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Tillering Behaviors of Promising Durum Wheat Genotypes and Bread Wheat Cultivar under Different Water Deficit Conditions

Ali Akbar Moayedi[1*] • Amru Nasrulhaq Boyce[1] • Syed Shahar Barakbah[1] • Masoud Ghodsi[2]

[1] Institute of Biological Sciences, University of Malaya, 509603, Kuala Lumpur, Malaysia
[2] Khorasan-e-Razavi Agricultural and Natural Resource Research Center, Mashhad, Iran

Corresponding author: * **moayediali@yahoo.com**

ABSTRACT

Water supply is the most important factor determining final production and crop yield. Hence, limitation of water during growth and development stages can cause different changes in plant components. In this sense, tiller production and survival are recognized as the main factors in final plant production affected by water deficit and other environmental stresses. For this purpose, the present study was carried out to study the tillering behavior of four durum wheat promising lines and a bread wheat cultivar under four irrigation regimes. A combined analysis of variance revealed that the effect of irrigation regimes were highly significant ($P < 0.01$) on total number of tillers (TNT), number of fertile tillers (NFT) and tiller survival percentage (TSP). Besides, genotypic effects were highly significant on TNT and significant ($P < 0.05$) on TFN TSP. The interaction effect of irrigation regimes × genotype was highly significant for TNT and significant for the NFT and TSP. The results showed that the most susceptible stage affected by water deficit was from one-leaf to floral initiation (D2), which recorded a decrease in NFT. On the other hand, Chamran bread wheat cultivar (G3) and RASCON_37/BEJAH_7 durum wheat genotype (G2) exhibited the highest values for TNT and NFT while GARAVITO_3/RASCON_37//GREEN_8 durum wheat (G5) produced the lowest value for all the tilling traits under D2 treatment. There was a strong positive relationship between NFT and TSP. In addition, NFT also indicated a positive association with TNT and finally grain yield.

Keywords: anthesis, fertile tiller, floral initiation, grain yield, tiller survival, water limitation

INTRODUCTION

Water is the most important factor determining crop production and yield. Its unavailability and limitation during growth and development can bring about negative effects on tiller production and plant survival. Water is the largest component in the make-up of plants and serves as the solvent which transports minerals and dissolved carbohydrates throughout the plant. However, the ecological and physiological responses of plants to water limitation vary during its growth and at its different developmental stages and limits crop production and yield in plants. It is particularly important and serious in arid and semi-arid regions. In addition to the complexity of water stress, plant reactions to drought are complex and different mechanisms are adopted by plants to affront water deficit. Thus an investigation of the plant response to drought at its different developmental stages can be useful to overcome the negative effects of water stress in plants (Casati and Walbot 2004; Dai and Li 2004; Guo *et al*. 2004; Jones 2004; Canadian Food Inspection Agency 2006; Passioura 2007).

Among plant characteristics, tillering capability is considered and recognized as one of the main plasticity traits in response to different environmental conditions. It is a remarkably important trait in cereals because the potential number of tillers, fertile tillers and also tillers survival changes with genetic factors and environmental conditions (Mosaad *et al*. 1995; Acevedo *et al*. 2002). A dry winter followed by high temperatures and reduced rain largely affected the number of fertile tillers and 1000-kernel weight on wheat while in a better year as temperature and rain, higher fertile tillers, 1000-kernel weight and grain yield values were observed for all wheat genotypes. (Embrapa Clima Temperado 2007). Besides, findings of Sparkes *et al*. (2006) indicated that light quality affects tiller production in wheat. By increasing the red to far-red ratio, tiller survival percentage increased. With regard to genetic factors, De Vita *et al*. (2007) and also Slafer and Araus (2007) suggested that the genetic gains of durum wheat have mainly been assigned to a balanced improvement in fertility because of higher allocation of assimilates to the growing tillers and spikes. This caused a general increase in total biomass production, with the harvest index remaining practically unchanged.

