t/ha for faba bean, 1.36, 2.63, 3.36, and 3.74 t/ha for chickpea, and 0.64, 1.16, 1.42, and 1.58 t/ha for lentil respectively. Grain yield reductions due to the application of 2/3SI were around 10, 5, 15.6, and 10.2% of FSI on average for wheat, chickpea, faba bean, and lentils, respectively. Deficit irrigation at 2/3SI increased water productivity compared to rainfed treatments, by 200, 223, 126, 148 and 190% for bread wheat, durum wheat, faba bean, chickpea, and lentils, respectively. However, differences in total water productivity of crops grown under full irrigation compared to deficit irrigation were not significant. Irrigation water productivity ranged from 25 kg ha^{-1} mm^{-1} in wheat with 1/3SI to 10 kg ha^{-1} mm^{-1} for legumes under the FSI treatment. Unlike legumes, maximizing wheat grain yield caused a decline in water productivity.

1. Introduction

Dry areas of the Mediterranean region are characterized by low rainfall with high fluctuation in precipitation. Weather prediction studies show that these conditions are likely to increase with the effects of climate change (FAO, 2008). Negative effects of rainfall fluctuations and dry spells on the production of rainfed crops can be overcome by the application of supplemental irrigation. However, water has become scarce and the share that can be devoted to agriculture is progressively diminishing in drought prone areas. Yields can be increased and sustained applying limited amounts of water at critical stages only, to maximize crop productivity per unit of water used, otherwise known as water productivity (WP). During the last three decades, drought frequency and intensity have increased and hence water resources have become very limited in the dry areas of the Mediterranean basin (Margat and Vallae, 1999). Consequently, it may be more appropriate to maximize water productivity rather than grain yield to sustain crop production.

Deficit supplemental irrigation can help achieve this objective (Mugabe and Nyakatawa, 2000; Zhang et al., 2004) under rainfed conditions. However, no one has compared WP between wheat and food legumes under the same experimental conditions.

Among the crops that are affected by increasing drought and water scarcity in dry areas of the Mediterranean region are wheat (bread and durum) and food legumes (faba bean, chickpea and lentil). These crops are, with barley, the most dominant species in Mediterranean cropping systems and play a major role in feeding people and livestock. In addition, food legumes are an excellent source of protein and improve soil fertility. Nevertheless, yields of wheat and food legumes are, in general variable and, on average,

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Table 1
Irrigation amounts applied at full supplemental irrigation (FSI)[a] for bread wheat (BW), durum wheat (DW), faba bean (FB), chickpea (CP), and lentil (LT) at Tel Hadya, northern Syria over the growing seasons 2007/2008 to 2009/2010.

Season	Crop	Irrigation amount (mm) and dates of application (in parentheses)	Total (mm)
2007/2008	BW	100 (16-04); 80 (24-04); 80 (01-05); 80 (10-05); 90 (22-05)	430
	DW	100 (16-04); 80 (24-04); 80 (01-05); 80 (10-05); 90 (22-05)	430
	FB	70 (16-04); 80 (01-05); 80 (10-05); 75 (22-05)	305
	CP	70 (16-04); 80 (01-05); 60 (10-05); 75 (22-05)	285
	LT	70 (16-04); 80 (01-05); 80 (10-05)	150
2008/2009	BW	100 (05-04); 120 (29-04); 70 (09-05); 60 (21-05)	390
	DW	140 (05-04); 120 (29-04); 70 (09-05); 60 (21-05)	390
	FB	100 (05-04); 80 (29-04); 70 (09-05)	250
	CP	100 (05-04); 80 (29-04); 70 (09-05); 60 (21-05)	310
	LT	100 (05-04); 80 (29-04)	180
2009/2010	BW	60 (17-03); 75 (24-03); 90 (14-04); 80 (25-04)	305
	DW	60 (17-03); 75 (24-03); 90 (14-04); 80 (25-04)	305
	FB	60 (17-03); 50 (24-03); 70 (14-04); 80 (25-04)	260
	CP	60 (17-03); 50 (24-03); 70 (14-04); 80 (25-04)	260
	LT	60 (17-03); 70 (14-04)	130

[a] For the 1/3SI and 2/3SI treatments, the irrigation amounts were 1/3 and 2/3 of the amounts indicated in the table for the full supplemental irrigation treatments (FSI).

low due mainly to terminal drought and heat stress that characterize the Mediterranean basin. For all these crop species, the growth stages most sensitive to drought and heat stress are the periods of reproduction and grain filling (Otegui and Slafer, 2004; Royo et al., 1999; Ghassemi-Golezani et al., 2009; Jalota et al., 2006) during which the seeds are set and grow.

