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Effect of Supplementary Irrigation on Agronomical and Physiological Traits in Durum Wheat (*Triticum durum* Desf.) Genotypes

Nadjim Semcheddine[1] & Miloud Hafsi[1]

[1] Department of Agronomy, Faculty of SNV, Sétif1 University, Algeria

Correspondence: Nadjim Semcheddine, Department of Agronomy, Faculty of SNV, Sétif1 University, Algeria. Tel: 213-776-337-585. E-mail: semcheddinenadjim@gmail.com

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Abstract

Drought, one of the abiotic stresses, is the most significant factor restricting crop production in large agricultural fields of the world. Wheat is generally grown on arid-agricultural fields. Drought often causes serious problems in wheat production. Ten durum wheat (*Triticum durum* Desf.) genotypes were tested under rain-fed (T_0) and three irrigated treatments (T_1 = 50 mm at Booting stage, T_2 = 50 mm at Booting and 15 mm at heading stages and T_3 = 50 mm at Booting and 30 mm at heading stages) in semi-arid conditions of Eastern Algeria. Grain Yield, components of yield, heading evolution, leaf relative water content, leaf specific weight, grain filling rate and duration and chlorophyll content were measured. The irrigation treatments affect significantly all characters. Application of 50 mm of irrigation at booting stage increased significantly grain yield by 23%, compared to rain-fed treatment. Another supplementary irrigation of 15 or 30 mm, at heading, increased significantly grain yield by 45 and 61%, respectively. Stressed condition affects negatively thousand kernel weights (105%). In addition, combined analysis of variance showed high genetic variation for all parameters measured, excepted leaf relative water content and leaf specific weight, when measured at heading stage suggesting the possibility of selecting tolerant genotypes for drought tolerance under semi arid condition.

Keywords: drought, tolerance, *Triticum durum*, water stress, yield

1. Introduction

Drought stress, which is the most serious environmental problem limiting crop production in rain-fed agriculture (Bahieldin et al., 2005), can severely impact plant growth and development, limit plant production and the crop performance (Shao et al., 2009). Drought is a major abiotic factor that limits agricultural crop production (Reddy et al., 2004). Drought stress affects 40 to 60% of the world's agriculture lands (Shahryari & Mollasadeghi, 2011).

In the semi-arid high plains of Algeria, drought is often a serious wheat production problem. The temperature regime in those parts of Algeria which receive adequate rainfall (300 mm) is reasonably suitable for wheat production. These areas generally lie north of latitude 34.5° N, along the Mediterranean coast. Even in the Sahara, with a hot sub-tropical desert climate (rainfall <100 mm), the mean daily temperature in winter seldom exceeds 20 °C. Lack of water confines rain-fed wheat to the north of the country. Annual rainfall here ranges between 250 mm and 400 mm, and most of this falls during winter. Average daily temperatures during the wheat growing period vary from 9 °C to 15 °C.

Drought is a polygenic stress and is considered as one of the most important factors limiting crop yields around the world (Kiliç & Yağbasanlar, 2010). So, it is essential to develop drought stress tolerant wheat genotypes to ensure sustainable and productive wheat production (Taheri et al., 2011). Survival under the stressful condition depends on the plant's ability to perceive the stimulus, generate and transmit the signals and initiate various physiological and chemical changes (Sayar et al., 2008; S. Tas & B. Tas, 2007). Due to occurrence of different forms of drought stress, during different stages of wheat growth, the average yield which was obtained in such areas every year is 30% of the maximum yield which can be harvested (Denge et al., 2005). The objective of this study is to test the effect of different water supply on the agronomical and physiological traits in durum wheat.

2. Material and Methods

2.1 Material Treatment and Experimental Design

Field trials were conducted during the cropping season 2009/2010 at Nouari Dahal EAC (Exploitation Agricole

Collective) (Lat 36°9′ N & Long 5°21′ E, 1175 m at above the sea level) in Setif, (Algeria). The genetic materials used which comprised six durum wheat cultivars were obtained from the CIMMYT/ICARDA selection while the four other cultivars were obtained from the agricultural research Station of Field Crop Institute, ITGC, Setif, Algeria. The cultivars were tested in four levels of water. The treatments of applied water included rain-fed treatment (T_0) and three levels of irrigation; T_1 (50 mm at booting), T_2 (50 mm at booting and 15 mm at heading), and T_3 (50 mm at booting and 30 mm at heading).

The experiment was laid down for each treatment in a randomized complete block design (RCBD) with three replications at a sowing distance of 0.18 m between the rows. Each elementary plot was made up of four rows (2.5 m long) and the first middle row was used for destructive sampling, while observations were taken from the second middle row. To eliminate border/edge effects, the middle rows, 0.25 m of extremities were neglected. The cultivars were hand sown on 30 and 31 December 2009 and 2 January 2010 at a rate of 350 seeds/m^2. One hundred kg ha^{-1} of triple super phosphate 46% were applied in autumn, at sowing and 100 kg h^{-1} of urea 35% were broadcasted at tillering stage. Weeds were removed by hand, to avoid any negative effect of hormonal herbicides that may have differentially affected the cultivars.

