Sowing date effects on dry matter remobilization and yield of triticale (*Triticosecale wittmack*) under late season drought stress

Ehsan Bijanzadeh¹, Vahid Barati¹, Yahya Emam², Mohammad Pessarakli³

¹Agroecology Department, College of Agriculture and Natural Resources of Darab, Shiraz University, Iran

²Department of Crop Production and Plant Breeding, College of Agriculture, Shiraz University, Iran

³School of Plant Sciences, the University of Arizona, Tuscan, Arizona 85721, USA

Corresponding Author*: pessarak@email.arizona.edu

ABSTRACT

A 2-year field experiment using a randomized complete block design with the treatments arranged as split-split-plot with three replicates was conducted to investigate the effects of different sowing dates . Different irrigation regimes and different triticale cultivars were tested during 2014 and 2015 growing seasons. Under cutting off irrigation at milk development stage, Sanabad with 46.2% had higher relative water content on December 3 sowing date. Assimilate remobilization in cutting off irrigation at dough development was more than that at milk development and Sanabad had the highest assimilate remobilization on 3 December sowing date in both years. In both years, Sanabad had the highest remobilization efficiency. The highest contribution of pre-anthesis assimilates to grain was obtained on 3 December sowing date in both years in Sanabad. Lower grain yield in Juanillo cultivar under cutting off irrigation, appeared to be due to reduction in remobilization efficiency, especially by

cutting off irrigation at milk development stage in late sowing date. Overall, Sanabad was more tolerate to cutting off irrigation than Juanillo.

Keywords: Assimilate remobilization, cutting off irrigation, remobilization efficiency, relative water content

Introduction

Triticale (*Triticosecale wittmack*) is the first domesticated crop. It was designed to obtain a cereal with combination of a good quality grain yield from wheat parent with tolerance to abiotic and biotic stresses (Villegas et al. 2010). Pfeiffer (2003) suggested that under drought stress conditions and problematic soil regions, triticale showed distinct yield superiority and had adaptive advantages over wheat. Overall, triticale is often reported as a suitable crop for unfavorable conditions, where productivity of common crops is more or less limited (Estrada-Campuzano et al. 2008; Janusaukaite 2013).

In Mediterranean environments, the warm and dry conditions, occurring during the grain-filling stage, reduce the current photosynthesis rate after anthesis, limiting the contribution of the current assimilates to the grain (Alvaro et al. 2008). Palta et al. (1994) declared that dry matter accumulation before anthesis in vegetative parts of the plant, and its remobilization to the grain during the grain filling becomes particularly important, especially under terminal drought stress. In the Fars Province located in southern Iran, with a typically arid or semiarid Mediterranean climate, most precipitation occurs in winter, thus winter cereals experience some water shortage at sensitive periods (booting, flowering, and grain filling) of their life cycle in spring. Drought stress and high temperature usually occur in these areas during the grain-filling stage, severely suffering formation, accumulation, and remobilization of the assimilates during the grain-filling period, and consequently declined the grain yield and yield components (Bijanazadeh and Emam 2012; Bijanazadeh and Naderi 2015).

Current assimilate is a main source of carbon for grain filling, depending on the variable light intercepting green surfaces of the plant after anthesis. This source size is declined after anthesis due to natural senescence and the effect of abiotic stress such as drought. At the same time, the demands of the growing kernel increases, due to increase respiration and maintenance of the current biomass (Blum 1994). The relative contributions of stem reserves to grain have been estimated to be 6–100% and these variations may be attributed to environmental conditions and genetic diversity (Yang and Zhang 2006). It seems that stimulation of dry matter and N for transfer to grain by mild water stress at the later grain-filling stage is mainly related to promote whole-plant senescence (Yang et al. 2000). Gebbing et al. (1999) reported that in cereals, the supply of assimilates to the developing grain originates both from the current assimilates transferred directly to kernels, and from the remobilization of the assimilates stored temporarily in the vegetative plant parts. The reserves deposited in the vegetative plant parts before anthesis may buffer the grain yield when conditions become adverse to photosynthesis and nutrient uptake during grain filling (Tahir and Nakata 2005).

Borras et al. (2004) showed that crops experience periods during the growth cycle when yield is mainly limited by the source strength, the sink capacity, or both. There are many factors that can affect the source-sink relations during the different growth phases, including sowing date, genotype, rainfall, and fertilization (Aynehband et al. 2011; Dardas 2009). Nowadays, there has been an improved understanding of the yield responses to alterations in assimilates availability during different phenological phases, as affected by sowing dates (Takahashi and Nakaseko 1993). Sowing date is one of the most important management factors involved in producing high-yielding small grains (McLeod et al. 1992; Dahlke et al. 1993). Chatha et al. (1999) declared that late sowing dates (i.e., due to unfavorable environmental conditions) reduced both shoot biomass and grain yield, in addition to their N content when compared to the optimum sowing dates. On the other hand, Ehdaie and Waines (2001) reported that early

sowing date showed no advantage over the optimum sowing date. Schwarte et al. (2005) reported that dry matter production decreased as planting was delayed from late September to late October.

Little information is available about the effect of sowing date on accumulation and translocation of assimilates in the triticale stem. The objectives of this research were to study the status of dry matter accumulation during the vegetative period, and the contribution of the pre-anthesis assimilates to the grains of the triticale cultivars grown under different sowing dates and cutting off irrigation.