Since rainfall is very erratic, and dry spells usually coincide with the most sensitive growth stages of wheat and food legumes in the dry Mediterranean region, there is a need for better management of available water through the conjunctive use of rain and irrigation water. Deficit supplemental irrigation can be an option to minimize the variations in yields due to aberrant weather conditions and to stabilize production at an economically acceptable level (Mugabe and Nyakatawa, 2000; Zhang et al., 2004).

Research results indicate that deficit irrigation can increase water productivity for various crops without causing severe yield reductions (Geerts and Raes, 2009). Zhang et al. (2006) demonstrated that under rainfed conditions, wheat grain yield, harvest index and water productivity were greatly improved under regulated deficit irrigation when compared to the non-water stressed treatment. Li et al. (2009) showed that the highest grain yield was obtained when supplemental irrigation water was supplied at jointing and heading stages, during which spikelets are formed. However, El-Bably (1998) found that water productivity was highest when irrigated at 70% depletion of available soil moisture. Oweis et al. (2000) demonstrated that 1/3 (81% of ET) to 2/3 (96% of ET) of full supplemental irrigation requirements corresponding to 81 and 96% of actual ET, respectively, during and after anthesis, substantially improved irrigation water productivity, with limited yield losses. Oweis et al. (2004a, 2004b, 2005) found that both grain and biomass yields of chickpea, lentil and faba bean increased with increased supplemental irrigation. These authors indicated, however, that applying 2/3 of full supplemental irrigation gave the highest level of water productivity.

Deficit irrigation usually maximizes water productivity, and the water saved may be used to irrigate extra land or crops to better increase overall production (Oweis and Hachum, 2008). Deficit irrigation implies that we accept some reduction in crop yields to attain the highest WP. Maximizing WP may be economically more profitable for the farmer than maximizing yields or land productivity (LP) (English, 1990) in areas where water is the most limiting factor. This can be achieved by applying deficit irrigation (Zhang and Oweis, 1999). This study compares the performance of wheat (durum and bread) and food legumes (faba bean, chickpea and lentil) under the same environmental and management conditions in terms of yields, water use and water productivity. It aims to evaluate the trade-offs between water savings and yield reductions under different levels of supplemental irrigation.

2. Materials and methods

The experiment was conducted during the 2007/2008, 2008/2009 and 2009/2010 growing seasons at ICARDA's main research station, Tel Hadya, Aleppo, in northern Syria (36°01′N, 36°56′E; elevation 284 m asl). Mean annual rainfall in the area is 320 mm with considerable year-to-year variation (rainfall ranging from 200 mm to more than 500 mm). The soil at this station is generally more than 1 m deep, fine textured (Ryan et al., 1997), and classified as fine clay (montmorillonitic, thermic Calcixerollic Xerochrept). This soil has a good structure for plant growth and is well drained, with a basic infiltration rate of about 11 mm/h. At field capacity and at the permanent wilting point, mean volumetric soil moisture content in the top 100 cm of the soil is about 48 and 24%, respectively.

The crops studied were bread wheat (variety Cham 10), durum wheat (Cham 5), faba bean (Giza 643), winter chickpea (Ghab 4), and lentil (Idleb 3). These varieties are chosen because they are among the ones that are largely grown and used by farmers in Syria. This research is the first at the Tel Hadya station where all crops were studied together in the same experiment and compared during the same season under the same meteorological and management conditions. The preceding crops in the experiment plots were chickpea for wheat and wheat for food legumes.

Planting dates were December 24, 2007, November 26, 2008 and November 26, 2009. The seeding rate was 140 kg/ha for wheat, 100 kg/ha for faba bean, 140 kg/ha for chickpea, and 120 kg/ha for lentil. Phosphorus (P) and nitrogen (N) were applied at planting as superphosphate (45%) and urea (46%). These were supplied at rates of 100 kg P/ha and 60 kg N/ha for wheat and 100 kg P/ha and 25 kg N/ha for food legumes. During the tillering of wheat, 60 kg N/ha was added as urea. Soil moisture and grain yields were recorded and ET and water productivity were calculated. Data were analyzed using SAS computer software (SAS, 1997).

The water treatments applied to the plots were: full supplemental irrigation (FSI) to prevent any moisture stress over the season, two deficit irrigation treatments – 2/3 of FSI (2/3SI) and 1/3 of FSI (1/3SI), and finally a rainfed (RF) treatment with no irrigation. In 2007/2008, 40 mm of irrigation water was applied before planting for weed control and 40 mm was applied when