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Combined effect of tillage system, supplemental irrigation and genotype on bread wheat yield and water use in the dry Mediterranean region

Mohammed Karrou

ICARDA, P. O. Box 6299, Rabat – Instituts, Morocco.

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Approaches that can help reduce future water shortages and increase food production in the Mediterranean region include the capture of more rainwater and better use of scarce irrigation water. The objective of this study is to evaluate the additive effect of combining zero tillage, supplemental irrigation and adapted varieties of bread wheat on yield and water use. For this purpose, a trial was conducted at the International Center for Agricultural Research in the Dry Areas' (ICARDA) research station in Tel Hadya, Aleppo, Syria in 2008/2009 and 2011/2012 under two tillage systems: zero tillage (ZT) vs. conventional tillage (CT); two water regimes: rainfed (RD) vs supplemental irrigation (SI); and five genotypes. Results showed that in 2008/2009, grain yield increased on average, from 4515 kg ha^{-1}, under CT in the rainfed regime, to 5929 kg ha^{-1} when ZT and SI were combined. ZT and SI increased respectively, the yield by 548 and 729 kg ha^{-1} as compared to CT under rainfed condition. The combination of ZT and SI increased water use by 110 mm as compared to CT under rainfed condition. In year 2011/2012, ZT tended to have no effect on yield and a negative influence on water use. Irrigation increased yields from 5055 to 5927 kg ha^{-1} under CT tillage and from 4996 to 5448 kg ha^{-1} under zero tillage. The genotypes Cham 6, Cham 8 and Shuha were the most responsive to SI and ZT in year 1. In year 2, Shuha and Cham 10 tended to be in general, more performing. The preliminary results showed that in dry year, the combination of the two technologies, zero tillage and supplemental irrigation, increased water use and yield. In wetter year, the effect of SI was still positive; but that of ZT was not significant on yield and negative on water use. Further studies are needed, for a longer period, to consolidate the obtained results using more diversified genetic material.

Key words: Wheat, zero tillage, irrigation, genotype, yield, evapotranspiration, productivity.

INTRODUCTION

Increasing scarcity of water due to more frequent droughts and growing demand for resources for industrial, tourism and domestic uses (due to population growth) will result in the future in less water for agricultural production. The crops that will suffer most from this situation are cereals and this is for two reasons: First, because when there is drought this crop are the least to benefit from irrigation water. Second, because these species are mainly grown in arid zones where the possibilities of irrigation are very low. Consequently, the reduction of cereals production will affect seriously the poor that live in dry areas, because this product is the main human nutritional food.

Despite the significant increase in wheat yields since the beginning of the green revolution, there are still management and environmental causes underlying water

E-mail: m.karrou@cgiar.org

and environmental problems (FAO, 1996). Severe drought and climate change that the Mediterranean basin has been facing (Giorgi and Lionello, 2008) imposed the development of new strategies that will allow less water loss, a better use of scarce resource and the preservation of natural resources and hence the sustainable increase of land and water productivity. To reach this objective there is a need, not only for a better management of irrigation, but also for the use of improved cultural practices and cultivars that are adapted to drought and global warming conditions.

Plant breeders have always considered early flowering time as one of the most important traits to select adapted wheat varieties for water limited environments (Passioura, 2006). With climate change, this criterion will be more emphasized in breeding programs as the length of the growing period will shrink more and earlier cultivars are needed to escape terminal drought and heat stress. However, plants that flower early may achieve large harvest indices but do not produce enough biomass to set a large enough number of seeds to generate a good yield (Fischer, 1979). Plants that flower too late will have, usually, high seeds abortion because of heat stress and too little water left for post-flowering photosynthesis and remobilization of carbohydrates from the vegetative organs to the grains (Passioura, 2006).