Materials and methods

To investigate the effects of different sowing dates and irrigation regimes on assimilate remobilization and yield of triticale cultivars, a 2-year field experiment was conducted in Darab area (28°29' N, 54°55' E), Fars province, Iran during 2014 and 2015 growing seasons. The soil type was loam (fine, loamy, carbonatic, hyperthermic, typic Torriorthents) with pH of 7.9 and 0.6% organic matter. The climatic data for the experimental site are given in Table 1. The experimental design was a randomized complete block, and the treatments were arranged as split-split-plot with three replicates. There were three levels of irrigation regimes, as main plots, including full irrigation, and cutting off irrigation at the milk development (ZGS70) and dough development stages (ZGS 80), and two triticale genotypes, including Sanabad and Juanillo were cultivated in sub-plots and three sowing dates, including 3 November, 3 December, and 3 January were assigned into sub-subplots.

Triticale seeds were hand-sown in each sowing date during the 2014 and 2015 growing seasons, in rows 30 cm apart giving 250 plants m⁻² in plots of 2m × 5m. Plots were 1 m apart for minimizing water and N lateral movement. Dikes were established around the plots for surface furrow irrigation. The field was fertilized on the basis of the soil test recommendations

with 100 kg nitrogen ha⁻¹ (as urea). Nitrogen fertilizer was applied to each plot at three splits; i.e., one third applied at tillering stage (ZGS21) (Zadoks et al. 1974), again, one third at the beginning of the stem elongation stage (ZGS31), and the remaining at the ear emergence stage (ZGS57).

For full irrigation treatments, the soil samples were taken at 0.3 m intervals down to 0.9 m using posthole auger from four spots at the center of each plot in three replications, before each irrigation event. The volumetric water content of the soil layers was measured using the gravimetric method and the depth of the irrigation for the full irrigation treatments was calculated using Equation (1) (Edalat et al. 2010):

$$D = \sum_{i=1}^n (\theta_{fci} - \theta_i) \Delta Z_i \quad (1)$$

Where, D is the irrigation water depth (mm), i is equal to one layer, n is the number of the soil layer, $\sum_{i=1}^n$ is summation of the amount of irrigation water depth (mm) in 'n' number of layer, θ_{fci} is volumetric water content at field capacity (cm³ cm⁻³) in the ith soil layer, θ_i is the volumetric water content (cm³ cm⁻³) in the ith soil layer, and ΔZ_i is the soil layer thickness (mm) in the ith soil layer. Water was applied when the mean soil moisture of the full-irrigation plots dropped to less than 50% of the available moisture. The amount applied was calculated in terms of the water needed to refill 0–0.9 m depth to field capacity.

In the full irrigation treatment, irrigation continued up to late season, while in cutting off irrigation at milk development and dough development stages, irrigation was interrupted at ZGS 70 and 80 (Zadoks et al. 1974) up to late season, respectively. The amount of applied water was measured by time–volume technique (Grimes et al. 1987; Edalat et al. 2010; Barati et al. 2015). Total water use (TWU) was calculated by a soil profile water balance using Equation (2) (Ram et al. 2013).

$$TWU = P + I + \Delta W - R - D + CR \quad (2)$$

Where, P is rainfall (mm), I is the amount of water applied by irrigation (mm), ΔW is the change in soil moisture between sowing minus harvesting (mm), R is the surface runoff from irrigation (mm), D is the deep percolation or drainage loss from irrigation (mm), and CR is capillary rise (mm).

Figure 1 shows TWU (mm) for the triticales cultivars in different irrigation regimes and sowing dates during 2014 and 2015 growing seasons. Also, water use efficiency (WUE) was calculated by dividing economic yield by total water used (Thind et al. 2010). To determine the remobilization during grain filling, plants were harvested at anthesis (ZGS 69) and physiological maturity (ZGS90).

Assimilate remobilization, remobilization efficiency, and contribution of the pre-anthesis assimilates to grain were calculated according to Ercolia et al. (2008) (Equations 3, 4, and 5):

$$\text{Assimilate remobilization} = [\text{dry matter at anthesis} - \text{dry matter of vegetative plant parts (leaf + culm + spike) at maturity}] \times 100 \quad (3)$$

$$\text{Remobilization efficiency} = (\text{assimilate remobilization} / \text{dry matter of the whole plant at anthesis}) \times 100 \quad (4)$$

$$\text{Contribution of the pre-anthesis assimilates to grain} = (\text{Dry matter at anthesis} / \text{Grain yield at maturity}) \times 100 \quad (5)$$

Also, relative water content of the flag leaf (RWC) was measured immediately after cutting the flag leaf, which was sealed within the plastic bags and quickly transferred to the laboratory at the soft dough development stage (ZGS 85) in 2014 and 2015. Fresh weight was determined within 1 h after excision. The turgid weight was obtained after soaking the leaves in distilled water for 5–7 h at laboratory temperature (25°C). After soaking, leaves were carefully blotted dry with tissue paper to determine turgid weight. Dry weight was obtained after oven drying

the leaf sample at 72°C. Then, the RWC was calculated according to Beadle et al. (1993) using Equation (6):

$$\text{RWC} = [(\text{Fresh weight} - \text{Turgid weight}) / (\text{Turgid weight} - \text{Dry weight})] \times 100 \quad (6)$$

To calculate the growth degree day (GDD) at phonological stages of triticale cultivars daily GDD (4 °C base temperature) were calculated by using the equation (7) daily (Schwarte et al. 2005):

$$\text{GDD} = [(\text{daily maximum temp.} - \text{daily minimum temp.}) / 2] - \text{base temp} \quad (7)$$

Finally, data were statistically analyzed for variance using the SAS software (SAS Institute, Cary, NC, USA). When, analysis of variance demonstrated a significant treatment effect, a Fisher's Least Significant Difference (LSD) test was employed to compare the means at 5% probability level.