2.2 Leaf Chlorophyll Content

A chlorophyll meter, Minolta SPAD-502 (Soil Plant Analysis Development), has been used to estimate Nitrogen status in wheat. The instrument measures transmission of red light at 650 nm, at which chlorophyll absorbs light, and transmission of infrared light at 940 nm, at which no absorption occurs. On the basis of these two transmission values the instrument calculates a SPAD value that is quite well correlated with chlorophyll content (Wood et al., 1993; Markwell et al., 1995). In each water treatment, three replications chlorophyll meter readings (SPAD values) were repeatedly taken at the abbatial slide of the two same flag leaves during; booting (BOT), early heading (EHD), medium of heading (MHD), late heading (LHD), flowering (FLW), early grain filling (EGF), medium of grain filling (MGF) and late grain filling (LGF).

2.3 Leaf Relative Water Content (RWC) and Leaf Specific Weight (LSW)

Two measures of RWC and LSW were performed at heading and grain filling. The RWC is determined from a sample of 5 flag leaves. Flag leaves are weighed to determine their fresh weight (FW), then they are trapped in vials containing distilled water and they put on at darkness. After 4 hours: the leaves are brought out and dried with blotting paper and then weighed to obtain turgid weight (TW). Then, the leaves are placed in an oven at 65 °C for 16 hours. After this time, leaves, one last time, were reweighed to obtain their dry weight (DW). The RWC is calculated from the formula given by the method of Barrs and Weartherly (1962):

$$RWC\ (\%) = (FW - DW) / (TW - DW) \times 100 \tag{1}$$

Concerning leaf specific weight, ten meter flag of leaf blade is removed and cut them at the base of the blade length (L) and width (l) of each leaf measured. Leaf area (LA) is determined by the formula:

$$LA\ (cm^2) = 0.606\ (Lx\ l) \tag{2}$$

Where L is the average length, l the average width and 0,606 is the regression coefficient of the surface estimated from the weight of paper that deduced by the product (Lx l). Then, the leaves are dried at 85 °C for 48 hours and then weighed to obtain dry weight (DW). Density (LSW) is calculated from the formula given by Sakar et al. (2003):

$$LSW\ (mg/cm^2) = DW / LA \tag{3}$$

2.4 Grain Filling

At anthesis until the maturity, 5 plants in each plot were sampled each two days. Then, dry weight of the ten grains of the central spikelets was measured. Grain filling rate (GFR) was calculated as the value of slope of the regression line of evolution of grain dry weight (Triboi, 1990). The grain filling duration (GFD) was calculated as the ratio of final grain weight to mean grain filling rate (Bahlouli et al., 2008).

2.5 Phenologic and Yield Parameters

Degree-days to heading (HDD) were computed by simple arithmetic accumulation of daily mean temperature above the base temperature value 0 °C considered for wheat crop. The accumulated HDD was obtained by:

$$\text{Accumulated HDD} = \sum_{i}^{n}\left[\left(\frac{\mathbf{T_{max} + T_{min}}}{\mathbf{2}}\right) - \mathbf{T_b}\right] \tag{4}$$

Where: T_{max} and T_{min} are the maximum and minimum daily temperature and T_b is the base temperature (Cao & Moss, 1989a, 1989b; Kirby et al., 1999), i: start of phenophase or date of sowing and n: end of phenophase or date at when 50% of spikes had completely emerged from the boot; growth stage 55 (Zadoks et al., 1974).

At maturity, a subsample (1 m), for each elementary plot was harvested manually on 14 and 22 July, respectively for early and late cultivars. Grain yield (g m^{-1}) was determined and expressed in t ha^{-1}. The same sample was used to assess: number of spikes per m^2, number of kernels per spike, number of grains per m^2 and thousand kernels weight.

2.6 Climatic Conditions

The Ombrothermic diagram (Figure 1) showed a marked dry season between April to August and a rainy season from December to March. Total precipitation for the growing period (from November to June) was 385 mm. Maximum was unregistered in May (71 mm) and minimum in November (26 mm). Monthly mean maximum and minimum temperature was recorded in June (29 °C) and January (1.6 °C) respectively.

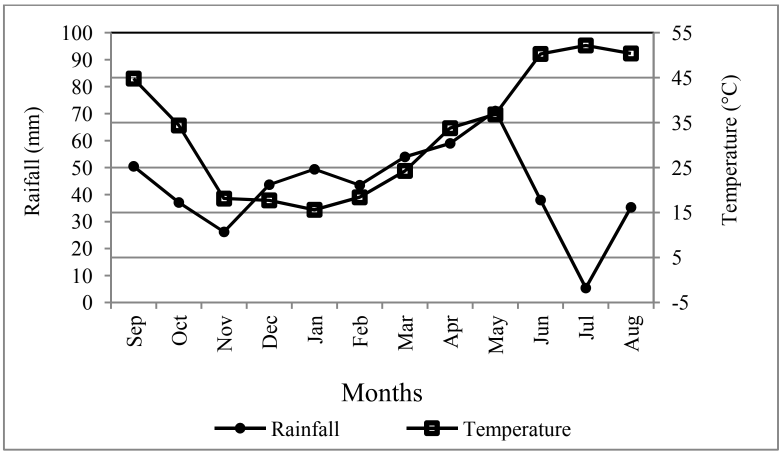

Figure 1. Chirhoum Ombrothermic diagram during 2009/2010 cropping season

2.7 Data Analysis

Collected and estimated data were subjected to analyze of variance (ANOVA), firstly on individual irrigation treatment (only for grain yield) basis before combined ANOVA over irrigation treatment using the SAS statistical analysis package (version 9.2; SAS Institute, Cary, NC, USA). Differences among treatments and genotypes were examined for statistical significance using the least significant difference (LSD) test at ($P<0.05$) significance levels. Linear correlation coefficients between all possible pairs of traits were calculated on the combined data using STATISTICA program StatSoft France (1997). Liner regression was used to evaluate the relationships between measured parameters.

