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The Performance of Durum and Bread Wheat Genotypes Associated with Yield and Yield Component under Different Water Deficit Conditions

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Abstract: Although drought stress has been well documented as an effective parameter in decreasing crop production in arid and semi arid regions, developing and releasing new varieties which are adaptable to water deficit conditions can be a constructive program to overcome unsuitable environmental conditions. The present study was carried out to study the performance of durum and bread wheat genotypes in relation to yield and yield component under different water deficit conditions. The experiment was laid out in split plot based on a complete randomized block design, with three replications at Mashhad Agricultural Research stations in Iran. Irrigation regimes were considered as the main plots and included four levels. Sub-plots were assigned to five wheat genotypes, four durum promising lines and a bread wheat cultivar. The number of spike m^{-2}, number of kernel $spike^{-1}$, 1000-kernel weight, plant height, day to maturity, maturity duration, harvest index and grain yield were highly significant ($P<0.01$) affected by water deficit conditions and genotype effects. In addition to this, the effect of genotype on the biological and grain yield was significant ($P<0.05$). It was observed that water limitation significantly decreased plant height in the early water deficit, while water limitation during double ridge to anthesis reduced the number of spike m^{-2} and number of kernel $spike^{-1}$. Besides, water deficit condition at post-anthesis decreased the number of day to maturity, maturity duration, 1000-kernel weight, harvest index and grain yield. Chamran bread wheat cultivar and a promising durum wheat genotype (RASCON_37/BEJAH_7) produced the highest values for the plant height, kernel numbers, harvest index traits and lastly grain yield compared to all the other genotypes.

Key words: Anthesis, floral initiation, grain filling, grain yield, water deficit

INTRODUCTION

Drought is a major limiting factor affecting crop production in addition to other environmental stresses, particularly high temperature, salt, acid and cold stresses. The negative effect of drought stress on yield performance has been well documented as a major problem in many developed and developing countries of the world (Hernandez, J.A., 2004; Guo, T.C., 2004; Passioura, J.B, 2007). Amongst the crop plants, wheat cultivation inadvertently faces drought conditions under arid and semi arid regions. It is widely consumed by humans in producer countries and other countries where wheat cannot be grown. About 95% of the wheat grown worldwide is bread wheat (Shewry, P.R, 2009; Dixon, J., 2009), but durum wheat (*Triticum turgidum durum*) with a global production of 30 million ton, is an important adapted crop under drought conditions, particularly in the Mediterranean region where 75% of the world's durum grain is produced (Araus, J.L., 2002; Condon, A.G., 2004). Recently Siddique *et al*. (2000) has suggested that one important strategy for crop production, yield improvement, and yield stability is to develop drought tolerant crop varieties under water deficit conditions.

Developing plants with suitable advantages under water stress conditions is a basic challenge for wheat improvement programs. In bread and durum wheat, grain yield can be assessed in terms of three yield components, namely; the number of spikes per unit area, the number of kernels per spike and kernel weight. Guinta *et al*. (1993), Zhong-hu, and Rajaram (1994) revealed that kernels $spike^{-1}$ and the number of spikes m^{-2} were the most sensitive yield components to drought stress under water limitation treatments, while kernel weight remained relatively stable. It has also been reported by Simanae *et al*. (1993) that the number of spikes m^{-2} and also the number of grain $spike^{-1}$ were the effective factors to determine the drought stress. Hence

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decreasing the amounts of these traits under water deficit conditions will indicate a negative effect on grain yield. Sharif Alhosainy (1998) and Saleem (2003) observed that water deficit affected the number of spike m^{-2} and kernels $spike^{-1}$ in bread and durum wheat genotypes. Furthermore terminal drought stress significantly reduced grain weight and plant dry mass in their study. However, they observed that durum wheat genotypes showed comparatively lower reduction with regard to biomass production in comparison to the bread wheat genotypes. They also reported that plant height, spike length, the number of spikelets $spike^{-1}$ and grain yield decreased under water stress in both the durum and bread wheat genotypes. Other studies have shown that the number of grain $spike^{-1}$ has a predominant importance over kernel weight in defining yield in high latitudes (Peltonen-Sainio, P., 2007) whereas kernel weight is well known as a major yield component, determining final yield in certain Mediterranean environments (García Del Moral, L.F., 2003). The objective of present study was to investigate the effect of irrigation regimes during different growth and developmental phases on yield and yield components in durum and bread wheat genotypes.