Results and discussion

Total water use (TWU) and growth degree days (GDDs)

Results showed that in all treatments TWU in 2015 was higher than 2014 and it might be due to higher mean temperature and evaporation as well as lower relative humidity (Table 1) throughout the second year in comparison to the first year of the experiment (Figure 1). In both years, at cutting off irrigation at milk development, Sanabad triticale cultivar consumed water less than Juanillo. The sowing date had noticeable effect on TWU, so that late sowing date (3 January) in each irrigation regime, had the lower TWU compared to the other sowing dates. In both triticale cultivars, GDDs from germination to stem elongation did not have a significant effect, while by improving mean temperature from March up to late season (Table 1), GDDs from stem elongation to physiological maturity increased significantly ($p \leq 0.05$) (Table 2). The maximum total GDDs received by plant were obtained on 3 November sowing date, ranged from 2881 to 3236. Likewise, in all sowing dates, full irrigation received total

GDD more than cutting off irrigation regimes. At the physiological maturity, the highest growing season length was observed on 3 November sowing date, ranged from 212 to 241 d, while on 3 January, decreased in range of 170-191 d, significantly ($p \leq 0.05$) (Table 2). Overall, growing season length was more affected by the sowing date and irrigation regime compared to cultivar.

Relative water content (RWC)

In all treatments, RWC of the flag leaf at the soft dough development stage (ZGS85) decreased by progress in drought stress from full irrigation to cutting off at milk development, significantly ($p \leq 0.05$) (Figure 2). Interestingly, in both years and all sowing dates and irrigation regimes, Sanabad triticale cultivars had higher RWC in comparison to Juanillo. Also, under cutting off irrigation at the milk development stage, Sanabad with 46.2% had higher RWC on 3 December sowing date. Generally, 3 December sowing date in all treatments had higher RWC, ranged from 34.8% to 62.5%. Similar to our results, Moustafa et al. (1996) reported that the RWC in drought stressed plants was significantly lower than that of the full irrigation plants. Our findings are in agreement with Khanna-Chopra and Selote (2007) who reported that drought resistant wheat cultivars maintained higher RWC than the sensitive cultivars under severe drought stress conditions. Also, Bijanzadeh and Emam (2012) reported that in all wheat cultivars, increased drought stress was associated with decreased RWC, and decreasing rate could be varied depending on the drought stress level and the cultivar type.

Assimilate remobilization

The values of the dry matter of the whole plant at anthesis and maturity on 3 January sowing date were significantly ($p \leq 0.05$) less than that of the other sowing dates (Table 3). Differences in the dry matter of the vegetative parts at maturity between the cultivars were even less noticeable than those in the grain yield (Tables 3 and 4). Assimilate remobilization in cutting off irrigation at dough development was more than that of the cutting off irrigation at

milk development, and Sanabad with 301.8 and 305.1 g m⁻² had the highest assimilate remobilization on the 3 December sowing date in 2014 and 2015 growing seasons, respectively (Table 3). On the other hand, by increasing drought stress from full irrigation to cutting off irrigation at milk development, assimilate remobilization on 3 January sowing date, from 155.6 and 127.7 g m⁻² decreased sharply to 50.3 and 33.5 g m⁻² in 2014 and 2015, respectively. In three sowing dates, significant difference in remobilization efficiency was observed between the two triticale cultivars and the cutting off irrigation regimes ($p \leq 0.05$) (Table 3). In both years, Sanabad had the highest remobilization efficiency, ranged from 13% to 27.6% under cutting off irrigation at dough development. Increase remobilization efficiency at cutting off irrigation in dough development compared to the cutting off irrigation at milk development might be attributed to early senescence, especially in Sanabad in all of the sowing dates.

Contribution of the pre-anthesis assimilates to grain ranged from 16.7% to 53.3% of grain weight and this difference (36.6%) depended on the irrigation regime, cultivar, sowing date, and whether conditions during the 2014 and 2015 growing seasons (Tables 1 and 3). The highest contribution of the pre-anthesis assimilates to grain was obtained on the 3 December sowing date in Sanabad and sharply decreased by progress in drought stress from cutting off irrigation at dough development to milk development (Table 3). The lower contribution of the pre-anthesis assimilates to grain in Juanillo might be attributed to the lower adaptation of this triticale cultivar to the late season drought stress and weather conditions, including higher mean temperature and evaporation in the study area, especially in the second year of the experiment (Tables 1 and 3).