Consequently, ensuring a balance between the source (vegetative biomass production) and sink (seeds production) under early flowering is an important strategy to increase and stabilize yields in rainfed areas. Both breeding and field management can play an important role in capturing more water and improving its efficient use. So, in addition to the selection of varieties that have the characteristics described above, other technologies such as early planting facilitated by zero tillage technique can help the plants take advantage from the early rains and escape terminal drought and heat. Moreover, zero tillage can also reduce rainwater losses by evaporation and increase transpiration early in the season and hence improve yield and water productivity of wheat (Mrabet, 2000a, b; Cantero-Martinez et al., 2007).

In this study, a no-till drill was used to plant directly the seeds without any previous cultivation, but a very small amount of residues was retained on the soil to simulate the farmer technique that consists of using all the straw as forage in summer. Therefore, the beneficial effects the authors seek from this zero tillage is the early planting to take advantage from early rains and the conservation of water because the soil is not disturbed. A very little effect of the residues is expected. In fact, in the southern part of the Mediterranean basin, the no-till is practiced with little or no straw left on the soil surface and this is the technique of conservation tillage or zero tillage that was tested. The application of supplemental irrigation is another option that can help to compensate the rainfall deficit late in spring. This technique can reduce the seeds abortion and increase soil moisture during the post-anthesis period and seed size. Research conducted in dry areas (Oweis and Hachum, 2006; Karrou and Boutfirass, 2007) showed that supplemental irrigation is a technology that can improve significantly, water productivity and save the resources without reducing land productivity.

Oweis et al. (1999) demonstrated that water productivity under supplemental irrigation after heading was as high as 2.5 kg of wheat grain per cubic meter of water, compared to 500 g under rainfed conditions and 1 kg under full irrigation. To take advantage from more water conserved under zero tillage due to non soil disturbance (no-tillage) and from supplemental irrigation, it is important to use adapted varieties to these systems. Laaroussi (1991) and Boutfirass (1997) showed in semi arid rainfed areas of Morocco, genotypic differences in yield and water use efficiency under rainfed and SI conditions. Haul and Cholick (1989) and Ciha (1982) found that the ranking of wheat cultivars across tillage systems, including ZT, changed for grain yield.

Further to the positive effects of supplemental irrigation at critical stages, zero tillage and drought tolerant varieties on sustainability of wheat productivity in rainfed areas, information concerning the beneficial impacts of combining these two techniques and the use of more adapted improved varieties is still limited. The objective of this study is to evaluate the effects of this combination on durum wheat grain yield, water use and water productivity.

MATERIALS AND METHODS

The experiment was carried out during 2008/2009 and 2011/2012 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 was 320 mm with considerable year to year variation ranging from 200 mm to over 500 mm. The soil at Tel Hadya station is generally deep, over 1 m and fine textured (Ryan et al., 1997) and is classified as fine clay (montmorillonitic, thermic Calcixerollic Xerochrept). The soil has good structure and is well drained, with a basic infiltration rate of about 11 mm/h. At field capacity and at the permanent wilting point, mean soil moisture content in the top 100 cm of the soil is about 48 and 24% by volume, respectively.

The factors studied were tillage system (Conventional tillage vs Zero tillage), water regime (Rainfed vs supplemental irrigation) and the genotype (5 genotypes of bread wheat). The experimental design used was a split-split plot with tillage as the main plot, water regime as the sub-plot and genotype as the split-split plot with 3 replications. In the zero-till plot, seeds were sown directly with a no-till drill without any previous soil cultivation. For the conventional tillage plot, the soil was plowed twice with an offset disk and this was followed by a roll-packing operation. In the case of zero tillage, a very small amount of residues were kept on the soil surface to simulate the conditions of the farmer where all the straw after harvest is used as forage. Rainfed treatment received only rainfall. However, supplemental irrigation plot received, in addition to rainfall, amounts of irrigation water of 35 mm at boot stage and 35 mm at kernel milky stage. The genotypes tested were Cham 6 (V1), Cham 8 (V2), Shuha (V3), Cham 10 (V4) and Raaid-3 (V5). The experiment was planted on November 17 in 2008 and November27 in 2011 and the seeding rate was 140 kg ha^{-1}.