It is well documented that tillering is one of the first developmental processes during the early growth of a cereal plant and it depends heavily on the accessibility of water and minerals (García del Moral *et al*. 1991; Simane *et al*. 1993; Miralles *et al*. 2000). Some studies on small grain cereals have shown a relationship between crop yield and the tillering process (Larbi and Mekliche 2002; García del Moral *et al*. 2003). With regard to this, Valério *et al*. (2009) and Ozturk *et al*. (2006) reported that low tillering ability wheat genotypes showed a close association between the number of fertile tillers and grain yield. However, they observed an inverse relationship between the number of fertile tillers and 1000-kernel weight.

It has also been shown that the number of tillers increases rapidly after the floral initiation stage under favorable field conditions but decreases before spike emergence and stabilizes until the harvest stage (Dofing and Knight 1992; Royo and Tribó 1997; Garcıá del Moral *et al*. 2003). Furthermore, Mosaad *et al*. (1995) reported that tillering is the main yield component in bread and durum wheat and consequently its grain yield is significantly affected under water limitation conditions. In addition to this, the results of growth-room experiments by Izanloo *et al*. (2009) revealed that grain number spike^{-1} and the percentage of aborted tillers were the major components that affected wheat grain yield under water stress. Many other studies have demons-

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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	GARAVITO_3/RASCON_37//GREEN_8	83	53	62

trated that tiller emergence and survival are influenced by water deficit conditions (Maas and Grieve 1990; Nicolas *et al*. 1993).

Other researchers (Blum *at al*. 1990; Cabeza *et al*. 1993; García del Moral *et al*. 2003) found that with increasing water deficit, tiller production and survival significantly decreased in different growth and development stages. In contrast, Nazeri (2005) in triticale genotypes and Ghodsi (2004) in bread wheat cultivars showed that there was no significant difference in the total and fertile tillers and tiller survival percentage under water deficit conditions. However, they noted the different cultivars significantly affected tiller survival percentage. Besides, Kirby (2002) revealed that 1.5 fertile tillers plant^{-1} is a normal number under suitable conditions. With regard to the reduction of tillers due to water deficit (Miralles *et al*. 2000), a decrease in fertile tillers and tiller survival are of great concern depending on their contribution in plant production.

The principal aim of the present study was to understand the effects of water deficit on tillering traits amongst four promising durum wheat genotypes and also a bread wheat cultivar at different growth and development stages. In addition to this, the contribution of different components in final wheat production and the relationship between tillering characters and grain yield were computed using correlation coefficients.

MATERIALS AND METHODS

The study was conducted during the 2007-2008 growing season in two locations at the Khorasan-e-Razavi Agricultural and Natural Resource Research Center, Iran. The field experiments were laid out in Mashhad (13°, 36′ N and 40°, 59′ E, elevation 985 m) and Neishabour (37°, 36′ N and 48°, 58′ E, elevation 1320 m) research stations with a split plot design based on a complete randomized block design including three replications. Irrigation regimes were considered as the main plots and included four levels: D1, optimum irrigation; D2, water limitation from one-leaf to floral initiation stage; D3, water limitation from floral initiation to anthesis and prevention of precipitation using a mobile rain shelter; D4, water limitation from anthesis to late grain filling stage and prevention of precipitation using a mobile rain shelter. The growth and developmental stages (from emergence to maturity) considered in the main plots were represented as complete growth stage, vegetative, reproductive and grain filling periods due to D1, D2, D3 and D4, respectively. In addition, the total amount and number of irrigation water used for each main plot (7.2 m^2) were assigned 5.5 m^3 in 7 periods (including rainfall), 3.5 m^3 in 4 periods (including rainfall), 4 m^3 in 5 periods (without rainfall during vegetative growth) and 4.1 m^3 in 5 periods (without rainfall during grain filling) for D1, D2, D3 and D4 treatments across the planting to harvesting, respectively. However, prevention of precipitation in the reproductive and grain filling periods was done for calculating the effect of water deficit on crop characteristics , by cutting of irrigation, without the effect of rainfall. Therefore, the amounts of irrigation water used were shown similar values (approximately) during the reproductive and grain filling.