Sam Dalirie et al. (2010) concluded that reserves accumulated before anthesis play an important role in grain yield; however, the extent of their contribution depends on the prevailing environmental conditions and type of cultivar. Similar to our results, vegetative dry matter losses from anthesis to maturity were reported by the other researchers for barley

(Bonnett and Incoll 1992; Barati and Ghadiri, 2017) and durum wheat (Ercoli et al. 2008), and it may vary greatly with drought stress (Barati et al., 2015). In agreement to our results, Barati and Ghadiri (2017) reported that with increasing water shortage from mild to severe drought stress, the assimilate remobilization to grain declined in barley. On the other hand, Yang and Zhang (2006) declared that the low and moderate water stress did not substantially modify the patterns of dry matter and nitrogen deposition in grain, which is not surprising, since it has been shown that mild soil drying may not seriously disrupt phloem function. Bijanzadeh and Emam (2012) concluded that mild drought stress could enhance the contribution of the pre-anthesis assimilates to grain, ranged from 6.1 to 53.6% and 3.6 to 50.1% in the 2008 and 2009 growing seasons, respectively, and this variation depended on the wheat cultivar, water availability and field conditions. Likewise, Iravani et al. (2008) reported that contribution of the pre-anthesis assimilate before flowering play a main role in grain filling; however, the extent of their contribution depends on the prevailing environmental conditions and the type of cultivars. This is particularly important for triticale grows under Mediterranean conditions, due to the hot and dry weather and low photosynthesis after flowering. Ayneband et al. (2011) reported that with a delay in sowing date, and or increase in N-P-K levels, the amount of the dry matter remobilization decreased, mainly due to a decrease in stem weight, and the sowing dates had greater influence on dry matter accumulation.

Yield and yield components

Variation in 1000-grain weight was observed in all treatments which ranged from 26.1 to 41.2 g. Sowing date had significant effect on 1000-grain weight. The 1000-grain weight sharply decreased on 3 December sowing date (Table 4). On the other hand, in both years and each irrigation regime, Sanabad had higher 1000-grain weight compared to Juanillo ($p \leq 0.05$). By increasing growing season length from 3 December to 3 January, biological yield decreased significantly ($p \leq 0.05$) (Table 4). On December 3 sowing date, Sanabad with 1383 and 1371 g

m⁻² had the highest biological yield under cutting off irrigation at dough development in 2014 and 2015, respectively. Between 3 November and 3 December sowing dates, grain yield was not affected by the cultivars and irrigation regimes, while in both years by decreasing growing season length on 3 January sowing date, grain yield sharply decreased, especially in Juanillo (Table 4). On 3 December sowing date, Sanabad with 581.2 and 572.1 g m⁻² had the highest grain yield under cutting of irrigation at dough development in 2014 and 2015, respectively. In contrast, on 3 January sowing date, Juanillo grain yield decreased sharply under cutting off irrigation at milk development to 218.2 and 200.4 g m⁻² in 2014 and 2015, respectively.

The higher grain yield and dry matter remobilization in Sanabad triticale cultivar, compared to Juanillo, showed the higher tolerance of this cultivar to cutting off irrigation at late season (Tables 3 and 4). The cultivar-dependent dry matter remobilization was demonstrated by other researchers in wheat (Bijanzadeh and Emam 2012) and barley (Bijanzadeh and Naderi 2015; Barati and Ghadiri, 2017) under Mediterranean condition. Bijanzadeh and Emam (2012) reported that delayed whole-plant senescence, caused by heavy use of water, results in plants staying green when the grains should be ripe and, therefore, shows a low harvest index with much non-structural carbohydrate left in the straw. They also reported that water deficit around anthesis may lead to a loss in yield by reducing 1000-grain weight, and from anthesis to maturity, especially if accompanied by high temperature, hastening of whole-plant senescence and reducing biological yield. In our study, Juanillo was more sensitive to cutting off irrigation than Sanabad due to a reduction in assimilate remobilization to grain (Table 3) and 1000-grain weight (Table 4). Similar to our results, a large variability in the contribution of pre-anthesis assimilates to grain has been reported in cereals that most of them can be attributed to differences in sowing date (Ehdaie and Waines 2001; Aynehband et al. 2011), genotypes (Alvaro et al. 2008), and environmental conditions (Barati and Ghadiri, 2017; Bijanzadeh and Naderi, 2015).

In a similar study on sowing date, Schwartz et al. (2005) reported that triticale should be planted in September to maximize spring biological yield, although later sowing dates would provide a higher quality of biological yield if harvest was delayed into late spring and summer. Also, they stated that Trical 815 cultivar produced more biological yield by 1.67 and 0.86 Mg ha⁻¹ than DANKO Presto at 1400 GDDs for the mid-September and early-October plantings, respectively, and there were no differences between the two cultivars for the late-September and mid-October plantings. Rezaii et al. (2011) reported that sowing date had main effect on grain yield, so that the highest grain yield was observed on November 22 sowing date and by delay in sowing date, grain yield decreased 29% on 6 December compared to 22 November sowing date. Overall, in both years, grain yield at late sowing date (3 January) was reduced by 17-25% in Sanabad and 37-48% in Juanillo compared to the optimum sowing date (i.e., 3 December) (Table 4).