3. Results and Discussion

3.1 Phenology, Yield and Components of Yield

In each water treatment, the results of analysis of variance showed highly significant differences between genotypes for grain yield (Table 1) indicating high genetic variation and possibility of selection in this rich gene pool for improvement of drought tolerance.

Table 1. The average grain yields (t ha^{-1}) of genotypes and statistical groups*

Genotype	T_0	T_1	T_2	T_3
Bousselem	6.01^{a}	5.68^{a}	7.35^{a}	7.58^{a}
Dukem	4.76^{ab}	4.70^{abc}	5.57^{b}	6.32^{bc}
Mexicali	4.24^{abc}	5.46^{ab}	6.54^{ab}	6.51^{ab}
Waha	4.22^{abc}	4.61^{abc}	5.68^{ab}	6.40^{bc}
Altar	4.20^{abc}	4.72^{abc}	5.40^{b}	5.53^{bc}
Hoggar	3.90^{abc}	4.40^{bc}	6.20^{ab}	6.36^{bc}
Sooty	3.88^{abc}	4.68^{bc}	5.45^{b}	5.46^{bc}
Kucuk	3.72^{bc}	3.72^{c}	4.89^{b}	5.49^{bc}
Oued Zenati	2.41^{c}	3.48^{c}	2.71^{c}	3.99^{d}
Polonicum	2.31^{c}	3.63^{c}	3.10^{c}	5.21^{c}
Means	3.96^{d}	4.50^{c}	5.28^{b}	5.88^{a}
$LSD_{5\%}$	1.95	1.10	1.59	1.11

*Means followed by the same letter(s) are not significantly different at the 0.05 probability level.

Analysis of environmental and genotypic factors is always important in plant breeding (Jackson et al., 1996; Yan & Hunt, 1998). In these study and throughout combined analysis of variance, effects of genotype and irrigation treatment were found to be highly significant ($P<0.001$) for grain yield (GY), number of spike per m^2 (NSM), number of kernel per spike (KN) and number of grains per m^2 (NGM). The effect of irrigation treatment for 1000 kernel weight (TKW) and for degrees days to heading (HDD) was significant at $P<0.05$ and $P<0.01$ respectively and highly significant ($P<0.001$) for genotype effect (Table 2). Moreover, interaction effect of irrigation treatment * genotype was significant, only, for number of kernel per spike ($P<0.001$).

Table 2. Mean square values of combined analysis of variance

	Mean square					
	NSM	HDD (°C)	NGM	KN	TKW (g)	GY (t h^{-1})
Treatment	90 795***	8965**	214 791 667***	83***	63*	21***
Genotype	41 465***	29 287***	112 618 431***	146***	269***	12***
Treatment*Genotype	5367	1301	14 084 787	31***	27	0.603
CV (%)	13.55	3.12	16.73	7.27	10.37	12.71

NSM: Number of spike/m^2, HDD: degrees days to heading, NGM: number of grains/m^2, KN: number of kernel/spike, TKW: 1000 kernel weight and GY: Grain yield. *, **, *** significant at 5, 1 and 0.1%, respectively.

Traits related to drought resistance, such as early maturity, lead to reduced total seasonal evapo-transpiration (Rizza et al., 2004). Our results showed that, irrigation prolonged significantly vegetative growth period. Degree days to heading (HDD) was significantly smaller (1304 °C) in stressed treatment (T_0) compared to the watered treatments which varied between 1333 and 1344 °C (Table 3).

Table 3. Means values of measured parameters for different water treatments and genotypes

Water treatments	NSM	HDD (°C)	NGM	KN	TKW (g)	GY (t h^{-1})
T_3	558.69^{a}	1333.0^{a}	20 064^{a}	35.76^{a}	50.51^{a}	5.88^{a}
T_2	530.21^{a}	1333.4^{a}	18 161^{b}	34.11^{b}	48.28^{ab}	5.28^{b}
T_1	530.59^{a}	1344.9^{a}	18 446^{b}	34.46^{b}	47.02^{b}	4.50^{c}
T_0	433.09^{b}	1304.3^{b}	13 808^{c}	31.73^{c}	48.45^{ab}	3.96^{d}
Means	513.14	1328.9	17 620	34.02	48.56	4.91
$LSD_{5\%}$	35.73	21.37	1515	1.27	2.58	0,5
Genotype						
Bousselem	529.1^{ab}	1326.2^{b}	17528.7^{bc}	32.68^{de}	57.17^{a}	6.65^{a}
Dukem	561.9^{a}	1352.4^{b}	21424.6^{a}	37.70^{ab}	41.53^{d}	5.34^{bc}
Mexicali	574.9^{a}	1268.0^{c}	19834.6^{ab}	34.67^{cd}	50.67^{bc}	5.69^{b}
Waha	592.9^{a}	1291.2^{c}	19827.3^{ab}	33.41^{de}	45.14^{cd}	5.22^{bc}
Altar	468.0^{bc}	1283.7^{c}	15355.7^{cd}	32.58^{de}	50.64^{bc}	4.96^{cd}
Hoggar	544.8^{a}	1287.4^{c}	19964.8^{ab}	36.49^{bc}	49.84^{bc}	5.22^{bc}
Sooty	463.8^{bc}	1321.1^{b}	18369.4^{abc}	39.36^{a}	44.30^{d}	4.87^{cd}
Kucuk	527.2^{ab}	1344.8^{b}	18407.5^{abc}	34.92^{cd}	43.93^{d}	4.46^{d}
Oued Zenati	444.0^{c}	1403.4^{a}	12089.5^{e}	27.00^{f}	52.40^{b}	3.15^{e}
Polonicum	424.5^{c}	1410.5^{a}	13399.7^{de}	31.38^{e}	50.04^{bc}	3.56^{e}
Means	513.1	1328.9	17620.2	34.02	48.56	4.91
$LSD_{5\%}$	56.4	33.79	2395.5	2.00	4.09	0.50

