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Options for Improving Land and Water Productivities of Durum Wheat under Water and High Temperature Stresses in North Africa Dry Areas

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Abstract: *Wheat production in the rainfed areas of North Africa is constrained by drought and heat stress, especially when anthesis and grain filling periods are delayed due to late planting. For optimization of yield, an early sowing and/or application of supplemental irrigation (SI) are critical to ensure a good kernel set and grain filling. The objective of this study is to develop potential options that improve the adaptation of wheat to high temperature and drought through better management and use of green and blue water resources. To expose the crop to different soil moisture and temperature conditions, four bread wheat genotypes were sown at two planting dates - December 12 and January 30 in year 2012-2013 and November 19 and December 23 in 2013-2014 under two water regimes, Rainfed and Supplemental irrigation. Data shows that late planting, under rainfed conditions, decreased 1000-seed weight from 38.7 to 32.3 g in 2012-2013 and from 45.6 to 26.8 g in 2013-2014. This corresponds to reductions of yields from 2.5 to 1.2 t/ha and from 2.8 to 0.3 t/ha, for years 1 and 2, respectively. However, under supplemental irrigation regime, yields from early and late plantings were similar in both years. The yield increase during 2012-13 growing season due to supplemental irrigation was from 2.5 to 4.3 t/ha under early planting and from 1.2 to 4.4 t/ha under late planting. The application of irrigation water increased productivity from 2.8 to 5.4 t/ha in early planting and from 0.3 to 5.3 t/ha in late planting in 2013-14. Under rainfed conditions, actual evapotranspiration varied from 236 mm to 330 mm under early planting and from 181 mm to 232 mm under late planting. Under SI, it varied, in general, from 396 mm to 593 mm. Data shows also that, early planting increased significantly water productivity (WP) under rainfed conditions. However, the effect of planting date on this parameter under supplemental irrigation was observed only during year 2. On average, WP was respectively, for early and late planting, 9.2 and 7.8 kg ha^{-1} mm^{-1} in year 1 and 10.5 and 5.1 kg ha^{-1} mm^{-1} in year 2. The effect of SI on WP was not consistent. It was positive only in year 1 under both early and late planting dates. The increase, in year 1, varied from 144% for early planting to 218% for late planting. From this study, we can conclude that early planting, and supplemental irrigation in late planting are key options to mitigate the effects of drought and heat stress which are getting exacerbated by the effects of climate change in the dry areas in North Africa.*

Keywords: *Wheat, planting date, climate change, drought, water productivity*

1. Introduction

General circulation models indicate that rising levels of greenhouse gases are likely to increase the global average surface temperature by 1.5-4.5 °C over the next 100 years and to amplify extreme weather events such as storms, droughts and heat waves [1]. More severe droughts and heat stress will be mong the extreme events that will have additive adverse effects on crop growth and development. [2] stated that temperature effects are increased by water deficits so that understanding the interaction of temperature and water will be needed to develop more effective adaptation strategies to offset the impacts of greater temperature extreme events associated with changing climate.

Increasing scarcity of water due to more frequent droughts and growing water demand 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 for two reasons. First, because when there is drought, these crops are the least to benefit from irrigation water. Second, because they are mainly grown in dry 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 source of human nutritional needs. One of the approaches to cope with the future water shortage, droughts and heat stress will be the adoption of technological options that allow a conjunctive use of available water resources (green as well as blue water) and hence generate sustainable increase of land and water productivities.

Under rainfed conditions, soil-water loss by evaporation is the most important process of non-beneficial loss of water in dry areas. One source of water loss by evaporation is related to planting time of the crop. As a matter of fact, most of the farmers in the region delay wheat planting until it rains enough in autumn to be able to till and cultivate the soil and hence prepare a good seedbed and control the early emerging weeds. Nevertheless, this technique involves wet soil disturbance and consequently an increase of soil-water evaporation and exposure of plants to terminal drought and heat.