Water use efficiency (WUE)

Among the three sowing dates, December 3 had the highest WUE, especially for Sanabad cultivar (Figure 3). In contrast, the lowest water productivities 0.56 and 0.49 kg m⁻³ were obtained in Juanillo under cutting off irrigation at milk development on 3 January sowing date in 2014 and 2015, respectively. The higher WUE in Sanabad compared to Juanillo might be attributed to the effectiveness of small amount of water in alleviating drought stress due to cutting off irrigation treatments during the grain-filling period. The lower total water use (TWU) (Figure 1) and higher WUE (Figure 3) of Sanabad may contribute to water saving, which is urgently needed to develop sustainable agriculture in arid and semi-arid areas, where the rapid depletion of water resources is threatening crop production (Blum 1998). Zhang et al. (1998) reported that although the grain yield in the severe drought treatment was reduced by ~15% compared with well-watered conditions, WUE for total water consumption increased by 24%. Zhang et al. (2006) reported that appropriate degree of regulated deficit irrigation could

result in high WUE in spring wheat in an arid environment and compared to the full irrigation condition, WUE was improved by 33–40% under regulated deficit irrigation. In our study, during both years, cutting of irrigation at milk development decreased WUE by 42-57% in Juanillo, while cutting off irrigation at dough development increased WUE by 5 to 10% in Sanabad compared to full irrigation at late sowing date. It can be concluded that variation in WUE compared to full irrigation depended on sowing date, irrigation regime, and type of cultivar.

Relationships between grain yield and assimilate remobilization

The grain yield was correlated with assimilate remobilization (Figure 4b) in 2014 and 2015 growing seasons by the following polynomial Equations (9) and (10), respectively:

$$Gy_{(2014)} = -0.007(\text{assimilate remobilization})^2 + 4.571 (\text{assimilate remobilization}) \quad (9)$$

$$Gy_{(2015)} = -0.008(\text{assimilate remobilization})^2 + 4.422 (\text{assimilate remobilization}) \quad (10)$$

Where, Gy is grain yield (g m^{-2}). As it was shown in Figure 4a, the assimilate remobilization was correlated to grain yield positively ($R^2=0.79$), and by increasing assimilate remobilization from 33.5 g m^{-2} to 305.1 g m^{-2} , grain yield sharply increased from 220.4 g m^{-2} to 572.1 g m^{-2} . This equation can be used for yield prediction under different sowing dates and irrigation regimes. Similar trend was observed concerning remobilization efficiency (Figure 4b) and during both years, by improving remobilization efficiency from 6.3% to 27.6%, grain yield positively increased from 218.2 g m^{-2} to 572.1 g m^{-2} ($R^2=0.79$ and 0.83 in 2014 and 2015, respectively).

Conclusions

These results indicated that the estimation of the amount of stem reserves accumulated and mobilized were dependent on environmental conditions (i.e., sowing date and genotype). Also, the late season drought stress accompanied by rise in temperature that occurs during the

grain-filling stage of wheat, has a negative impact on dry matter production. Therefore, the contribution of stored carbohydrates may become the predominant source of transported materials. In arid–Mediterranean areas such as southern Iran, applying suitable irrigation regimes, including cutting of irrigation at dough development (ZGS 80) can control soil drying during the grain-filling period, so that using suitable cultivars such as Sanabad triticale cultivars can increase remobilization efficiency, and their grain yield might not be severely reduced.

References

- Alvaro, F., J. Isidro, D. Villegas, L. F. Garcia del Moral, C. Royo. 2008. Breeding effect on grain filling, biomass partitioning, and remobilization in Mediterranean durum wheat. *Agronomy Journal* 100: 361-370.
- Aynehband, A., M. Valipour, and E. Fateh. 2011. Stem reserve accumulation and mobilization in wheat (*Triticum aestivum* L.) as affected by sowing date and N–P–K levels under Mediterranean conditions. *Turkish Journal of Agriculture Forestry* 35: 319-331.
- Barati, V., H. Ghadiri, S. Zand-Parsa, and N. Karimian. 2015. Nitrogen and water use efficiencies and yield response of barley cultivars under different irrigation and nitrogen regimes in a semi-arid Mediterranean climate. *Archives of Agronomy and Soil Science* 61: 15–32.
- Barati, V., and H. Ghadiri. 2017. Assimilate and nitrogen remobilization of six-rowed and two-rowed winter barley under drought stress at different nitrogen fertilization. *Archives of Agronomy and Soil Science* 63: 841–855.
- Beadle C.L., M. M. Ludlow, and J.L. Honeysett. 1993. Water relations. In: *Photosynthesis and Production in a Changing Environment: A Field and Laboratory Manual*. (ed. by D.O. Hall, J.M.O. Scurlock, H.R. Boolhar-Nordenkamp, R.C. Leegood and S.P. Long), Chapman and Hall, London: Chapman and Hall. pp. 113–128.

- Bijanzadeh E, Emam Y. 2012. Evaluation of assimilate remobilization and yield of wheat cultivars under different irrigation regimes in an arid climate. *Archives of Agronomy and Soil Science* 58: 1243–1259.
- Bijanzadeh, E., and R. Naderi. 2015. Remobilization efficiency and photosynthetic characteristics of five barley (*Hordeum vulgare* L.) cultivars under terminal drought stress. *Archives of Agronomy and Soil Science* 61: 1199–1210.
- Blum, A.1998. Improving wheat grain filling under stress by stem reserve mobilization. *Euphytica* 100: 77-83.
- Borras L, G. A., Slafer and M. E. Otegui. 2004. Seed dry weight response to source-sink manipulations in wheat, maize and soybean: a quantitative reappraisal. *Field Crops Research* 86: 131-146.
- Chatha, E., A. Ghaffar, and M. A. Randhawa. 1999. Dry matter partitioning into root and shoot of wheat genotypes sown at different depths and dates under rainfed conditions. *International Journal of Agriculture and Biology* 1: 250-253.
- Dahlke, B.J., E.S. Oplinger, J. M. Gaska, and M. J. Martinka. 1993. Influence of sowing date and seeding rate on winter wheat grain yield and yield components. *Journal of Production Agriculture* 6: 408–414.
- Dordas, C. 2009. Dry matter, nitrogen and phosphorus accumulation, partitioning and remobilization as affected by N and P fertilization and source–sink relations. *European Journal of Agronomy* 30: 129-139.
- Edalat, M., H. Ghadiri, and S. Zand-Parsa. 2010. Corn crop water stress index under different redroot pigweed (*Amaranthus retroflexus* L.) densities and irrigation regimes. *Archives of Agronomy and Soil Science* 56: 285–293.
- Ehdaie, B., and J. G. Waines. 2001. Sowing date and nitrogen rate effects on dry matter and nitrogen partitioning in bread and durum wheat. *Field Crops Research* 73: 47-61.