Table 1. Mean monthly precipitation, September to May at Tel Hadya, northern Syria, during 2008/2009-2011/2012).

Year	Mean monthly rainfall (mm)									
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
2009/2010	21	15	16	36	27	72	32	20	3	241
2011/2012	1.1	27	93	65	117	4	27	4	5	343
Long-term mean (1980/2012)	4	20	44	56	63	54	46	30	16	333

Phosphorus (P) and nitrogen (N) were applied at planting as Superphosphate (45%) and urea (46%) at rates of 80 Kg P ha^{-1} and 60 Kg N ha^{-1} respectively for P and N. At stem elongation, 30 Kg N ha^{-1} were added as urea. The measurements taken were grain yield, actual evapotranspiration (ETa) and grain water productivity (WP) at harvest. Water productivity was calculated as the ratio of grain yield to actual evapotranspiration. Soil moisture was measured at planting and harvest using a neutron probe device. Measurements were taken at 0-15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-105, 105-120, 120-135 and 135-150 cm. ETa was calculated using the water balance equation. All data were analyzed using SAS (1997) statistical software. The analysis of variance (ANOVA) was performed to examine the various treatment differences and interactions. LSD test at 5% and 1% probability levels was applied to compare the differences among the treatment means. Data on rainfall for the two seasons are presented in Table 1. The total amounts received were 241 mm in 2008/2009 and 343 mm in 2011/2012. In year 2, rainfall was very high and concentrated mostly between November (planting period) and January with 93 mm in November, 65 mm in December and 117 mm in January. In March, rainfall was 27 mm; but in February and April there was only around 4 mm per year. In year 1, rainfall was less during November (16 mm), December (36 mm) and January (27 mm). However, in February and April, the quantities were 72 mm and 20 mm, respectively.

RESULTS AND DISCUSSION

Grain yield per hectare obtained under different tillage systems, water regimes and genotypes is presented in Table 2. Due to the difference in rainfall pattern between years, the interaction year x tillage system for the different parameters measured was significant. Consequently, the data were discussed separately by year. In year 1, the analysis of variance showed that the effects of supplemental irrigation, the genotype, the interactions zero tillage x genotype and supplemental irrigation x genotype were statistically highly significant. However, the effects of ZT and the interactions ZT x SI and ZT x SI x G were not significant; although zero tillage increased yield by 600 kg ha^{-1} as compared to the conventional tillage. During this year, supplemental irrigation increased productivity from 4789 to 5586 kg ha^{-1}, on average; in year 2, only water regime and genotype effects were significant.

The yield was increased on average, from 5025 to 5687 kg ha^{-1} by the application of irrigation water. The positive effect of ZT observed in year 1 was also demonstrated in Iran by Hemmat and Eskandari (2004a, b, 2006); in Morocco by Mrabet (2000a, b, 2008) and in Tunisia by Vadon et al. (2006). The higher yield in zero tillage treatment than in conventional tillage in the first year in this study was probably due to the uptake of more water (30 mm) under the former system. This result confirmed the finding of Passioura (2006) who demonstrated that capturing 30 mm of rainwater could be translated into an increased yield of about 1 t/ha. In year 2, there was no effect of tillage system on wheat and some scientists (Pala, 2000; Thomas et al., 2007) showed even negative response. This negative effect was attributed mainly to disease infestation (Thomas et al., 2003) which was not observed in our trials and to too high early biomass production (Kumudini et al., 2008) that increased more completion for water later and reduced yield. It seems that the positive effect of zero tillage shown by many scientists in the southern Mediterranean region was offset in our study by the high precipitation during most of the 2011/2012 growing season. The positive effect of supplemental irrigation during the two seasons confirmed the results of Oweis and Hachum (2006) and Karrou and Oweis (2012).