Early planting in autumn is the best strategy to sustain wheat production in rainfed areas in the context of climate change. It allows the crop to take advantage from early rains and from the warm soil and air temperature required for the seedling growth and vigor; but also to escape terminal drought and heat. [3] reported that of all technical options that mitigate the effects of climate change, adjusting planting date to synchronize plant growth stages with optimum temperatures and soil moisture regimes seems to be a practical and eco-friendly approach to sustain yields under elevated temperatures and water stress conditions. [4] and [5] reported an increased yield with early sowing and a reduction in productivity when sowing is delayed beyond the optimum time. Late planting is generally associated with a reduced kernel weight [6], a reduced number of spikes per plant and per unit area [7], harvest index and grain number per spike [8]. [9] showed that in Biskra, Algeria, that soil moisture deficit and high temperature during the grain filling period of cereals reduced 1000-seed weight by 50%.

In addition to early planting, another measure of adaptation to negative effects of climate change in rainfed areas is the selection of varieties that have the capacity to capture more water for use in transpiration process, to use CO_2 more effectively in producing biomass and to convert more of the biomass into grain [10]. [11] stated that the combination of early planting and early maturing varieties neutralizes water stress during the growth period of the spike and minimizes its effect during the grain filling phase.

In irrigated zones, the increasing scarcity of and the competition with other sectors for water will impose the reduction in the share of this resource for irrigation. To increase and sustain wheat production in the regions where there is some access to irrigation water, farmers have to shift from the strategy of maximizing yields to that targeting the maximization of water productivity and optimization of land productivity. Among the technologies that can allow this are the application of supplemental irrigation at critical stages and the use of varieties that are more efficient in using water. Research conducted in dry areas [12]; [13], [14] showed that supplemental irrigation is a technique that can improve significantly, water productivity and save the water resources without reducing land productivity. [15] 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 supplemental irrigation, it is important to use adapted varieties to these systems. [16] and [17] showed in semiarid rainfed areas of Morocco, genotypic differences in yield and water productivity under rainfed and SI conditions.

The objective of this study was to contribute to the development of potential options that improve the adaptation of wheat to high temperature and drought through a better synchronization of the wheat growing season to the rainfall period and conjunctive use of green and blue water resources.

2. Materials and Methods

The study was carried out during the growing seasons of 2012-13 and 2013-14 at the experimental station of the National Institute of Agronomic Research (INRA) located in Tadla perimeter-Morocco (32°3’N; 6°31'W; elevation 450 m asl). The soil is classified as luvisols chromic, according to Badraoui and Stitou [18]. The climate in this area is arid with a high irregularity of rains. Average annual precipitation is 268 mm; average temperature is 18 °C, with a maximum in August that often exceeds 45 °C and a minimum in January of approximately 0 °C.

The factors studied were planting date -mid (D1) vs late (D2)- plantings, water regime -rainfed vs. supplemental irrigation- and the genotype (4 genotypes of durum wheat). The experimental design used was a strip-split plot with planting date as the main plot, water regime as the subplot and genotype as the split-split plot with 3 replications. In 2012-2013 cropping season, early planting treatment was established on December 12, 2012 and the late planting treatment on January 30, 2013. In 2013-2014, the plantings were on November 19, 2013 and December 23, 2013, respectively. The rainfed treatment received only rainfall. However, supplemental irrigation plots received, in addition to rainfall, 120 mm of irrigation water in four applications for the early planting and 210 mm in six applications for the late planting, according to the rainfall events. Water was applied using a drip irrigation system, which was equipped with a flow meter. Irrigation was applied to all irrigated plots at the same time for each planting date when the root zone of the irrigated treatment had lost 50% of its available moisture, defined as the difference in water storage in the root zone between field capacity and wilting point. The genotypes tested were Karim (V1), Louiza (V2), Nassira (V3), and PM9 (V4). The experiment plot was plowed twice with an offset disk and the seeding rate was 160 kg/ha. Phosphorus (P) and nitrogen (N) were applied at planting as DAP (18-46-0) at a rate of 200 kg/ha. At tillering and stem elongation, 60 kg N/ha were added as ammonium nitrate. The measurements taken were grain yield, 1000-seed weight and gravimetric soil moisture at planting and harvest time at soil depths of 0-20, 20-40, 40-60 and 60-80 cm. It was not possible to take soil moisture at deeper layers because of rocks and stones. Therefore, the amount of water applied was determined so as to refill the root zone to field capacity. The amounts of irrigation water applied for the irrigated plots were 3560 m^3/ha (early planting) and 4004 m^3/ha (late planting). Water productivity was calculated as the ratio of grain yield to actual evapotranspiration (ETa). ETa was computed using the water balance equation. All data were analyzed using SAS statistical software [19]. The analysis of variance (ANOVA) was performed to examine the interactions and difference between various treatments. LSD test at 5% level was applied to compare the differences among the treatments means.