- Ercoli, L., L. Lulli, M. Mariotti, A. Masoni, and I. Arduini. 2008. Post-anthesis dry matter and nitrogen dynamics in durum wheat as affected by nitrogen supply and soil water availability. *European Journal of Agronomy* 28: 138–147.
- Estrada-Campuzano, G., D. J. Miralles, G. A. Slafer. 2008. Genotypic variability and response to water stress of preand post-anthesis phases in triticale. *European Journal of Agronomy* 28: 171–177.
- Gebbing T, H, Schnyder, and W. Kuhbauch. 1999. The utilization of pre-anthesis reserves in grain filling of wheat. *Plant Cell Environment* 22: 851-858.
- Grimes D.W., H. Yamada, and S. W. Hughes. 1987. Climate-normalized cotton leaf water potentials for irrigation scheduling. *Agricultural Water Management*. 12: 293–304.
- Janusauskaite, D. 2013. Spring triticale yield formation and nitrogen use efficiency as affected by nitrogen rate and its splitting. *Zemdirbyste-Agriculture* 100: 383–392.
- Iravani M., M. Solouki. A. Rezaie, B. Siasar, and S. A. Kouhkan. 2008. Investigating the diversity and relationship between agronomical traits and seed yield in barley advanced lines using factor analysis. *Journal of Agricultural Science and Natural Resources* 45: 137–145.
- Khanna-Chopra, R., and D. S. Selote, 2007. Acclimation to drought stress generates oxidative stress tolerance in drought-resistant than susceptible wheat cultivar under field conditions. *Environmental and Experimental Botany* 60: 276–283.
- Moustafa M. A., L. Boersma, and W. E. Kronstad. 1996. Response of four spring wheat cultivars to drought stress. *Crop Science* 36: 982–986.
- Palta, J. A., T. Kobata, I. R. Fillery, and N. C. Turner. 1994. Remobilization of carbon and nitrogen in wheat as influenced by post anthesis water deficits. *Crop Science* 34: 118-124.
- Pfeiffer, W. H. 2003. Triticale improvement strategies at CIMMYT: Exploiting adaptive patterns and end-use orientation. *Triticale Top* 21: 18-27.

- Ram H, V. Dadhwal, K. K. Vashist, and H. Kaur. 2013. Grain yield and water use efficiency of wheat (*Triticum aestivum* L.) in relation to irrigation levels and rice straw mulching in North West India. *Agricultural Water Management* 128: 92–101.
- Schwarte A. J., L. R. Gibson, D. L. Karlen, M. Liebman, J. L. Jannink. 2005. Sowing date effects on winter triticale dry matter and nitrogen accumulation. *Agronomy Journal* 97: 1333–1341.
- Tahir, I. S. A. and N. Nakata. 2005. Remobilization of nitrogen and carbohydrate from stems of bread wheat in response to heat stress during grain filling. *Journal of Agronomy and Crop Science* 191: 106-115.
- Takahashi, T, and Nakaseko K. 1993. The influence of sowing time on dry matter partitioning in spring wheat. *Japanese Journal of Crop Science* 62: 88-94.
- Thind, H. S., G. S. Buttar, and M. S. Aujla. 2010. Yield and water use efficiency of wheat and cotton under alternate furrow and check-basin irrigation with canal and tube well water in Punjab. *Indian Irrigation Science* 8: 489–496.
- Villegas D., J. Casadesus, S. Atienza, V. Martos, F. Maalouf, F. Karam, I. Aranjuelo, S. Nogues. 2010. Tritordeum, wheat and triticale yield components under multi-local Mediterranean drought conditions. *Field Crops Research* 116: 68–74.
- Yang, J., J. Zhang, Z. Huang, Q. Zhu, and L. Wang. 2000. Remobilization of carbon reserves is improved by controlled soil drying during grain filling of wheat. *Crop Science* 40: 1645–1655.
- Yang, J., and J. Zhang. 2006. Grain filling of cereals under soil drying. *New Phytology* 169: 223–236.
- Zadoks J.C., T. T. Chang, and C. F. Konzak. 1974. A decimal code for the growth stages of cereals. *Weed Research* 14: 11–16.