NSM: Number of spike/m^2, HDD: degrees days to heading, NGM: number of grains/m^2, KN: number of kernel/spike, TKW: 1000 kernel weight and GY: Grain yield. Means followed by the same letter (s) are not significantly different at the 5% probability level.

Among genotypes, maximum and minimum HDD were observed by Polonicum (1410 °C) and Mexicali (1268 °C) respectively. Polonicum and Oued Zenati have an early heading, Mexicali, Altar, Waha and Sooty have late heading and the other genotypes have an intermediary heading (Figure 2).

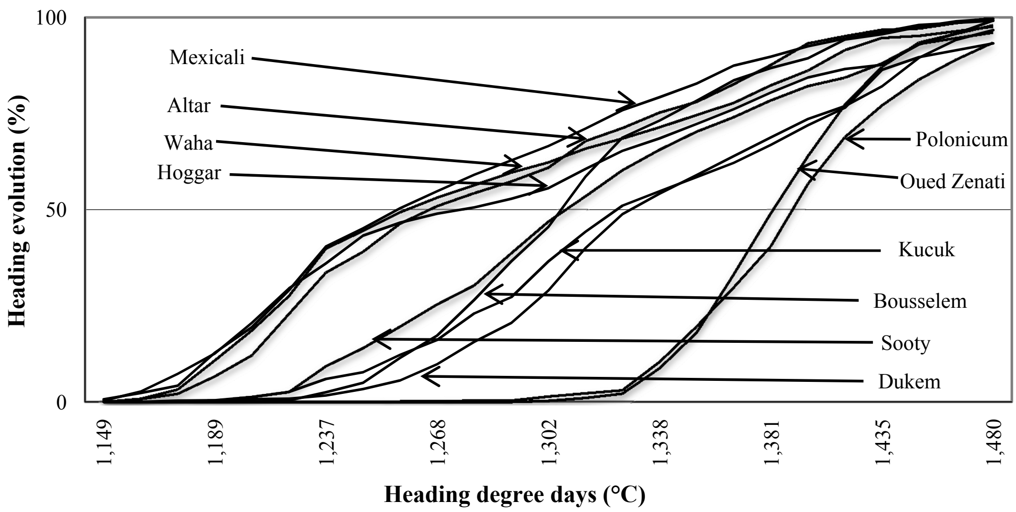

Figure 2. Average heading evolution of ten genotypes

Identification of high potential varieties under optimum moisture and water deficit conditions (low stressing) is a principal breeding approach for durum wheat genotypes (Blum, 1988). Considering irrigation treatment, grain yield of treatments over genotypes ranged from 3.96 t ha^{-1} for rain-fed treatment (T_0) to 5.88 t ha^{-1} for well watered treatment (T_3). Genotypes grain yield over treatments ranged from 3.15 t ha^{-1} to 6.65 t ha^{-1} (Table 3).

In each water condition, Bousselem has a higher grain yield compared to Polonicum and Oued Zenati which had the lowest grain yield. Zhang and Oweis (1999) reported that wheat response to water stress is more sensitive from stem- elongation to booting, followed by anthesis and grain- filling stages. Zhang et al. (2004) and Kang et al. (2002) reported significant increases in wheat grain yield, varying from 20-45% after application of 30-60 mm of reduced irrigation at jointing.

Compared to rain-fed treatment, our results showed that mean grain yield increased significantly by 23% after application of 50 mm at boot stage. Another supplementary irrigation of 15 or 30 mm, at heading, increased significantly mean grain yield by 45 and 61% respectively. Under different drought-stress conditions in field and greenhouse experiments, Simane et al. (1993) indicated that yield reduction was largest under mid-season stress (58%), followed by terminal stress (30%) and early stress (22%). In case of Eastern High Plains of Algeria, Chenafi et al. (2006), indicated that over 10 cropping seasons, grain yield obtained in conditions of limited irrigation has been increased by 93.4% compared to rain-fed treatment.

Erchidi et al. (2003) mentioned that the wheat yield can be expressed as the product of two components; the kernel number per unit area and the kernel weight. In this study, results showed that water deficit, , decreased significantly number of spikes per m^2 at booting stage; however, it reduced significantly but gradually grain number per unit area and grain number per spike at heading stage (Table 3). Kernel weight wasn't statistically different compared to watered treatment (T_1, T_2 and T_3) and rain-fed treatment (T_0). The only significant difference exists between T_3 (50.51 g) and T_1 (47.02 g).