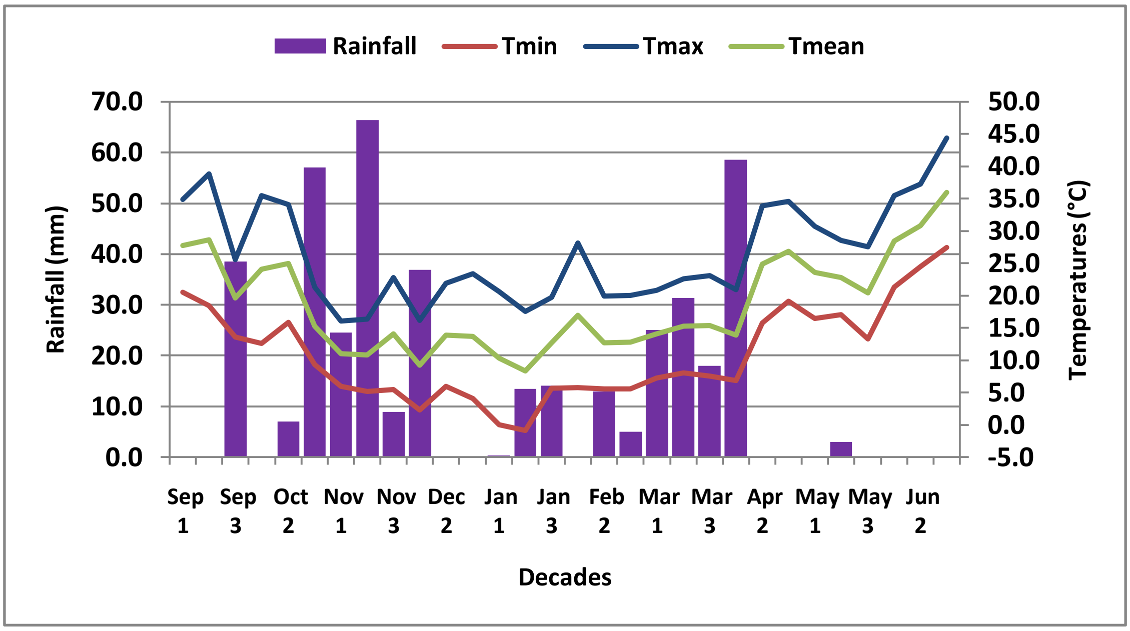

Figure1. *Monthly rainfall distribution and average minimum (Tmin), maximum (Tmax) and mean (Tmean) temperatures in Afourer experiment station during 2012-2013 cropping seasons.*

Climatic data (rainfall and temperature) are presented in figures 1 and 2. During the cropping season of 2012-2013 (Figure 1), the total rainfall from September 2012 to June 2013 was 421 mm, of which 46% was received during the period from the last decade of September to the first decade of December. The three weeks following the first week of December were dry. In terms of rainfall distribution, this season could be considered as of bimodal distribution type. The first wet period was

October 20 to December 10, 2012 and the second was March 1 to April 10, 2013. In 2013-2014 (Figure 2), the total amount of rainfall received was only 284.9 mm. The deficit of rainfall compared to the previous year for the same period is very important (more than 30%). It is also important to note that about 20% of the rainfall was received during the first two decades of September and was lost by evaporation from bare soil that was disturbed because of plowing. Furthermore, the distribution of rainfall was non-uniform.