MATERIALS AND METHODS

Field Experimental Setup:

Field experiment was done during the 2007-2008 growing season at the Khorasan-e- Razavi Agricultural and Natural Resource Research Center, Iran. The statistical design employed was split plot based on a complete randomized block design (CRBD) with three replications. Water limitations were considered as the main-plots and included four different irrigation regimes: I1, Optimum water condition; I2, water limitation from one-leaf to floral initiation stage; I3, water limitation from floral initiation to anthesis stage and the prevention of precipitation using a mobile rain shelter; I4, water limitation from anthesis to late of grain filling stage and the prevention of precipitation. Sub-plots were assigned to five wheat genotypes, four promising durum lines and one bread wheat cultivar. The soil texture at the experimental fields was clay loam. The soil pH and EC (ds m^{-1}) were 8-8.1 and 1.7-2.2 respectively. Before sowing, 50, 90 and 50kg $NPKha^{-1}$ amount of fertilizer was added to all the fields. Additionally, 70 kg N was top-dressed. The seeds for the experiments were obtained from the elite durum yield trial (EDYT, 2006-2007) from the Seed and Plant Improvement Institute (SPII), Iran. Table 1 presents the genotype pedigree of the seeds used in the study.

Table 1: List of durum and bread wheat genotypes used in study

Entry	Genotype	Pedigree	Plant height (cm)	1000KW (g)	Spike length (mm)
G1	Durum	HAI-OU_17/GREEN_38	85	50	61
G2	Durum	RASCON_37/BEJAH_7	87	54	62
G3	Bread	CHAMRAN	85	49	83
G4	Durum	RASCON_39/TILO_1	87	54	61
G5	Durum	GARAVITO3/RASCON37//GREEN8	83	53	62

In the experimental design used, each plot consisted of 12 rows, 3 meters in length spaced 20 cm apart. Based on this, the sub-plot size was 7.2 m^2 (12 x 3 x 0.2) and the seed density was 450 seed m^{-1} based on 1000-kernel weight. Data was statistically analyzed by MSTAT-C software package. Finally, comparative analyses of the means were performed using the Duncan's Multiple Range Test ($P < 0.05$ and $P < 0.01$).

RESULTS AND DISCUSSION

A shown in Table 2, analysis of variance revealed that GY, SPKN, KN, TKW, HI, PLH, DMA and MD were highly significant ($P < 0.01$) affected under irrigation regime treatment whilst HI was shown significant ($P <0.05$). In addition, the genotypic effect was shown highly significant for SPKN, KN, TKW, DMA and significant for BY, GY, HI, PLH. Moreover, interaction effect of irrigation regime ×genotype was highly significant for SPKN, KN, PLH and significant for TKW.

Biological and Grain Yield:

The results of the present study indicated that different irrigation regimes during growth and developmental stages had different considerable effects on grain yield. The highest grain yield (6.4 t ha^{-1}) was produced under optimum irrigation treatment (I1) whilst the lowest (3.2 t ha^{-1}) was observed in the I4 treatment. Water deficit decreased grain yield at the different growth and developmental stages although the highest negative effect was observed in the I4 treatment. Generally, with water limitation during the different growth and developmental stages (one-leaf to physiological maturity), grain yield decreased gradually from the I2 to I4 treatments. These grain yield reductions were 9%, 15% and 50% under the I2, I3 and I4 treatments respectively, when compared with the optimum irrigation treatment (I1). However, there were no significant differences between I2 and I3 water limitation treatments due to grain yield (Fig.1 and Table 1). The negative effects of water deficit at post-anthesis decreased the DMA and consequently MD in the durum and bread wheat genotypes. These deleterious effects caused reduction in KN and TKW in the genotypes studied which are concurrent with the findings of Sharif Alhosainy (1998), Saleem (2003), García Del Moral *et al*. (2003), and Krigwi *et al*. (2004) on durum and bread wheat. Moreover, Donaldson (1996) and Nazeri, (2005) have reported that water deficit after anthesis stage decreased grain filling period, kernel weight and crop production. Therefore, it is reasonable to suggest that a severe reduction in grain yield under the I4 treatment is associated with a decrease in MD and also some of the yield components such as kernel weight spike^{-1} and TKW.