Among genotypes, Polonicum (424 spike /m^2) and Oued Zenati (444 spike/m^2) registered the lowest number of kernel per spikes, number of kernel per m^2 and high TKW (Table 3). Sooty and Altar recorded medium values of spike/m^2 (463 and 468 spike/m^2 respectively). The other genotypes recorded high number of spikes ranging between 529 and 592 spike/m^2. Dukem is characterized by high number of grain per m^2 (21424 g/m^2) and number of kernel per spike (37.70 kernel/spike) but its TKW (41.53 g) was significantly the lowest one. Bousselem had low number of kernel per spike (32.68 g/spike) but compensed significantly by high TKW (57.17 g). Mexicali, Waha, Hoggar and Kucuk were characterized by medium values for NGM which varied between 18407 and 19964 g/m^2. For TKW, Mexicali and Hoggar registered high values (50.67 and 49.84 g respectively) and Kucuk the low one (43.93 g). Finally, Waha was characterized by both low number of grains per spike (33.41 grains/spike) and TKW (45.14 g).

3.2 Relative Water Content

Teulat et al. (1997) reported that leaf relative water content can be used as screening techniques for drought resistance in breeding programs. According to Siddique et al. (2000), drought stress during plant development reduced significantly RWC values. Significant difference in RWC was observed between wheat genotypes at various stages and more reduction was recorded in drought susceptible varieties (Almeselmani et al., 2011). At heading and grain filling stages, our findings indicated that relative water content differed significantly among water treatments. Between genotypes, no significant difference was observed (Table 4).

Table 4. Mean square values of combined analysis of variance for grain filling rate, grain filling duration, relative water content and specific leaf weight

	Mean square					
	GFR	GFD	RWC		LSW	
			At heading	At grain filling	At heading	At grain filling
Treatment	0.185**	132***	249*	515**	3.91***	19.43***
Genotype	0.120**	97***	64	196	0.87	16.31***
Treatment*Genotype	0.058*	26	60	91	0.58	1.75
CV (%)	12.97	12.94	11.36	13.26	11.72	14.80

GFR: grain filling rate, GFD: grain filling duration, RWC: relative water content and LSW: leaf specific weight. *, **, *** significant at 5, 1 and 0.1%.

For all water treatments, highest (77%) and lowest (74%) RWC mean values were recorded at grain filling and heading stage, respectively (Table 5).

At heading, RWC was higher in all watered conditions (T_1, T_2 and T_3) than in stress condition (T_0). During grain filling, RWC decreased significantly in T_3 compared to T_0, T_1 and T_2.

Table 5. Means values of measured parameters in each water treatment

Water treatment	RWC (%)		LSW (mg/cm^2)		GFR (mg/g/d)	GFD (day)
	At heading	At grain filling	At heading	At grain filling		
T_3	73.21^{ab}	70.79^{b}	7.74^{ab}	6.53^{b}	1.59^{a}	30.32^{b}
T_2	77.34^{a}	79.75^{a}	8.12^{a}	8.02^{a}	1.44^{b}	34.50^{a}
T_1	74.81^{ab}	78.62^{a}	7.49^{b}	7.93^{a}	1.43^{b}	30.51^{b}
T_0	70.46^{b}	78.68^{a}	7.28^{b}	8.43^{a}	1.44^{b}	33.43^{a}
Means	73.96	76.96	7.66	7.70	1.47	32.19
$LSD_{5\%}$	4.32	5.24	0.46	0.58	0.09	2.14

RWC: relative water content, LSW: leaf specific weight, GFR: grain filling rate and GFD: grain filling duration.
** Means followed by the same letter(s) are not significantly different at the 5% probability level.

At heading and grain filling, Dukem realized maximum values for RWC, respectively, 78 and 82%. Waha (70%) at heading, Polonicum (71%) and Oued Zenati (71%) at grain filling obtained the minimum values (Table 6). Our results are in agreement with the findings of Taheri et al. (2011) who mentioned significant difference, for RWC, among water stress level and any significant difference among wheat lines and for interaction between wheat lines and water stress level.

Golestani Araghi and Assad, (1998) showed that six wheat genotypes differed to relative water content in ear emergence and grain filling in the stress environment.

Table 6. Means values of measured parameters for each genotype

Genotypes	RWC (%)		LSW (mg/cm^2)		GFR (mg/g/d)	GFD (day)
	At heading	At grain filling	At heading	At grain filling		
Bousselem	74.88	80.75	7.16	7.82^{a}	1.48^{b}	34.53^{ab}
Dukem	78.36	82.49	7.65	8.46^{a}	1.47^{b}	31.31^{abcd}
Mexicali	74.67	76.43	7.56	8.29^{a}	1.46^{b}	35.56^{a}
Waha	69.87	78.88	7.49	8.42^{a}	1.40^{b}	33.83^{abc}
Altar	73.19	80.54	7.91	8.85^{a}	1.38^{b}	35.38^{a}
Hoggar	72.09	79.50	7.58	8.21^{a}	1.40^{b}	33.46^{abc}
Sooty	74.50	74.57	7.74	7.57^{a}	1.41^{b}	31.81^{abcd}
Kucuk	73.99	73.89	7.49	8.22^{a}	1.47^{b}	29.96^{bcd}
Oued Zenati	72.19	71.40	7.87	5.59^{b}	1.57^{ab}	28.90^{cd}
Polonicum	75.84	71.18	8.13	5.59^{b}	1.70^{a}	27.14^{d}
Means	73.96	76.96	7.66	7.70	1.47	32.19
$LSD_{5\%}$	6.83	8.29	0.73	0.91	0.15	3.38

*RWC: relative water content, LSW: leaf specific weight, GFR: grain filling rate and GFD: grain filling duration.
**Means followed by the same letter(s) are not significantly different at the 5% probability level.