Subplots were assigned to four promising durum lines and one bread wheat cultivar The seeds were obtained from the elite durum yield trials (EDYT, 2006-2007) in the Seed and Plant Improvement Institute (SPII), Iran from among 20 studied genotypes, which were tested also under different osmotic stress conditions using polyethylene glycol (PEG 6000), and four durum wheat genotypes selected based on stress tolerance indices (Moayedi and Barakbah 2007; Boyce *et al*. 2009). Hence, G2 and G4 were assigned in the subplot as severe and moderate drought tolerant genotypes while G1 and G5 were applied as susceptible durum wheat genotypes. **Table 1** presents some characteristics and pedigree of the seeds used in the study.

According to results of the Soil and Water Research Department, Mashhad (Keshavarz *et al*. 2006) the classifications of soil were Fine- Loamy over Sandy- Skeletal, Mixed, Mesic and Fine-Loamy Mixed Thermic at the Mashhad and Neishabour experimental sits. In addition, soil pH and EC (ds m^{-1}) were calculated as approximately 8-8.1 and 1.7-2.2, respectively.

Before sowing, the fields were similarly fertilized with 50, 90 and 50 kg NPK/ha. Additionally, 70 kg N was top-dressed and split into two applications.

To prevent the occurrence of diseases, the experimental seeds were coated with Vitavax fungicide (Carboxin Thiram). It was used at 2 g kg^{-1} seed before planting. In addition, stages, weeds were chemically controlled by 2,4-D (2,4-dichlorophenoxyacetic acid) at the end of the tillering stage by 2 l ha^{-1}. Additionally, all other weeds were removed manually during booting to anthesis. With regard to usable experimental design, each plot consisted of 12 rows 3 m in length and spaced 20 cm apart. Therefore, the subplot size was calculated as 7.2 m^2 (12 × 3 × 0.2) and the seed density was 450 seeds m^{-2} based on 1000-kernel weight.

In order to compute the tillering traits, five plants were randomly chosen from each plot at the emergence of the flag leaf stage. Then in the laboratory, the roots of the selected plants were washed and separated carefully to provide a single plant sample. Then, the average of total number of tillers (TNT) of each single plant was counted. In addition to this, the number of fertile tillers (NFT) was also determined at the maturity stage. From the obtained TNT and NFT values, the tiller survival percentage was calculated as follows:

TSP % = (NFT/TNT) * 100

To calculate grain yield at harvest time, an area of 3.6 m^2 from the middle area of each plot was sampled in three replications.

Correlation analysis among tillering traits and also grain yield were computed using SPSS version 13 software package to determine the relationship between grain yield and tillering traits. In addition to this, the homogeneity between locations was assessed using Bartlett's test to determine if location data could be combined and compared. The final data from two locations were statistically analyzed by MSTAT-C and SPSS software packages. Comparative analyses of the means were performed by Duncan's Multiple Range Test (P < 0.05 and P < 0.01).

RESULTS

Total number of tillers (TNT)

A combined analysis of variance revealed that location, water deficit, genotype effect and also the interaction effect of water deficit × genotype were highly significant at P < 0.01 for the number of total tillers (**Table 2**).

The results of the effect of irrigation regimes on TNT are shown in **Fig. 1**. Significant differences among the various irrigation treatments were observed. Surprisingly, highest TNT was observed in D3, which had water deficit from floral initiation to the anthesis stage, while the lowest TNT value was in the control (D1), which had optimum irrigation. As a result of water limitation TNT value increased gradually from the one-leaf to the anthesis stage but subsequently decreased significantly after anthesis (**Fig. 1**).

Fig. 2 shows the different TNT and NFT values in various durum and bread wheat genotypes. The Chamran bread wheat (G3) cultivar exhibited the maximum TNT and NFT

Table 2 Combined analysis of variance for total number of tillers (TNT), number of fertile tillers (NFT) and tiller survival percentage (TSP) in durum and bread wheat genotypes under different water deficit conditions.