Table 2: Analysis of variance for biological yield (BY), grain yield (GY), no. spike m^{-2} (SPKN), no. kernel spike^{-1} (KN), 1000-kernel weight (TKW), harvest index (HI), plant height (PLH), day to maturity (DMA) and maturity duration (MD) of the durum and bread wheat genotypes under different water deficit conditions

		Mean square (MS)								
Source of variations	df	BY	GY	SPKN	KN	TKW	HI	PLH	DMA	MD
Replication	2	4.65	0.3	752.2	13.9	7.24	2.3	161	11.3	26.2
Irrigation (I)	3	28.1 ^{ns}	59.8**	90388**	227**	1830**	2123*	584**	320**	710.6**
Error	6	0.9	0.1	613.7	43.3	0.21	4.2	35	10.6	12.3
Genotype(G)	4	12.4*	2.4*	59151**	1193**	260.7**	144*	64.2**	93.3**	13.6 ^{ns}
I×G	12	5.9 ^{ns}	0.9*	8718**	479**	16.02*	41 ^{ns}	17.2**	21.8 ^{ns}	16.3 ^{ns}
Error	32	1.5	0.2	621.9	42	0.70	5.4	16.4	10.3	18.7
CV %	-	8.17	8.02	6.67	12.87	11.94	6.6	4.98	6.1	11.5

* Significant difference at $P < 0.05$ ** significant difference at $P < 0.01$ *ns*: no significant

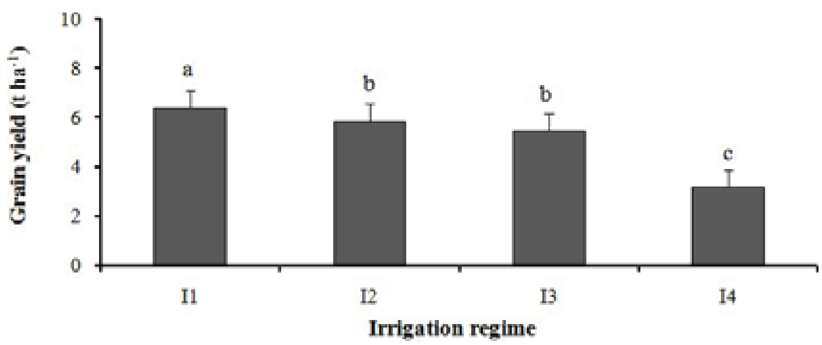

Fig. 1: The effect of different water deficit conditions on grain yield Bars indicated standard deviations. Different letters indicated significant differences at <0.01 level

Table 4 shows the different values for BY and GY in the various durum and bread wheat genotypes. The bread wheat cultivar (G3) produced the highest GY (5.6 tha^{-1}) compared to the durum wheat genotypes under the irrigation treatments, although there was no significant difference between the G3 and G2 genotypes. Genotype G4, which registered the lowest value (4.8 tha^{-1}), did not show a significant difference with the G1 and G5 genotypes. With regard to BY, apart from the G1and G3 genotypes that exhibited the highest yield, there were no significant differences among all the other genotypes studied.

Table 3: Response of grain yield (GY), no. spike m^{-2} (SPKN), no. kernel spike^{-1} (KN), 1000-kernel weight (TKW), harvest index (HI), plant height (PLH), day to maturity (DMA) and maturity duration (MD) under different irrigation regimes

Traits	GY	SPKN	KN	TKW	HI	PLH	DMA	MD
Irrigation regime								
I1	6.41 a	432 a	52 a	44.5 b	40.2 a	85.7 a	156 a	38 b
I2	5.83 b	398 b	52 a	49.9 a	40.5 a	75.2 c	156 a	44 a
I3	5.47 b	304 d	46 b	46.2 ab	37.1 a	82.1 b	154 a	37 b
I4	3.19 c	362 c	50 a	31.9 c	22.7 b	82.3 b	149 a	32 c
LSD	0.429	29.17	2.64	4.64	10.43	1.89	4.21	4.34
Sx	0.052	3.53	0.319	0.561	2.32	0.23	0.51	0.525

Column sharing the same letters indicates no significant differences

Regarding the interaction effects of the factors studied, the results revealed that the maximum grain yield was produced under optimum irrigation and early water limitation (I2) by the G2 (durum wheat) genotype (Fig.