The temperature was quite adequate especially during the beginning of the 2012-2013 and 2013-2014 growing seasons and allowed good stand establishment and development of the seedlings. However, from December to February, very low temperatures were registered in both growing seasons. The lowest temperatures were recorded during the first and second weeks of January in 2013 and during the last week of December in 2014.

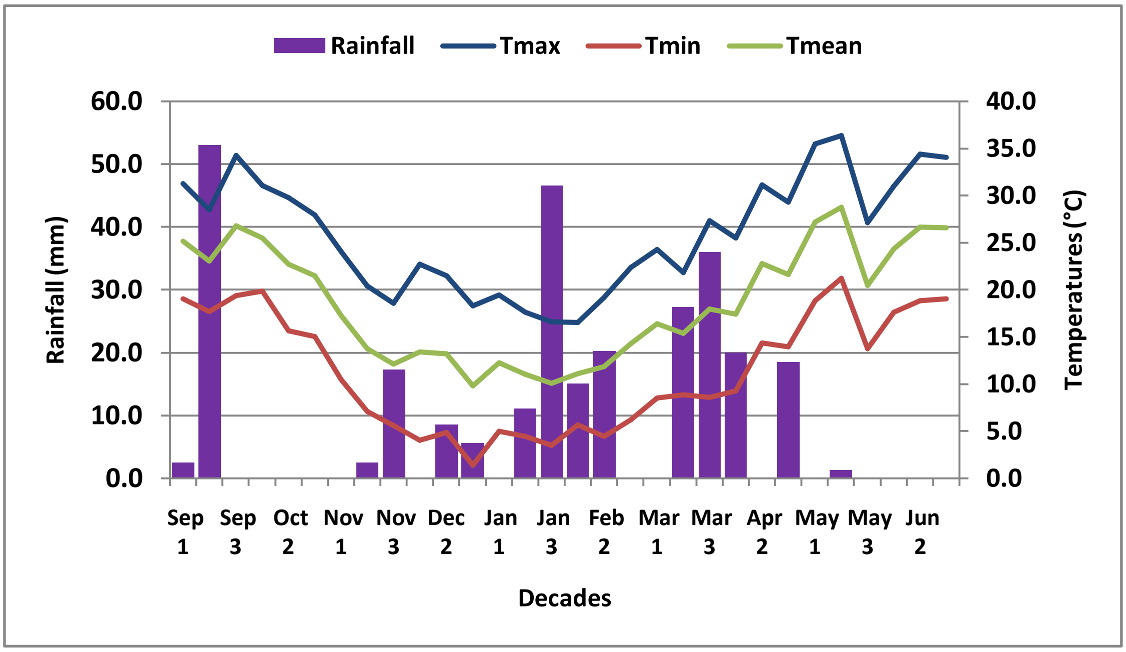

Figure2. *Monthly rainfall distribution and average minimum (Tmin), maximum (Tmax) and mean (Tmean) temperatures in Afourer experiment station during 2013-2014 cropping seasons.*

3. Results and Discussion

Among the options to cope with terminal drought and heat stress in North Africa are the choice of sowing date and adapted varieties and the application of supplemental irrigation during the onset and growth of wheat when there is possibility of access to irrigation water.