Source of variation	df	Mean square (MS)		TSP
		TNT	NFT	
Location (L)	1	4.957**	0.616**	1372.55**
Replication (R)	4	0.227	0.048	32.54
Water deficit (D)	3	0.547**	2.804^{ns}	4592.16**
L× D	3	0.002^{ns}	0.008^{ns}	92.67^{ns}
Error	12	0.233	0.054	60.54
Genotype (G)	4	1.236**	0.863*	575.22*
L× G	4	0.005^{ns}	0.002^{ns}	76.79^{ns}
D×G	12	1.159**	0.547*	127.38*
L× D ×G	12	0.005^{ns}	0.002^{ns}	44.43^{ns}
Error	64	0.144	0.032	37.37
CV %	-	12.22	13.22	14.33

*Significant difference at $P < 0.05$
**Significant difference at $P < 0.01$; ns: non significant

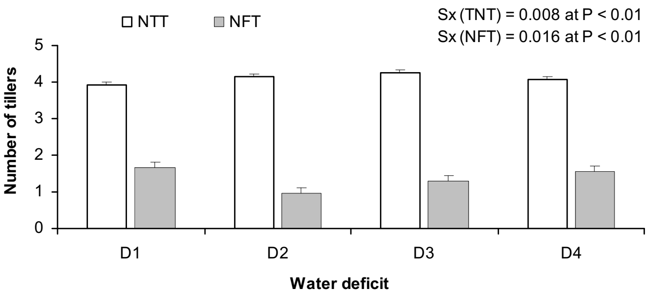

Fig. 1 The effect of different irrigation regimes on number of total and fertile tillers.

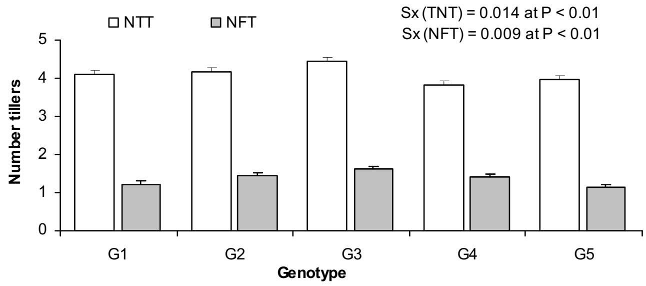

Fig. 2 Number of total and fertile tillers in different genotypes.

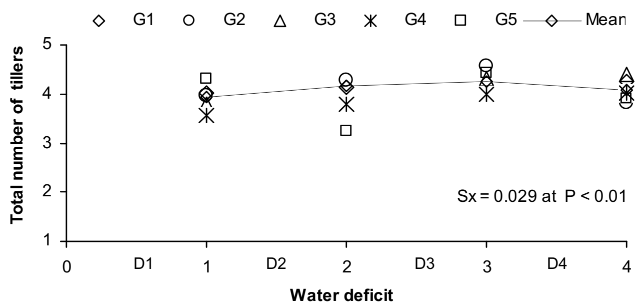

Fig. 3 Interaction effect of irrigation regimes × genotype on total number of tillers.

values, while G4 and G5 durum wheat genotypes produced the lowest values for TNT and NFT, respectively. In addition to this, there was a significant difference for TNT value between Chamran bread wheat cultivar and all the other durum wheat genotypes. However, there was no significant difference between G1 and G2 durum wheat genotypes.

As shown in **Fig. 3**, with regard to the combined interaction effects of irrigation regimes × genotype, the highest difference of TNT values amongst the genotypes was in D2 water deficit treatment. The highest TNT recorded under D2 was observed in G2 genotype, whereas the lowest TNT value was observed in G5. Besides, under D3 water deficit treatment, G2 genotype also produced the highest TNT value.