2). However, when the irrigation was reduced during the I3 and I4, the Chamran bread wheat cultivar (G3) exhibited the highest GY amongst all the genotypes. Water limitation at the terminal growth and developmental stages (I4) decreased GY remarkably. The GY reduction for the G2 genotype under I4 irrigation regime was 46% in comparison to the optimum irrigation. According to Blum (1988), identification of high potential varieties under optimum moisture and water deficit conditions (slow stressing) has been a principal breeding approach for durum and bread wheat genotypes. As results of the present study, have shown in Table 4, the G2 genotype produced the maximum GY under optimum irrigation and water deficit conditions amongst all the other durum wheat genotypes and consequently, may be a suitable genotype under drought stress conditions.

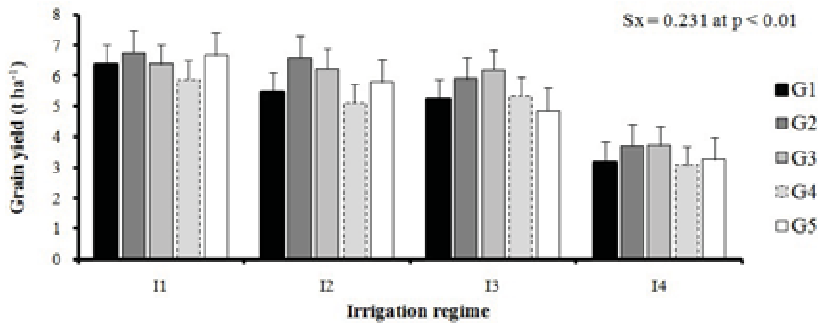

Fig. 2: Interaction effect of irrigation regime × genotype on the grain yield

Harvest Index (HI):

The harvest index is the proportion of grain yield to biological yield and it shows the ability of the plants to translocate physiological matters to grains. Table 2 shows that the lowest HI was produced under the I4 treatment. However, there was no significant difference among all the other treatments. In other words, there was no significant difference between the optimum irrigation and water limitation at the one-leaf to anthesis stage for this trait. There was a severe reduction of about 44% for the HI in the I4 treatment, compared to the other treatments. The significant reduction in the GY under the I4 treatment probably caused a decrease in the HI under I4 in comparison to the other treatments (Figs.1 and Table 3). The increase of the HI in the I2 treatment was related to the decreasing biological yield under water deficit conditions. These results are concurrent with the findings of Dakheel *et al*. (1993) on durum wheat and Guinta *et al*. (1993) on both durum wheat and triticale.

The genotypic effects on the HI values indicated that the G2 durum wheat genotype gave the highest harvest index of 37%, although there was no significant difference with the G3 and G5 genotypes. In general, there was a similar trend concerning the harvest index with regard to the NK and TKW for genotype effects (Table 4).

Table 4: Response of biological yield (BY), grain yield (GY), no. spike m^{-2} (SPKN), no. kernel $spike^{-1}$ (KN), 1000-kernel weight (TKW), harvest index (HI), plant height (PLH) and day to maturity (DMA) in different durum and bread wheat genotypes

Traits	BY	GY	SPKN	KN	TKW	HI	PLH	DMA
Genotype								
G1	15.9 a	5.1 c	372 b	41 c	40.9 c	31.7 c	80 bc	155ab
G2	14.3 b	5.5 ab	333 c	61 a	46.8 a	37.6 a	81abc	156 a
G3	15.1ab	5.6 a	450 a	50 b	38.6 d	37.1 a	83 a	152 bc
G4	14.6 b	4.9 c	327 c	51 b	43.9 b	33.6 bc	82 ab	151 c
G5	14.2 b	5.2 bc	388 b	49 b	45.3 ab	35.6 ab	79 c	152 bc
LSD	1.06	0.367	24.6	3.38	1.67	2.46	2.48	3.1
Sx	0.27	0.093	3.78	0.52	0.25	0.62	0.38	0.46