Data of the grain yield collected from an experiment conducted on the interaction “Date of planting” x “Water regime” x “Bread wheat genotype” are presented in Tables 1, 2, 3 and 4 for the cropping seasons of 2012-13 and 2013-14, respectively. The effects of planting date and water regime were significant during the 2 years. However, the effect of the variety changes was significant only in year 2 where the varieties Louiza and Nassira yields exceeded those of the other two cultivars. Early planting, under rainfed conditions, increased yields from 1.2 to 2.5 t/ha (208%) and from 0.3 to 2.8 t/ha (933%), respectively for years 1 and 2. The large difference between grain yields under early and late plantings were due to rainfall deficits and the increase in temperature starting early in late February which corresponded to the period of the seed set and growth. These results confirmed the review of [20] in which it was stated that delay of every one week in sowing date may result in a grain yield loss of up to 0.2 t/ ha for purely rainfed wheat. However, the rate of decrease in our study varied from one year to the other and was very high in the drier year (2013-14). Under supplemental irrigation regime, yields from early and late plantings were similar in year 1 and 2 and this finding is different than that of [20] where the yield reduction was estimated at 0.5 t/ha for each one week of planting date delay. Our data shows that early planting and the application of irrigation water in the case of late planting helps the plants avoid terminal drought and heat stress due to the availability of soil moisture and maintenance of transpiration and its cooling effects on the canopy. These favorable conditions have impacted positively the kernels growth. In fact, our data (Tables 3 and 4) show that early planting and irrigation application increased, on average, 1000-seed weight and that the effect of watering was more significant under late planting conditions. These results confirm the findings of [21] who showed that post and pre-flowering droughts affected significantly 1000-seed weight. Despite the fact that high temperatures cause reduction in grain numbers and reduce duration of grain filling period and hence seed weight [22], our findings confirm that the negative effect of these environmental stresses on seed weight can be overcome by the application of irrigation water during the development and growth of the kernels.

Table1. *Effect of planting date, water regime and genotype on grain yield (t/ha) of durum wheat in Afourer, Morocco, during the cropping season 2012/2013.*

Date	Early planting			Late planting		
Genotype	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
Karim	3.0	3.8	3.4	1.1	4.6	2.9
Louiza	2.4	4.6	3.5	1.3	4.2	2.8
Nassira	2.4	4.2	3.3	1.3	3.9	2.6
PM9	2.1	4.6	3.4	1.0	4.9	3.0
Mean	2.5	4.3	3.4	1.2	4.4	2.8

CV = 12%

ANOVA: Date effect: * with LSD = 0.3; Water regime effect: ** with LSD = 0.2; Variety effect: NS; Date x Water regime:*; Date x Variety: NS; Water regime x Variety: NS; Date x Water regime x Variety: NS

Table2. *Effect of planting date, water regime and genotype on grain yield (t/ha) of durum wheat in Afourer, Morocco, during the cropping season 2013/2014.*

Date	Early planting			Late planting		
Genotype	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
Karim	2.2	5.1	3.7	0.2	5.2	2.7
Louiza	3.3	6.3	4.8	0.4	5.5	3.0
Nassira	3.2	6.1	4.7	0.2	4.8	2.5
PM9	2.6	4.0	3.3	0.2	5.6	2.9
Mean	2.8	5.4	4.1	0.3	5.3	2.8

CV = 13%

ANOVA: Date effect: * with LSD = 0.5; Water regime effect: ** with LSD =0.4; Variety effect: * with LSD = 0.8; Date x Water regime: *; Date x Variety: *; Water regime x Variety: NS; Date x Water regime x Variety: NS.

1000-seed weight (Tables 3 and 4) was affected by the interaction "Planting date x Water regime x Genotype". Variety Karim had the highest kernel weight under rainfed conditions when planted early in year 1 and late in year 2 and under irrigated conditions when planted late. However, the genotype PM9 was, respectively, more and less performing than the other genotypes in late planting in years 1 and 2.

In addition to the main factors effects on grain yield, the interaction "planting date x water regime" was also significant during both years of study (Tables 1 and 2). The yield increase during the cropping season 2012-13 due to supplemental irrigation was from 2.5 to 4.3 t/ha (172%) in early planting and from 1.2 to 4.4 t/ha (367%) in late planting. The application of irrigation water increased productivity from 2.8 to 5.4 t/ha (193%) in early planting and from 0.3 to 5.3 t/ha (1767%) in late planting in 2013-14. The response to supplemental irrigation was more significant in late planting than in early one ; meaning that the application of irrigation water offsets the negative effects of more drought and heat stress to which the plants are usually exposed when the date of planting is delayed and this is confirmed by the data on 1000-seed weight (Tables 3 and 4). The rates of increase of wheat yield due supplemental irrigation under early and late planting conditions in our trials were very high as compared to those obtained in Syria by [23] where they were only 185%, 162.5% and 188% for the plantings of early November, early December and early January, respectively.