3.3 Leaf Specific Weight

Our results showed that leaf specific weight differed significantly among water treatments at heading and grain filling stages and only at grain filling stage among genotypes (Table 4). In both water treatments, maximum (7.70 mg/cm^2) and minimum (7.66 mg/cm^2) values of LSW were obtained at grain filling and heading stage respectively (Table 5). From heading to grain filling, LSW decreased significantly in T_3 (from 7.74 to 6.53 mg/cm^2). In the opposite, in the stressed condition (T_0), LSW increased significantly from heading to grain filling stage; 7.28 and 8.43 mg/cm^2 respectively.

Among genotypes, results showed that LSW of Oued Zenati (7.87 and 5.59 mg/cm^2 at heading and grain filling stage respectively) and Polonicum (8.13 mg/cm^2 and 5.59 mg/cm^2 at heading and grain filling stage respectively) decrease dramatically. For the other genotypes, leaf specific weight doesn't vary significantly. Altar presented high LSW at heading (7.91 mg/cm^2) and grain filling stage (8.85 mg/cm^2). Lowest LSW was observed by Bousselem; 7.16 mg/cm^2 at heading and Sooty; 7.57mg/cm^2 at grain filling stage (Table 6).

3.4 Grain Filling

Wheat sensitivity to soil drought is particularly important during the grain-filling period because the reproductive phase is extremely sensitive to plant water status (Saeedipour & Moradi, 2011). Combined analyses of variances, for grain filling rate (GFR) and grain filling duration (GFD), indicated the presence of the highly significant differences among genotypes and treatment. No significant irrigation treatment × genotype interaction was observed (Tables 4). Well watered treatment (T_3) presents high GFR (1.59 mg/g/d) and low GFD (30.32 days). In the opposite, rain-fed treatment (T_0) showed low GFR (1.44 mg/g/d) and high GFD (33.43 days) (Table 5). Excepted Polonicum (1.70 mg/g/d) which had similarity with only Oued Zenati (1.57 mg/g/d), all genotypes exhibits similarity in GFR that ranged between minimum of 1.38 mg/g/d and maximum of 1.48 mg/g/d showed by Altar and Bousselem respectively (Table 6).

For grain filling duration, high genetic variation was observed. Polonicum (27.14 days) and Oued Zenati (28.90 days) had short grain filling duration. Mexicali (35.56 days), Altar (35.38 days) and Bousselem (34.53 days) are characterized by long GFD. Wiegand and Cuellar (1981) suggested that the grain-filling rate is determined mostly by genetic factors and the grain-filling duration by environmental factors. Blum (1998) suggested that shorter grain filling duration may allow some avoidance of terminal stress while longer duration may allow greater utilization of stem reserves for grain filling under stress.

3.5 Leaf Chlorophyll Content

Leaf chlorophyll content is an important factor to determine the photosynthesis rate and dry mater production (Ghosh et al., 2004). Results of this study revealed that irrigation had significant effect on chlorophyll content, early at heading and grain filling and at flowering. Significant genotypic effect was observed from booting to grain filling. Irrigation and genotype interaction has significant influence, late at heading and early at grain filling (Table 7).

Table 7. Mean square values of combined analysis of variance for chlorophyll content at different stage

	Mean square							
	BOT	EHD	MHD	LHD	FLW	EGF	MGF	LGF
Treatment	19	78***	15	1	42*	369***	10	41
Genotype	192***	172***	137***	78***	90***	116***	92***	84***
Treatment*Genotype	14	9	13	17*	13	33***	15	12
CV (%)	7.42	6.14	7.30	6.22	6.86	6.67	7.12	8.47

BOT: booting, EHD: early heading, MHD: medium heading, LHD: late heading, FLW: flowering, EGF: early grain filling, MGF: medium grain filling and LGF: late grain filling. *, **, *** significant at 5, 1 and 0.1%.

Highest chlorophyll content means was observed in the middle of heading and grain filling stages; 51.54 and 51.61 respectively (Table 8). Lower values were recorded at boot stage (47.75) and early at grain filling (49.96). At all phonological stages, Dukem, Mexicali and Waha were characterized by high photosynthetic activities. Their leaves chlorophyll content varied between 53.19 and 55.02. Adversely, from booting to the end of heading, Bousselem, Oued Zenati and Polonicum registered low values of chlorophyll content that ranged between 41.42

and 49.32. Photosynthetic rate increased for Polonicum at flowering stage, but for Oued Zenati at middle grain filling stage (Table 6).

The other genotypes showed medium leaf chlorophyll content values which varied between minimum of 49.23 and 51.77 obtained by Kucuk and Sooty, respectively (Table 8).