Column sharing the same letters indicates no significant differences

Number of Spike m^{-2} (SPKN):

Figure 3 shows that water deficit conditions during the different growth and developmental stages decreased the SPKN. Water limitation decreased SPKN by 8%, 30% and 16% in the I2, I3 and I4 treatments compared to the I1 (optimum irrigation). This shows that the highest negative effect of water limitation was observed during the floral initiation and anthesis stage (I3), whereas the effect of water deficit at the early (I2) and late (I4) growth and developmental stages exhibited lower reduction in comparison to the I3 treatment. Other researchers, Nazeri (2005), Robertson and Guinta (1994) and Mustafa *et al.* also reported similar results on wheat and triticale. Water limitation can cause severe competition between the different plant organs for photosynthesis assimilates during the stem elongation. Therefore, spikes per unit area as the effective factor due to drought stress (Simane *et al*. (1993), Richards *et al*. (2001) and Kirigwi *et al*. (2004) has reduced under reproductive phase (Fig. 3).

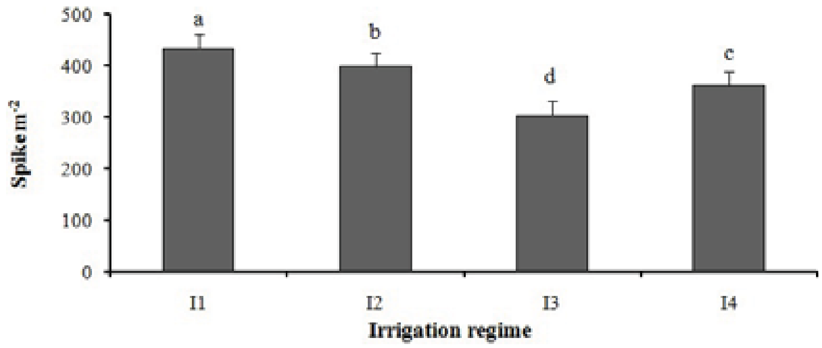

Fig. 3: The effect of different irrigation regime on spike number Bars indicated standard deviations. Different letters indicated significant differences at <0.01 level

With regard to genotype effects, the Chamran cultivar (bread wheat) exhibited, the highest SPKN (450) compared to the other durum wheat genotypes. Mossad *et al*. [24] suggested that amongst the genotypes studied, bread wheat genotypes indicated higher spike m^{-2} compared to durum genotypes. However, Except for the G3 genotype, there was no significant difference between the G1 and G5 genotypes and G2 and G4 genotypes (Table 4).

As shown in Fig.4, apart from the G5 genotype, which showed the highest SPKN (500) under optimum irrigation treatment, the G3 Chamran bread wheat genotype exhibited the highest number of spikes for all the other water limitation regimes. In addition, the highest negative interaction effect for irrigation regime and genotype was observed in the I3 treatment for the G2 genotype. It decreased by 59% compared to the I1G5 treatment.

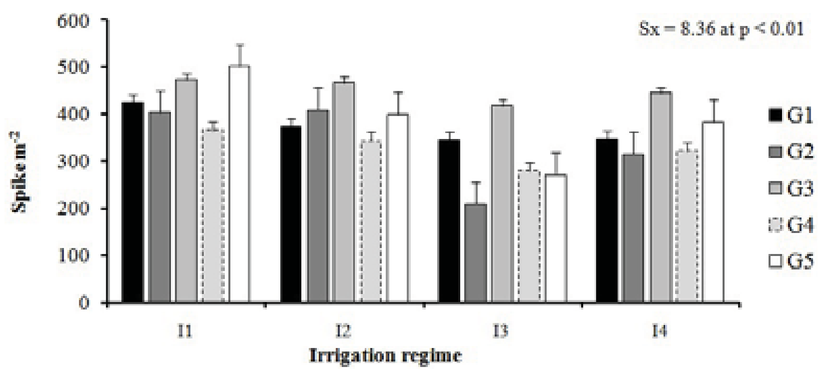

Fig. 4: Interaction effect of irrigation regime × genotype on spike number

Number of Kernels per Spike (KN):