In year 1, all the genotypes responded positively, but differently, to ZT and SI, except Raaid-3 for which the difference was not statistically significant. The finding on tillage confirmed those of Hernandez et al. (2004) who showed that the grain yields of the genotypes of wheat were higher by 7% under zero tillage than under conventional tillage. The genotypes Cham 6 and Cham 8 tended to respond more to the conservation tillage and to supplemental irrigation. Moreover, for these 2 genotypes, the beneficial effect of combining these two techniques as compared to their individual influences was noticed. The genotypes Cham 10 and Raaid-3 were the least to be affected by this combination. These results confirmed the genotypic variation observed by Laaroussi (1991) and Boutfirass (1997) under supplemental irrigation; and Haul and Cholick (1989) and Ciha (1982) under conservation tillage. In year 2, Shuha and Cham 10, tended to yield more, in average, than the others.

Table 3 shows that in year 1, there was a significant effect of tillage system, SI, genotype and ZT x SI on the actual evapotranspiration (ETa). In average, zero tillage and supplemental irrigation had, respectively, higher ETa than conventional and rainfed treatments. Supplemental irrigation increased ETa from 342 to 403 mm under conventional tillage and from 372 to 452 mm under conservation tillage. These increase amounted to 61 and 80 mm, respectively. Zero tillage increased water use from 342 to 372 mm under rainfed conditions and

Table 2. Effect of tillage system (TS), water regime (WR) and genotype on grain yield (kg ha^{-1}) of bread wheat in Tel Hadya, Syria during the cropping season 2008/2009 and 2011/2012.

Parameter	Genotype	Conventional tillage		Mean	Zero tillage		Mean
		Rd (*)	SI(*)		Rd (*)	SI (*)	
Year 1	Cham 6	4307	5020	4664	4920	6270	5595
	Cham 8	4810	5710	5260	5570	6950	6260
	Shuha	4720	5800	5260	5730	6520	6125
	Cham 10	4650	5380	5015	5610	5980	5795
	Raaid 3	4090	4320	4005	3490	3920	3705
	Mean	4515	5244	4841	5063	5929	5496
		CV = 11.2					
	Statistical analysis	**ANOVA:**TS effect: not significant at α = 5%; WR effect: highly significant at α = 5% with LSD = 420; Genotype effect: highly significant with LSD = 375; TS x WR effect: not significant; TS x Genotype effect: highly; significant WR x Genotype effect: significant;Interaction TS x WRI x Genotype effect: not significant					
Year 2	Cham 6	5117	5894	5506	4697	5417	5057
	Cham 8	4708	6286	5497	5376	5355	5366
	Shuha	5484	6164	5824	5565	5421	5493
	Cham 10	5116	6146	5631	5099	5901	5500
	Raaid 3	4849	5144	4997	4241	5144	4693
	Mean	5055	5927	5091	4996	5448	5222
		CV = 9.8					
	Statistical analysis	**ANOVA:** TS effect: not significant at α = 5%; WR effect: significant at α = 5% with LSD = 270; Genotype effect: Highly significant at α = 1% with LSD = 430; TS x WR effect: Not significant; TS x Genotype effect: Not significant; WR x Genotype effect: Not significant; Interaction TS x WR x Genotype effect: Not significant					

(*) Rd and SI are Rainfed and Supplemental irrigation, respectively.

from 403 to 452 mm in irrigated plots. Our results confirmed those of Power et al. (1986) who reported greater water storage and grain yield under no till than under conventional tillage. Merrill et al. (1996) attributed the increase in soil water use to greater root growth. The application of zero tillage under rainfed conditions and supplemental irrigation in conventional tillage system increased, respectively, water use by 30 and 61 mm as compared to the conventional tillage under rainfed (without irrigation) situation. More importantly, results showed the more significant effect of combining ZT and SI on water use. Literally, evapotranspiration increase due to this combination was 110 mm, so, there was an additive effect of the improved technologies of tillage and supplemental irrigation.