Table 8. Mean values of chlorophyll content at different stage

Genotype	BOT	EHD	MHD	LHD	FLW	EGF	MGF	LGF
Mexicali	53,40^{a}	55,25^{ab}	55,47^{ab}	54,76^{a}	53,09^{ab}	55,08^{a}	55,45^{a}	54,15^{ab}
Waha	52,15^{a}	54,30^{ab}	54,05^{abc}	53,32^{ab}	52,76^{abc}	51,46^{bc}	53,58^{abc}	53,88^{ab}
Dukem	51,67^{a}	56,35^{a}	56,50^{a}	54,46^{ab}	56,37^{a}	53,33^{ab}	54,94^{ab}	56,51^{a}
Altar	48,64^{b}	52,16^{bc}	52,34^{abc}	51,65^{abcd}	50,81^{bc}	51,06^{bc}	49,86^{cde}	50,63^{bc}
Sooty	48,07^{b}	52,14^{bc}	52,81^{abc}	52,86^{abc}	52,64^{abc}	50,96^{bc}	53,10^{abc}	51,58^{bc}
Hoggar	47,93^{b}	52,22^{bc}	50,59^{cd}	49,60^{cde}	50,29^{bc}	47,82^{cde}	51,50^{abcd}	50,96^{bc}
Kucuk	47,20^{b}	49,84^{c}	51,67^{bc}	50,81^{bcde}	48,56^{cd}	44,89^{e}	50,84^{bcd}	50,02^{bc}
Polonicum	43,65^{c}	46,94^{d}	47,26^{d}	48,46^{de}	50,87^{bc}	49,28^{cd}	48,26^{de}	49,34^{bc}
Bousselem	43,33^{c}	46,17^{d}	47,21^{d}	47,40^{e}	46,40^{d}	46,12^{de}	46,85^{e}	47,39^{c}
Oued Zenati	41,42^{c}	45,87^{d}	47,52^{d}	49,32^{cde}	49,87^{bc}	49,56^{bcd}	51,71^{abcd}	50,57^{bc}
Means	47,75	51,12	51,54	51,27	51,17	49,96	51,61	51,50
$LSD_{5\%}$	2,76	2,77	3,03	2,6	2,84	2,72	2,95	3,53

BOT: booting, EHD: early heading, MHD: medium heading, LHD: late heading, FLW: flowering, EGF: early grain filling, MGF: medium grain filling and LGF: late grain filling. Means followed by the same letter(s) are not significantly different at the 5% probability level.

3.6 Relationship Between Characters

Grain yield under irrigated conditions was significantly and positively correlated with grain yield under rain-fed condition (Figure 3) suggesting that a high potential yield under optimum condition can result in improved yield under stress condition. One main reason for the slow wheat improvement in semi arid environments is the lack of clear understanding of the interrelationships among yield components and their compensatory changes under water stress conditions.

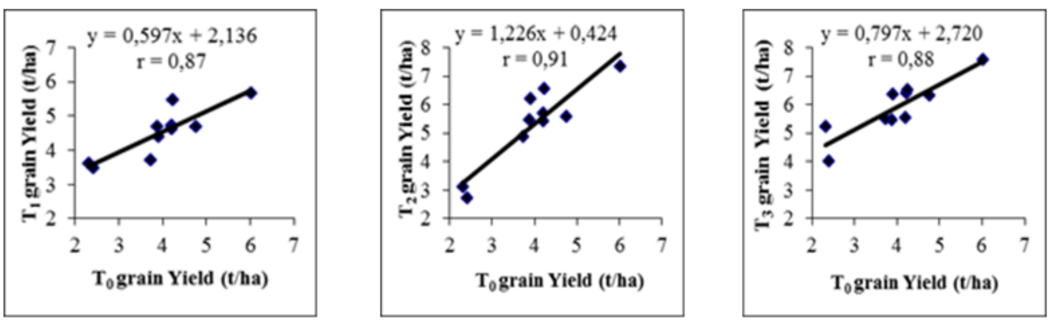

Figure 3. Relationship between genotypes grain yield of rain-fed treatment (T_0) and irrigated treatments (T_1, T_2 and T_3)

In the present study, positive correlation was registered between grain yield, number of spikes per m^2 and number of kernels per m^2 in combined treatments (Table 9). The results are in accordance with various studies which have revealed the positive impact of increased number of spikes per area on yield (Calderini et al., 1995; Garcia del Moral et al., 2003). Under rain-fed treatment, no significant relationship was registered between grain yield and number of kernels/spike; but, in irrigation treatments, positive correlation was observed. Cartelle et al.

(2006) reported that grain weight is a major component contributing to yield variation, especially in Mediterranean regions where grain weight is frequently exposed to terminal stresses affecting grain growth. Our finding showed positive relation between grain yield and 1000 kernels weight in T_0, T_1 and T_2, but in well watered treatment no association was observed between grain yield and 1000 kernels weight.

Table 9. Correlation coefficient between grain yield and measured characters

	NSM	NGM	KN	TKW	HDD	GFR	GFD	RWC_H	RWC_{GF}	LSW_H	LSW_{GF}
Combined treatment	0.69*	0.70*	0.49	0.15	-0.71*	-0.60	0.81*	0.13	0.79*	-0.79*	0.73*
T_0	0.50	0.29	-0.08	0.26	-0.53	-0.79*	0.80*	0.43	0.57	-0.79*	0.71*
T_1	0.52	0.55	0.43	0.27	-0.69*	-0.09	0.49	0.42	0.41	-0.50	0.65*
T_2	0.63*	0.83*	0.55	0.30	-0.66*	-0.56	0.69*	-0.23	0.78	-0.52	0.87*
T_3	0.84*	0.79*	0.44	-0.06	-0.58	0.10	0.00	-0,05	0.25	0.35	0.16

NSM: Number of spike/m^2, NGM: number of grains/m^2, number of kernel/spike, KN: TKW: 1000 kernel weight, HDD: degrees days to heading, GFR: grain filling rate, GFD: grain filling duration, RWC_H: relative water content at heading, RWC_{GF}: relative water content at grain filling, LSW_H: leaf specific weight at heading and LSW_{GF}: leaf specific weight at grain filling. * Significant at $P<0.05$.