Table3. *Effect of planting date, water regime and genotype on 1000-seed weight (g) of durum wheat in Afourer, Morocco, during the cropping season 2012/2013*

Date	Early planting			Late planting		
Genotype	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
Karim	43.3	43.7	43.5	28.0	47.3	37.7
Louiza	36.3	44.0	40.2	32.0	47.0	39.5
Nassira	39.0	44.3	41.7	32.3	49.0	40.7
PM9	36.3	43.3	39.8	37.0	43.0	40.0
Mean	38.7	43.8	41.3	32.3	46.6	39.5

CV = 8.9%

ANOVA: Date effect: NS; Water regime effect: ** with LSD = 2.1; Variety effect: NS; Date x Water regime: **; Date x Variety: NS; Water regime x Variety: NS; Date x Water regime x Variety: *.

Table4. *Effect of planting date, water regime and genotype on 1000-seed weight (g) of durum wheat in Afourer, Morocco, during the cropping season 2013/2014.*

Date	Early planting			Late planting		
Genotype	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
Karim	49.7	50.7	50.2	26.0	55.7	40.9
Louiza	45.0	55.3	50.2	27.3	48.3	37.8
Nassira	45.3	53.3	49.3	29.3	49.2	39.3
PM9	42.3	49.0	45.7	24.7	42.3	33.5
Mean	45.6	52.1	48.8	26.8	48.9	37.9

CV = 6.8%

ANOVA: Date effect: * with LSD = 1.7; Water regime effect: ** with LSD =1.5; Variety: ** with LSD = 2.5; Date x Water regime: **; Date x Variety: NS; Water regime x Variety: NS; Date x Water regime x Variety: **.

Tables 5 and 6 present actual evapotranspiration (ETa). This parameter was affected by planting date, water regime and planting date x water regime in year 1. During year 2, only the effect of water regime was significant. Under rainfed conditions, ETa was reduced due to delayed planting by 98 mm in year 1 and by only 19 mm in year 2. This has affected negatively yields because of the poor synchronization of the wheat growing season to the rainfall period [24]. Also, late sown material generally flowers late, thereby forcing the grain filling period to coincide with a high temperature regime. However, under supplemental irrigation, ETa was not affected by the changes in the planting date. Evapotranspiration increased significantly under supplemental irrigation. Under rainfed conditions, ETa varied from 236 to 330 mm in early planting and from 181 to 232 mm in late planting. Under SI, it varied, in general, from 396 to 593 mm. The values obtained are, on average, comparable to the findings of [25]. The difference between SI and rainfed treatments under the early planting was 66 mm and 357 mm, respectively for years 1 and 2. This difference was, for the late planting, 173 mm and 358 mm, respectively for 2012-13 and 2013-14. These results show that drier the season is, the more irrigation water is needed to keep the evapotranspiration rate and grain yield high, especially in late planting. Irrigation and, hence, the increase of ETa compensated for the loss of productivity due to late planting and drought. Many studies have shown a positive relationship between yield and water use. [26] reviewed a substantial amount of previous work on water use by crops and concluded that the yield of a given crop can generally be described as a linear function of cumulative ETa; meanwhile [14] found a quadratic relationship.

Table5. *Effect of planting date, water regime and genotype on actual evapotranspiration (mm) of durum wheat in Afourer, Morocco during the cropping season 2012/2013.*

Date	Early planting			Late planting		
Gentoype	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
Karim	333	381	357	228	403	316
Louiza	328	394	361	235	397	316
Nassira	333	394	364	231	404	318
PM9	326	414	370	232	414	323
Mean	330	396	363	232	405	319

CV = 5.3%

ANOVA: Date effect: ** with LSD=10.7; Water regime effect: ** with LSD =9.7; Variety effect: NS; Date x Water regime: **; Date x Variety: NS; Water regime x Variety: NS; Date x Water regime x Variety: NS.