Number of fertile tillers (NFT)

A combined analysis of variance as shown in **Table 2** indicated that apart from the location effect, which was highly significant at P < 0.01 for the number of fertile tillers, the genotype and interaction effects of water deficit × genotype was significant at P < 0.05.

As shown in **Fig. 1**, the highest NFT was produced under optimum irrigation treatment (D1) whereas the lowest value was obtained under D2. The results indicated that water limitation at the one-leaf to floral initiation stage caused a 42% reduction in TFN compared to optimum irrigation. In addition to this, there was no significant difference between D1 and D4. Therefore, the most susceptible growth and development stage of durum and bread wheat genotypes was the one-leaf to floral initiation stage for NFT under water deficit conditions.

With regard to the effect of genotype on NFT, Chamran bread wheat (G3) gave the highest value while G5 durum wheat exhibited the lowest. The values for G3 and G2 were similar for both TNT and NFT traits (**Fig. 2**).

As shown in **Fig. 4**, the interaction effects of the irrigation regime × genotype for NFT indicated that maximum NFT belonged to D1G2 treatment while the lowest value computed was associated with D2G5. Concerning the importance of drought stress tolerance, the results showed stability in fertile tiller number for G3 and G2 compared to the other studied genotypes under water deficit conditions.

Tiller survival percentage (TSP)

Based on a combined analysis of variance TSP, the location and water deficit effect were highly significant at P < 0.01 for this trait, while the genotype and interaction effect of irrigation regime × genotype were significant at P < 0.05. As shown in **Fig. 5**, the highest TSP (42%) belonged to D1 (optimum water condition) whilst the lowest value (23%) computed was associated with D2. However, there was no significant difference between D2 and D4 for this trait. The effect of genotype and the interaction effect of water deficit × genotype on TSP were similar to those shown in NFT

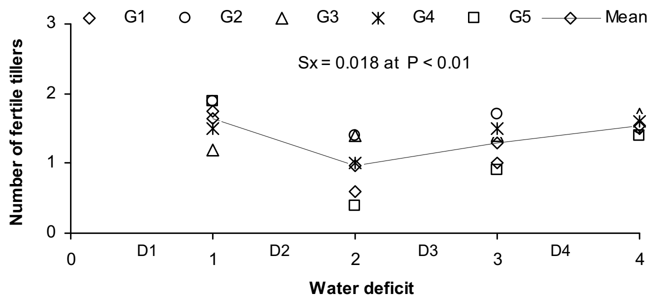

Fig. 4 Interaction effect of irrigation regimes × genotype on number of fertile tiller.

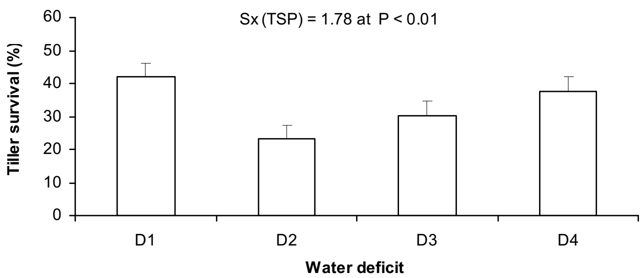

Fig. 5 The effect of different irrigation regimes on tiller survival percentage.

Table 3 Pearson correlation coefficients from the combined analysis of tillering traits and grain yield of durum and bread wheat genotypes under different water deficit conditions.

Traits	TNT	NFT	TSP	GY
Total number of tillers (TNT)	1	0.331	- 0.095	0.105
Number of fertile tillers (NFT)		1	0.836**	0.003
Tiller survival percentage (TSP)			1	-0.060
Grain yield (GY)				1

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

(**Figs. 2, 3**). Overall, G3, G2 and G4 showed a higher TSP then G1 and G5.