In year 2 (Table 3), the effects of tillage, supplemental irrigation, genotype, tillage x SI and tillage x SI x genotype on ETa were significant. The results obtained were different than the ones of year 1 because ETa under conventional tillage was higher under zero tillage in year 2. They also contrast those of Lopez-Bellido et al. (2007a, b) who found that under Mediterranean conditions, no-till was not more efficient than conventional tillage in soil water accumulation and productivity. However, the effect of supplemental irrigation remained positive. The application of irrigation increased, in average, ETa from 356 to 461 mm. Conventional tillage, as compared to zero tillage, increased water use from 336 to 377 mm under rainfed conditions and from 415 to 508 mm in irrigated plots; the difference was 41 and 93 mm respectively. Supplemental irrigation increased ETa from 377 to 508 mm under conventional tillage and from 336 to 415 mm under zero tillage and this corresponded to 131 and 79 mm, respectively.

The difference between year 1 and year 2 can be explained by the difference in rainfall distribution and amount. Rainfall in 2011/2012 was around 104 mm more and well distributed during the period of November-March. The soil under plowing was loose and allowed probably more water infiltration and storage in the soil and greater root growth, hence the increased amount of water used. Kirkegaard et al. (1994) found that direct drilling reduced the total root length in the soil profile at anthesis by 40% but there was no effect of stubble retention; and Martinez et al. (2008) demonstrated that the penetration resistance was higher under no-till as compared to conventional tillage.

Table 3. Effect of tillage system (TS), water regime (WR) and genotype on actual evapotranspiration (mm) of bread wheat in Tel Hadya, Syria during the cropping season 2008/2009 and 201120/12.

Parameter	Genotype	Conventional tillage		Mean	Zero tillage		Mean
		Rd(*)	SI(*)		Rd(*)	SI(*)	
Year 1	Cham 6	306	399	353	335	428	382
	Cham 8	374	398	386	356	407	382
	Shuha	330	407	369	358	479	419
	Cham 10	339	395	367	406	523	465
	Raaid 3	359	416	388	404	419	412
	Mean	342	403	373	372	452	412
	Statistical analysis	**CV =** 9.8 **ANOVA:** TS effect: not significant at α = 5%; WR effect: highly significant at α = 5% with LSD = 20; Genotype effect: significant with LSD = 32; TS x WR effect: significant; TS x Genotype effect: highly significant; WR x Genotype effect: not significant; Interaction TS x WR x Genotype effect: not significant					
Year 2	Cham 6	353	515	434	325	435	380
	Cham 8	350	498	424	341	414	378
	Shuha	421	511	466	328	417	373
	Cham 10	340	511	426	351	400	376
	Raaid 3	419	503	461	337	408	373
	Mean	377	508	442	336	415	376
	Statistical analysis	**CV =** 4.00 **ANOVA:** TS effect: highly significant at α = 1% with LSD = 8; WR effect: highly significant at α = 1% with LSD = 8; Genotype effect: with LSD = 3; TS x WR effect: highly significant at α = 1%; TS x Genotype effect: not significant; WR x Genotype effect: not significant; Interaction TS x WR x Genotype effect: highly significant at α = 1%					

(*) Rd and SI are Rainfed and Supplemental irrigation, respectively.

The genotypes responded differently to zero tillage in year 1 and to zero tillage and supplemental irrigation in year 2. In year 1, the genotype Cham 10 used the highest amount of water under ZT when compared to CT and then it was followed by the genotype Shuha. ETa of the genotypes Cham 6 and Raaid-3 were less affected by the variation of the tillage system; however, that of Cham 8 was not sensitive. In year 2, Cham 6, Cham 8 and Cham 10, responded more to the application of water under conventional tillage than the others. Under zero tillage, Cham 6 responded more and Cham 10 less than the other genotypes to supplemental irrigation. Zero tillage had a negative effect on ETa for all genotypes, but the degree of response differed from one genotype to another and with water regime. Under rainfed conditions, the effect of tillage system variation on ETa of Cham 6, Cham 8 and Cham 10 tended to be very small; while in the case of Shuha and Raaid, the reduction due to the application of zero tillage was statistically significant. Under SI, zero tillage was the most depressive for Cham 10 and less for Cham 6 and 8.