Table6. *Effect of planting date, water regime and genotype on actual evapotranspiration (mm) of durum wheat in Afourer, Morocco during the cropping season 2013/2014.*

Genotype	Early planting			Late planting		
	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
Karim	231	589	410	211	594	403
Louiza	236	601	419	215	583	399
Nassira	235	588	412	223	589	406
PM9	242	595	419	220	575	398
Mean	236	593	415	217	585	401

CV = 12%

ANOVA: Date effect: NS; Water regime effect: ** with LSD = 25; Date x Water regime: NS; Variety: NS; Date x Variety: NS; Water regime x Variety: NS; Date x Water regime x Variety: NS.

Data on water productivity are presented in Tables 7 and 8. WP was affected by the date of planting, water regime and date of planting x water regime. However, the effect of the variety was not significant. Data shows that, early planting increased significantly WP under rainfed conditions. This result confirms those reported by [27]. However, the effect of planting date on this parameter under supplemental irrigation was observed only in year 2. On average, WP was respectively, for early and late planting, 9.2 and 7.8 kg ha^{-1} mm^{-1} in year 1 and 10.5 and 5.1 kg ha^{-1} mm^{-1} in year 2. On average, these values are somewhat higher than those obtained by [27] (3.2-6.8 kg ha-1 mm-1) and lower than those of [28] (5.4-19.0 kg ha-1 mm-1). The effect of SI was not consistent. It was positive only in year 1 under both early and late planting dates. The increase, in year 1, varied from 144% for early planting to 218% for late planting. These results confirm those of [14] who showed that, in general, the application of supplemental irrigation increased significantly grain yield and water productivity when compared to the rainfed treatment. However, our findings contradict those of [29] which indicate higher mean WP in water-stressed than in well-watered conditions. The differences observed can be explained by the severe drought that prevailed during the two years of our study (more particularly in March and April) and affected negatively grain set and growth in rainfed plots and hence water productivity.

Table7. *Effect of planting date, water regime and genotype on water productivity (kg ha^{-1} mm^{-1}) of durum wheat in Afourer, Morocco during the cropping season 2012/2013.*

Date	Early planting			Late planting		
Genotype	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
Karim	9.1	9.9	9.5	4.6	11.5	8.1
Louiza	7.2	11.7	9.5	5.5	10.0	7.8
Nassira	7.3	10.6	9.0	5.3	9.6	7.7
PM9	6.3	11.1	8.7	4.1	11.8	8.0
Mean	7.5	10.8	9.2	4.9	10.7	7.8

CV = 12.1%

ANOVA: Date effect: * with LSD = 0.7; Water regime effect: ** with LSD = 0.6; Variety effect: NS; Date x Water regime: **; Date x Variety: NS; Water regime x Variety: NS; Date x Water regime x Variety: NS.

Table8. *Effect of planting date, water regime and genotype on water productivity (kg ha^{-1} mm^{-1}) of durum wheat in Afourer, Morocco during the cropping season 2013/2014.*

Date	Early planting			Late planting		
Genotype	Rainfed	SI	Mean	Rainfed	SI	Mean
Karim	9.5	8.7	9.1	0.9	8.8	4.9
Louiza	14.0	10.5	12.2	1.9	9.4	5.6
Nassira	13.6	10.4	12.0	0.9	8.1	4.5
PM9	10.7	6.7	8.7	0.9	9.7	5.3
Mean	12.0	9.1	10.5	1.2	9.0	5.1

CV =11.2%

ANOVA: Date effect: ** with LSD = 0.8; Water regime effect: ** with LSD = 0.7; Variety effect: NS; Date x Water regime: **; Date x Variety: NS; Water regime x Variety: NS; Date x Water regime x Variety: NS.

4. CONCLUSION

From this study, we can conclude that early planting and supplemental irrigation in late planting are key options to adapt to drought and heat stress exacerbated by the effects of climate change in the dry areas in North Africa. In fact, under rainfed conditions, early planting increased yields from, 1.2 to 2.5 t/ha in year 1 and from 0.3 to 2.8 t/ha in year 2. However under supplemental irrigation, late planting did not affect significantly the productivity. Early planting and supplemental irrigation helped the plants avoid terminal drought and heat and hence maintain the onset and growth of the gains late in the season.

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