Correlation studies between tillering traits and grain yield

Results of simple correlation analyses from the combined data of tillering traits and grain yield are shown in **Table 3**. The NFT showed the highest and lowest correlation coefficients with TSP (r = 0.836**) and grain yield (r = 0.003), respectively. Apart from the negative correlation between TSP and the TNT and grain yield, all the traits exhibited a positive correlation. Grain yield correlated positively with the TNT and NFT but correlated negatively with TSP. Furthermore, TSP was positively and significantly ($P < 0.01$) correlated with the NFT but negatively correlated with the TNT.

DISCUSSION

The effect of water deficit on tillering traits

The results of this study revealed that irrigation regimes at the different growth and development stages of durum and bread wheat had different effects on the tillering traits. In other words, the effect of irrigation regimes was highly significant for all tillering traits (**Table 2**). Limitation of water at the one-leaf to floral initiation (D2) and floral initiation to anthesis stages (D3) increased TNT. Bearing in mind that TNT is the total of fertile and unfertile tillers, it seems that the increase in TNT is due to an increase in unfertile tillers under water limitation treatments. This implies that the increasing TNT compensated the impact of water deficit on reduction of NFT at those stages (**Figs. 1, 4**). The compression of tillering traits under different irrigation regimes showed that the sensitivity of NFT to water deficit conditions were more than TNT. It seems that the most susceptible growth and developmental stage among the studied genotypes to water deficit was at the one-leaf to floral initiation period in NFT.

Our results concurred with the reports of Izanloo *et al.* (2009). They noted that the main yield components, which were associated with yield reduction, were grain number spike^{-1} and number of fertile tillers. Therefore, reduction in grain number and NFT were mainly associated with floret sterility and tiller abortion under water deficit. In addition to wheat, water deficit reduced grain yield in barley (Samarah 2005) by reducing the number tillers, spikes and grains plant^{-1} and individual grain weight. Post-anthesis water deficit was detrimental to grain yield regardless of the stress severity. On the other hand, the change of TNT under different irrigation regimes conditions in the present study agrees with the findings by other researchers (Mosaad *et al.* 1995; Acevedo *et al.* 2002). Additionally, reports by Maas and Grieve (1990) and Nicolas *et al.* (1993) related to tiller emergence of wheat under water deficit condition confirm these results. However, other studies by Cabeza *et al.* (1993) and García del Moral *et al.* (2003) working on bread and durum wheat have shown that with increasing water deficit, tiller production and survival decreased significantly during different growth and developmental stages. On the other hand, our results were incongruent with findings of Nazeri (2005) on triticale and Ghodsi (2004) on bread wheat. They reported no significant differences in TNT under water deficit conditions. Overall, the results revealed that tillering capability is an important plasticity trait in response to different environmental conditions.

The effect of genotype on tillering traits

The variation effects of genotypes on tillering traits have been previously reported by Acevedo *et al.* (2002), Ghodsi (2004), Izanloo *et al.* (2009) and Valério *et al.* (2009) in bread wheat, Nazeri (2005) in triticale, De Vita (2007) and Slafer and Araus (2007) in durum wheat and Samarah, (2005) in barley. They reported that various genotypes showed different values of TNT and NFT under different environmental conditions, similar to our study. It was observed that the genotypic effect on TNT was highly significant while its effects on NFT and tiller survival percentage (TSP) were only significant at $P < 0.05$ (**Table 2**).

The findings indicated that significant differences existed among the various genotypes studied in relation to the irrigation treatments. In general, apart from the Chamran bread wheat cultivar, which produced the highest values of TNT, NFT and TSP amongst all the genotypes, G2 gave the highest values amongst the durum wheat genotypes studied (G1, G4 and G5). With regard to G3, this was recognized as a drought stress tolerant cultivar (Ghodsi 2004), its preference compared to all the other studied genotypes is related to its tillering traits, which are suitable characteristics for drought tolerance under water deficit conditions. Therefore, it can be suggested that the G2 genotype, which exhibited similar results to that of the G3 genotype related to tillering traits may be introduce as a durum wheat drought tolerant genotype. Nazeri (2005) also reported similar results for TSP in triticale and Ghodsi (2004) in bread wheat. In addition, findings of Izanloo *et al.* (2009) showed that there were different behaviors in their studied genotypes due to tillers under water deficit conditions. The genotypes, which produced a high number of tillers, aborted large numbers of tillers under water deficit.