Figure 1. Total water applied (mm) in each sowing date, irrigation regime and triticale cultivar in 2014 and 2015 growing seasons. Vertical bars represent $\pm$ SE. LSD (0.05) = 18.2

Figure 2. Interaction effect of sowing date, irrigation regime and triticale cultivar on relative water content (RWC) of flag leaf at soft dough development stage (ZGS85) in 2014 and 2015 growing seasons. Vertical bars represent $\pm$ SE. LSD (0.05) = 2.1

Figure 3. Interaction effect of sowing date, irrigation regime and cultivar on water use efficiency (WUE) of triticale in 2014 and 2015 growing seasons. Vertical bars represent $\pm$ SE. LSD (0.05) = 0.45

Figure 4. Relationships between assimilate remobilization (a) and remobilization efficiency (b) with triticale grain yield in 2014 and 2015 growing seasons.

Table 1. Climatic data for the experimental site during the 2014 and 2015 growing seasons.

Month	Temperature (°C)						Precipitation (mm)		Pan evaporation (mm)		Relative humidity (%)	
	2014			2015			2014	2015	2014	2015	2014	2015
	Max	Min	Mean	Max	Min	Mean						
November	20.1	10.6	15.3	25.1	8.6	16.85	34.1	0.5	221.6	233.1	56.2	44.3
December	20.9	6.1	13.5	20.3	5.6	12.95	2.4	34.7	176.2	201.5	57.3	44.1
January	14.8	2.1	8.45	19.1	3.9	11.5	67.4	39.5	150.2	166.7	59.2	49.2
February	17	4.4	10.7	20.9	5.7	13.3	28.7	0.2	175.3	188.2	60.1	52.3
March	19.3	6.2	12.75	20.3	6.8	13.55	45.4	30.9	202.4	218.9	62.8	55.6
April	26.5	11.9	19.2	27.3	13.2	20.25	18.7	22.3	271.3	297.4	57.2	50.1
May	31.3	17.2	24.2	34.7	17.6	26.65	0.0	5.8	303.9	313.4	53.1	44.2
Jun	39.8	21.4	30.6	40.3	23.6	31.9	0.0	0.0	310.4	331.6	50.4	38.2
July	40.1	22.3	31.2	42.7	25.4	34.0	0.0	0.0	351.2	379.5	36.2	30.5
August	38.2	17.3	27.7	39.8	21.8	30.8	0.0	0.0	299.5	333.2	36.9	29.8
September	29.6	16.1	22.8	31.3	19.2	25.2	0.0	0.0	265.2	306.9	41.2	34.7
October	23.8	15.1	19.45	27.9	16.8	22.3	0.3	0.0	245.1	277.8	50.4	42.9
Total							197.0	163.9	2972.3	3248.2		

Table 2. Growth degree days (GDDs) in phenological stages of triticale cultivars at three sowing dates. (Data represents mean of two years).

Phenological stages	Sowing date																	
	3November						3December						3January					
	Irrigation regime						Irrigation regime						Irrigation regime					
	Full irrigation		cutting off irrigation at milk development		cutting off irrigation at dough development		Full irrigation		cutting off irrigation at milk development		cutting off irrigation at dough development		Full irrigation		cutting off irrigation at milk development		cutting off irrigation at dough development	
	Cultivar		Cultivar		Cultivar		Cultivar		Cultivar		Cultivar		Cultivar		Cultivar		Cultivar	
	Sanabad	Juanillo	Sanabad	Juanillo	Sanabad	Juanillo	Sanabad	Juanillo	Sanabad	Juanillo	Sanabad	Juanillo	Sanabad	Juanillo	Sanabad	Juanillo	Sanabad	Juanillo
Germination-emergence	211a	213a	210a	210a	210a	213a	201a	200a	205a	203a	201a	202a	171a	169a	172a	172a	168a	167a
Emergence-tillering	401a	400a	403a	402a	400a	399a	417a	415a	410a	412a	414a	416a	278a	273a	277a	275a	271a	269a
Tillering-stem elongation	269a	270a	268a	266a	260a	266a	165a	164a	165a	166a	167a	169a	204a	207a	203a	202a	205a	208a
Stem elongation-ear emergence	771a	768a	769a	773a	775a	769a	507b	504b	506b	510b	504b	505b	409c	403c	399c	401c	407c	410c
Ear emergence-physiological maturity	1573a	1585a	1231c	1243c	1281c	1288c	1397b	1401b	1096d	1103d	1178d	1181d	1291c	1297c	1072d	1075d	1140d	1047d
Total GDDs	3225a	3236a	2881b	2894b	2926b	2935b	2687c	2684c	2382d	2394d	2464d	2473d	2353de	2349de	2123f	2125f	2183ef	2101f
Growing season length (day)	241a	244a	212b	214b	218b	219b	211b	213b	188cde	192cd	202bc	205bc	191c	190c	171e	170e	175de	174e

In each row, means followed by similar letter are not significantly different at the 5% probability level using Fisher's Least Significant Difference (LSD) test.

Table 3. Interaction effect of sowing date, irrigation regime and cultivar on assimilate remobilization, remobilization efficiency and contribution of pre-anthesis assimilates to grain of triticale in 2014 and 2015 growing seasons.