In durum wheat, maximum grain yield results from an optimum balance between: number of spikes per unit land, number of kernels/spike and the weight of kernels (Prystupa et al., 2004). With regard to genotype effects and under all treatments, each genotype is characterized by high performance for one yield component. The best genotypes in terms of yield were Bousselem, Mexicali and Dukem which present similarity value of NSM. Bousselem has high TKW and low NGM compared to Mexicali and Dukem. Mexicali is characterized by high weight of 1000 kernels and low number of kernels per meter square as compared to Dukem which has low value of TKW and high number of kernels per spike.

Slafer and Rawson (1994) indicated that the lower kernel weight associated with increased number of kernels per meter square is not only due to a lower amount of assimilates per kernel but it is the result of an increased number of kernels with a lower weight potential coming from more distal florets. According to Freeze and Bacon (1990), these yield components have interdependent action and are able to compensate for one another in order to stabilize yield as cultural or climatic conditions change.

RWC, since it is easier and less expensive to measure, is a more suitable criterion for drought resistance compared to leaf water potential (Merah, 2001). It was also reported that the RWC decreases as drought stress increases (Halder & Burrage, 2003). Some findings also showed significant genetic variation in RWC of wheat with a high heritability, thereby making RWC as a drought screening tool only in wheat and not for water potential components (Schonfeld et al., 1988).

Our study indicated that, at grain filling stage (after second irrigation), grain yield was positively correlated with RWC and LSW. Adversely, at heading stage (before second irrigation), grain yield were strongly associated with LSW. ANOVA don't indicate significant difference between genotype for RWC when measured at heading or grain filling stages and for LSW at heading stage. But at grain filling stage, when terminal stress is occurred, genotypes differed significantly for LSW. So, Oued Zenati and Polonicum, characterized by low grain yield are also characterized by small LSW; 5.59 mg/cm^2 compared to the performing genotypes that their LSW varied from 7.57 to 8.85 mg/cm^2 (Table 6). Also, from heading to late grain filling, our finding indicate that chlorophyll content has positive correlation with $RWC_{\text{at grain filling}}$, $LSW_{\text{at grain filling}}$, GFD and grain yield and was negatively correlated with; $RWC_{\text{at heading}}$, $LSW_{\text{at heading}}$, GFR and HDD (Table 10).

Table 10. Correlation coefficient between chlorophyll content at different stages[1] and measured characters[2]

	BOT	EHD	MHD	LHD	FLW	EGF	MGF	LGF
Grain yield	0.46	0.40	0.36	0.21	-0.02	0.09	0.05	0,12
$RWC_{\text{at heading}}$	-0.35	-0.26	-0.30	0.16	-0.37	-0.29	-0.16	-0,54
$RWC_{\text{at grain filling}}$	0.33	0.45	0.41	0.58	0.39	0.46	0.40	0.11
$LSW_{\text{at heading}}$	-0.38	-0.35	-0.28	-0.15	0.01	-0.22	-0.24	-0.21
$LSW_{\text{at grain filling}}$	0.66	0.59	0.48	0.27	0.12	0.41	0.29	0.37
GFR	-0.38	-0.40	-0.39	-0.21	-0.13	-0.24	-0.40	-0.37
GFD	0.28	0.33	0.25	0.15	0.01	0.14	0.23	0.19
HDD	-0.79*	-0.74*	-0.61*	-0.42	-0.38	-0.65*	-0.50	-0.53

[1] BOT: booting, EHD: early heading, MHD: medium heading, LHD: late heading, FLW: flowering, EGF: early grain filling, MGF: medium grain filling and LGF: late grain filling. [2] RWC: relative water content, LSW: leaf specific weight, GFR: grain filling rate, GFD: grain filling duration, HDD: heading degree days.

*Significant at P<0.05.

4. Conclusion

Developing drought tolerant varieties in arid and semi arid environmental conditions has been accepted as the most important factor for increasing crop potential, yield improvement and stability. It is concluded from the results of this study that water stress reduced grain yield and affected some yield components in all genotypes. Supplementary irrigation at heading increased significantly grain yield from 45 to 61%. In addition, water deficit at booting stage, decreased significantly number of spikes per m^2 and number of kernels per spike. Among the studied genotypes, Bousselem had the highest values of grain yield and 1000 kernels weight; Dukem, Mexicali, Waha and Hoggar presented more number of spikes per square meter; Sooty exhibited high number of grains per spike. Oued Zenati and Polonicum were the low yielder genotypes; they had low number of spikes and grains per square meter and low number of kernels per spike. The results of correlation between the mean values of different treatment under study showed that grain yield presented significant and positive correlations with number of spikes per m^2, number of grains per m^2, grain filling duration; and relative water content and leaf specific weight at grain filling stage. However, it registered significant and negative correlations with heading degree days and leaf specific weight at heading stage. Also, chlorophyll content showed negative relationship with heading degree days at different growing stage. These results proved that the earlier genotypes with long grain filling duration, high chlorophyll content and relative water content, more number of spikes per m^2 and number of grains per m^2 recorded high yield under the conditions of the present study.

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