The number of the kernels per spike is an important grain yield component. It has been reported that high yield in the new bread and durum wheat varieties are associated with the increasing number of kernel per spike or unit area (Calderini, D.F., 1999). The results of the present study shows that there was no significant difference between I1, I2 and I4 irrigation treatments for KN, the exception being the I3 treatment, which yielded the lowest number for this important yield component. The highest KN was observed in I2 whereas the lowest was seen in the I3 treatment (Table 3). This suggests clearly that the floral initiation to anthesis stage (I3) was the most susceptible period for the KN under water-limited condition, which confirmed the findings of Mustafa and Ghodsi (2004). They also noted that the number of kernel $spike^{-1}$ is determined during the floral initiation to anthesis stage. As a result, this stage period can be considered the most crucial growth and developmental stage for the final grain yield.

With regard to genotype effects, Table 4 shows that the maximum and minimum KN was belonged to the G2 and G1 genotypes under irrigation treatments. It seems the lower SPKN in the G2 genotype has been compensated with increasing KN compared to all the studied genotypes. In addition to this, there were no significant differences among the G3, G4 and G5 genotypes. The results also showed that the difference in the kernel numbers between the highest (G2) and lowest (G1) genotypes was more than 30% (Table 4).

1000-kernel Weight (TKW):

Although the number of grain spike^{-1} has a predominant importance over kernel weight with regard to grain yield, kernel weight is well documented to be a major yield component determining final yield in Mediterranean environments (Peltonen-Sainio, P., 2007; García Del Moral, L.F., 2003). As shown in Table 3 water deficit during the anthesis to grain filling stage decreased the TKW by about 36% compared to the control and other water deficit conditions. Consequently, the most susceptible growth and developmental stage with regard to TKW is the anthesis to grain filling stage. Some researchers have reported that water limitation during grain filling significantly decreased the TKW although there were no significant effects at the early growth stages (Nazeri, M., 2005; Slafer, G.A. and E.M. Whitechurch, 2001; Martyniak, L., 2002). Regarding to the increase in the TKW at the early water deficit condition (I2) compared to optimum irrigation (I1), it may be a form of compensation for the spike reduction under water deficit condition. The result was in agreement with the findings of Robertson and Guinta (1994) and Ghodsi (2004) on bread wheat.

The effect of different genotypes on the TKW showed that the highest and lowest weight was shown by the G2 and G3 genotypes. In addition to this, there was no significant difference between the G5, G4 and G2 genotypes. As shown earlier the highest grain yield was observed in the Chamran bread wheat (G3) cultivar and it was closely associated with the maximum of the SPKN. The severe reduction in the SPKN in the G2 is compensated with an increase in the KN and also the TKW (Table 4).

The interaction effects of water deficit and genotype on the 1000-kernel weight showed that the G2 and G3 genotypes gave the highest and lowest 1000-kernel weight values under optimum and water deficit irrigation regimes, respectively. However, the kernel weight of all the genotypes studied decreased under water deficit conditions during the anthesis and the grain filing period (Fig.6.14). It seems that the bread and durum wheat genotypes are stable under the optimum and water deficit irrigation regimes in comparison to the other genotypes.

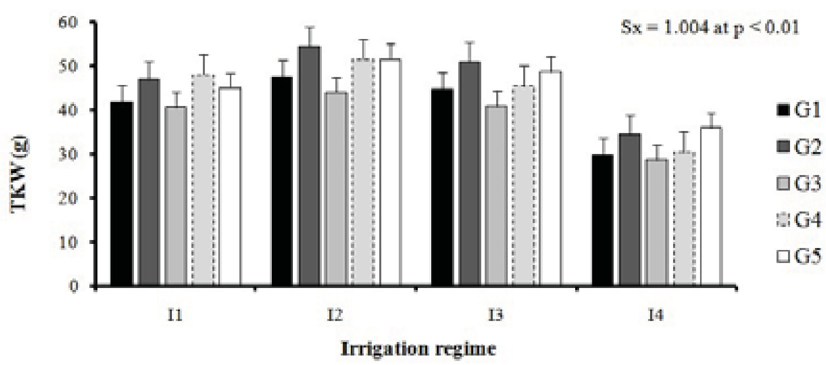

Fig. 5: Interaction effect of irrigation regime × genotype on thousands kernel weight