Water productivity was affected significantly only by the genotype in year 1 and by tillage system, water regime and the interaction tillage system x water regime x genotype in year 2 (Table 4). In year 1, although the interaction tillage system x genotype was not significant, the genotypes Cham 6, Cham 8 and Shuha tended to have the highest WP under ZT; while Cham 10 and Raaid-3 tended to use water more efficiently under the conventional tillage. The genotypes that used more water under zero tillage had their WP reduced. Positive effect of zero tillage was shown by Cantero-Martinez et al. (2007), Hemmat and Eskandari (2006) and Bouzza (1990). In year 2, rainfed and zero tillage treatments gave the highest water productivity and Raaid-3 was in average, the least efficient in water use. However, the genotypes responded differently to tillage system and water regime variation. Cham 6 and Cham 10, under conventional tillage, and Cham 6, Cham 8 and Shuha under conservation tillage, responded negatively to the application of irrigation water. For the other genotypes, the difference between the two water regimes was not significant.

Conclusion

From this experiment we can conclude that the

Table 4. Effect of tillage system (TS), water regime (WR) and genotype on water productivity (Kg/m3/ha) of bread wheat in Tel Hadya, Syria during the cropping season 2008/2009 and 2011/2012.

Parameter		Conventional tillage		Mean	Zero tillage		Mean
	Genotype	**Rd(*)**	**SI(*)**		**Rd(*)**	**SI(*)**	
Year 1	Cham 6	14.0	12.6	13.3	14.9	14.6	14.8
	Cham 8	12.9	14.3	13.6	15.9	17.1	16.5
	Shuha	14.3	14.4	14.4	16.2	13.9	15.1
	Cham 10	13.6	13.6	13.6	14.0	11.5	12.8
	Raaid 3	11.4	10.4	10.9	8.6	9.4	9.0
	Mean	13.2	13.0	13.2	13.6	13.1	13.6
	Statistical analysis	**CV =** 13.3 **ANOVA:** TS effect: not significant at α = 5%; SI effect: not significant at α = 5% Genotype effect: highly significant with LSD = 1.4; TS x WR effect: not significant; TS x Genotype effect: not significant; WR x Genotype effect: not significant; Interaction TS x WR x Genotype effect: not significant					
Year 2	Cham 6	14.5	11.5	13.0	14.4	12.5	13.5
	Cham 8	13.5	12.6	13.1	15.8	13.0	14.4
	Shuha	13.0	12.0	12.5	17.0	13.0	15.0
	Cham 10	15.0	12.0	13.5	14.5	14.8	14.7
	Raaid 3	11.6	10.2	10.9	12.6	12.7	12.7
	Mean	13.5	11.7	12.6	14.9	13.2	14.0
	Statistical analysis	**CV =** 10.1 **ANOVA:** ZT effect: significant at α = 5% with LSD = 0.7; SI effect: significant at α = 5% with LSD = 0.7; Genotype effect: highly significant with LSD = 1.1; ZT x SI effect: not significant; ZT x Genotype effect: not significant; SI x Genotype effect: not significant; Interaction ZT x SI x Genotype effect: significant at α = 5%					

(*) Rd and SI are Rainfed and Supplemental irrigation, respectively.

combination of zero tillage and supplemental irrigation late in the season can ensure an additive positive effect of the two technologies on total water uptake and land productivity in dry years. However, in wetter years, the beneficial effect of zero tillage disappears; but that of supplemental irrigation remains because there was rainfall deficit in spring during the formation of the grain. The genotype effect on yield and water use was in general significant; but the interaction with the other factors as tillage system and water regime, was not observed. However for water productivity, the genotypes responded differently to tillage system and water regime variation. Cham 6 and Cham 10 under CT, and Cham 6, Cham 8 and Shuha under conservation tillage, responded negatively to the application of irrigation water. For the other genotypes, the difference between the two water regimes was not significant. Further studies are needed, for a longer period, to consolidate the obtained results using more diversified genetic materials.

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