Interaction effects of genotype × irrigation regimes on tillering traits

A combined analysis of variance as shown in **Table 2** revealed that the interaction effect of genotype × irrigation regimes was highly significant ($P < 0.01$) for TNT and significant ($P < 0.05$) for NFT and TSP.

In this study G5 exhibited the lowest value for all tillering traits under D2, while G3 and G2 gave the highest values for TNT and NFT traits, respectively (**Figs. 3, 4**). A comparison of the interaction effects between TNT and NFT (**Figs. 3, 4**) showed different trends for tillering traits under water deficit conditions. Under D2 and D3 treatments, TNT increased. Besides, D2 caused a severe reduction in NFT. However, NFT increased because of water limitation in D3 compared to D2 treatment. Thus, the most susceptible stage to water deficit for NFT was D2. In addition to this, Chamran (G3) displayed the lowest NFT under optimum irrigation compared to durum wheat genotypes. However, G2 produced higher NFT values in both optimum and water deficit conditions. Researchers believe that the ability of determinate tillering under optimum conditions is a very important characteristic in durum and bread wheat (Izanloo *et al.* 2009; Valério *et al.* 2009). Their results showed that by increasing the number of tillers under optimum conditions, mortality of the tillers increased under water stress conditions, which confirmed our results under optimum and water deficit conditions. They also found a close association between NFT and grain yield in low tillering ability of the wheat genotypes under optimum irrigation. This indicated that ability to determine tillering under optimum conditions could be a suitable characteristic for determining a drought-tolerant cultivar.

The relationship between tillering traits and grain yield

With regard to the importance of association between grain yield with tillering behaviors and its dependence on the first developmental processes during early growth and developmental stages (Mosaad *et al*. 1995; Miralles *et al*. 2000; Larbi and Mekliche 2002; García del Moral *et al*. 2003), our results (**Table 3**) also exhibited a positive relationship between NFT with TSP, TNT and grain yield. However, TSP and grain yield indicated a negative association. A positive correlation of grain yield and NFT was confirmed by findings of the following researchers. Their results indicated the reduction of grain yield under water deficit in barley (Samarah 2005) and bread wheat (Izanloo *et al*. 2009) by reducing NFT and grains plant^{-1}. In addition, Valério (2009) report that low tillering ability genotypes showed a closer association of NFT with grain yield. However, the results of Akram *et al*. (2008) revealed a negative correlation between tillers and spike length with grain yield at phenotypic and genotypic levels. Consequently, these findings indicate that an understanding of the plant critical growth stages in relation to tillering under different water deficit conditions is very important to overcome grain yield reduction. Therefore, the results of the present study revealed that the most susceptible stage of the growing fertile tillers to water deficit was from the one-leaf to the floral initiation stage.

CONCLUSIONS

The differential tillering capability in the various genotypes has been recognized as a main plasticity trait in response to different environmental conditions. Accordingly, an investigation of the response of the different critical growth stages in tolerant genotypes to drought stress can help overcome the negative effects of water stress in plants. In this study, it was observed that the tillering traits responses of the promising durum wheat genotypes and bread wheat cultivar to optimum and water limitation conditions vary during the different growth and developmental stages, suggesting that tillering behavior depend on genetic factors and environmental conditions. It can be concluded that the one-leaf to the floral initiation was the most crucial growth stage for NFT in both the durum and bread wheat genotypes under water deficit condition. The results also indicated that G5 durum genotype produced the lowest value for all the tillering traits in D2 treatment while Chamran bead wheat (G3) and G2 durum wheat genotypes exhibited the highest values for TNT and NFT. Interestingly, G2 showed similar tolerance to drought stress as shown by G3, which has been recognized as a drought stress tolerant cultivar, and can thus be classified a durum wheat drought tolerant genotype related to tillering behaviors.

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