Final Plant Height (cm) at Maturity:

As shown in Table3, the highest and lowest plant height (PLH) was seen in the I1 and I2 treatments, respectively. It showed that water limitation during the one-leaf to floral initiation stage caused a significant reduction of about 27% in plant height compared to the plants under optimum irrigation. In addition to this, there was no significant difference between the I3 and I4 treatments for PLH. Saleem (2003), Richards *et al.* (2001), and Ghodsi (2004), have reported that one of the major effects of water stress is to decrease plant height, which also caused a reduction in dry matter accumulation and subsequently plant production.

With regard to genotypic effects, although the G3 genotype exhibited the highest PLH of 83.5cm under mean irrigation treatments, it was not significantly different from the G4 and G2 genotypes. On the other hand, genotype G5, which was showed the lowest plant height of 79.5cm, was not significantly different from the with G1 and G2 genotype (Table 4). Plant breeders have tried to select and release intermediate varieties. However these varieties produced less total dry matter although with increasing use of the fertilizers, grain yield has been increased Saleem (Richards, R.A., 2001; Calderini, D.F., 1999).

Number of Days to Maturity (DM) and Maturity Duration (MD):

The adaptation strategies of the plants to drought stress includes drought escape, drought avoidance and drought tolerance. Among these strategies, escaping drought involves the completion of the life cycle before the onset of the drought period. Therefore, early maturity has been known as a major drought escaping mechanism, particularly in terminal drought stresses Saleem (Levitt, J., 1980; Chaves, M.M., 2002). The effect of different irrigation regimes on the DM showed that except for the I4 treatment, which produced the least DM, there were no significant differences amongst all the other irrigation treatments. Maturity duration (MD) was calculated from the anthesis stage to physiological maturity in the studied genotypes under different water deficit conditions. The highest MD belonged to the I2 treatment compared to optimum irrigation and the I3 and I4 treatments. This showed that water limitation significantly decreased the DM and MD only at the terminal growth and developmental stages (anthesis to grain filling) in the durum and bread wheat genotypes. Accordingly, water limitation in the I4 treatment exhibited early maturity possibly to overcome terminal drought stress (Table 3). These results are concurrent with the findings of Simane *et al*. (1993) and Sharif Alhosainy Saleem (1998) who both worked on durum wheat, Krigwi *et al*. (2004) and Ghodsi (2004) on bread wheat and Nazeri (2005) on triticale.

Studies have shown that early maturity trait is a superior characteristic under drought stress conditions. Furthermore, early maturity in the durum wheat genotypes has been known as a drought tolerance parameter in comparison to bread wheat cultivars (Simane, B., 1993; Sharif Alhosainy, M., 1998). The results of the present study on the genotype effects on the DM, showed a significant difference between the G2 and G4 genotypes, both of which exhibited the maximum and minimum value for this trait, respectively**.** However, there was no significant difference amongst the G4, G3 and G5 genotypes. The Chamran bread wheat cultivar (G3) which has been released as an early maturity cultivar and consequently a drought stress tolerant genotype (Ghodsi, M., 2004) exhibited similar days to maturity as the G4, G3 and G5 durum wheat genotypes (Table 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. Therefore, the identification of effective parameters on yield and their relationship under water deficit conditions is a fundamental challenge for cereals improvement programs. The analysis of variance revealed that GY, SPKN, KN, TKW, PLH and DM were highly significant (at $P < 0.01$) under water deficit conditions and genotype effects. In addition to this, the effect of genotype on the HI, BY and GY was significant (at $P < 0.05$). Moreover, the effect of irrigation regimes on HI was significant. In this study, it was observed that water limitation during anthesis to terminal grain filling stage significantly decreased the DM. Furthermore, reduction of the MD at the grain filling phase reduced dry matter accumulation in the durum and bread wheat grains. It can be the reason for the decreasing TKW under the same treatment conditions. Overall, the severe decrease in the SPKN and KN under water limitation during floral initiation to anthesis stage and TKW at the grain filling phase contributed to the reduction in GY and the HI under terminal water deficit conditions.

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