Sowing date	Irrigation regime	Triticale cultivar	Dry matter of whole plant at anthesis (g m ⁻²)		Dry matter of vegetative parts at maturity (g m ⁻²)		Assimilate remobilization (g m ⁻²)		Remobilization efficiency (%)		Contribution of pre-anthesis assimilates to grain (%)	
			2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
3November	Full irrigation	Sanabad	1051.6c	1034.6c	873.2abc	864.9defg	178.4ef	169.7fgh	17.0defg	16.4def	29.6fg	28.4ij
		Juanillo	1036.5cd	1011.4cd	868.9abc	859.2defg	167.6fgh	152.2hij	16.2efg	15.0fg	28.8g	26.7j
	cutting off irrigation at milk development	Sanabad	1013.5cd	1024.6c	847.4bc	881.6cde	166.1fgh	143.1ijk	16.4efg	14.0gh	34.2de	30.0ghi
		Juanillo	1012.4cd	1010.6cd	900.3ab	921.2ab	112.1l	89.6m	11.1h	8.9j	23.1j	19.1lm
	cutting off irrigation at dough development	Sanabad	1063.4c	1035.6c	870.4abc	840.3fgh	193.5d	195.6de	18.1cde	18.9bc	36.2cd	37.3c
		Juanillo	1015.3c	1009.1cd	891.9ab	923.4a	123.4jkl	86.1m	12.2h	8.5j	24.2ij	17.7m
3December	Full irrigation	Sanabad	1163.4a	1153.1a	930.5a	915.5abc	232.9b	237.6b	20.0bc	20.6b	34.5de	35.6de
		Juanillo	1023.5cd	1019.3c	864.3abc	881.1cde	159.5gh	138.2j	15.6f	13.6hi	25.7hij	23.0k
	cutting off irrigation at milk development	Sanabad	1101.3b	1103.1b	887.1ab	891.5bcd	214.2c	212.1cd	19.4bcd	19.2bc	43.0b	43.3b
		Juanillo	1020.3cd	1011.4c	865.1abc	850.8efgh	155.3hi	160.6ghi	15.2f	15.9efg	38.2c	38.1c
	cutting off irrigation at dough development	Sanabad	1103.8b	1104.6b	802.2cd	799.5ij	301.8a	305.1a	27.3a	27.6a	51.9a	53.3a
		Juanillo	1021.6cd	1023.5c	806.9cd	829.3fghi	214.7c	194.2de	21.0b	19.0bc	37.5c	34.9e
3January	Full irrigation	Sanabad	998.3d	997.2cd	803.3c	815.3hi	195.1d	181.9ef	19.5bcd	18.2cd	38.8c	36.5cde
		Juanillo	804.3e	806.8e	648.7e	679.1l	155.6hi	127.7kl	19.3bcd	15.8efg	39.0c	31.8fg
	cutting off irrigation at milk development	Sanabad	996.5d	998.5cd	880.1ab	881.4cde	116.4k	117.1l	11.7h	11.7i	28.2gh	29.2hi
		Juanillo	800.3e	805.6e	750.3d	772.1jk	50.3n	33.5n	6.3i	4.2l	23.1j	16.7n
	cutting off irrigation at dough development	Sanabad	986.5d	977.3d	840.1bc	850.3efgh	146.4i	127.2kl	14.8g	13.0hij	32.8e	29.0hi
		Juanillo	796.1e	809.2e	701.5de	738.3k	94.6m	70.9m	11.9h	8.8k	29.4fg	22.3k

In each column, means followed by similar letter are not significantly different at the 5% probability level using Fisher's Least Significant Difference (LSD) test.

Table 4. Interaction effect of sowing date, irrigation regime and cultivar on 1000-grain weight, biological yield, and grain yield of triticale in 2014 and 2015 growing seasons.

Sowing date	Irrigation regime	Triticale cultivar	1000-grain weight (g)		Biological yield (g m ⁻²)		Grain yield (g m ⁻²)	
			2014	2015	2014	2015	2014	2015
3November	Full irrigation	Sanabad	40.4abc	40.1ab	1476.3b	1403.1cde	603.1ab	598.2abc
		Juanillo	38.7cdef	38.2bcde	1450.2bc	1428.4bcde	581.3bcd	569.2cdef
	cutting off irrigation at milk development	Sanabad	36.1hi	35.8fg	1253.4gh	1271.5gh	500.1cd	491.3ghi
		Juanillo	34.2i	33.7g	1249.5gh	1215.6hi	486.2def	470.2ij
	cutting off irrigation at dough development	Sanabad	38.3def	37.6cdef	1342.1ef	1311.1fg	533.1bcd	524.1fghi
		Juanillo	36.7gh	36.5ef	1275.4g	1281.7gh	510.9cd	485.2hi
3December	Full irrigation	Sanabad	41.2a	41.1a	1604.7a	1583.6a	674.2a	668.1a
		Juanillo	39.3bcde	39.4abc	1485.3b	1481.8b	621.3ab	600.7abc
	cutting off irrigation at milk development	Sanabad	38.4defg	38.1bcde	1185.2h	1181.2i	498.1cde	490.2ghi
		Juanillo	38.0efg	37.9cde	1022.4k	1009.1k	406.1fghi	400.3jk
	cutting off irrigation at dough development	Sanabad	39.7abcd	39.2abc	1383.2cde	1371.6ef	581.2bc	572.1bcde
		Juanillo	37.3fgh	37.1def	1380.1de	1385.4de	573.2bc	556.1defg
3January	Full irrigation	Sanabad	31.4j	31.0h	1306.4fg	1313.5fg	503.1cd	498.2fghi
		Juanillo	27.1k	27.2ij	1047.3jkl	1081.2j	398.6ghi	402.1jk
	cutting off irrigation at milk development	Sanabad	26.2k	25.9j	1083.6ijk	1094.7j	413.1fghi	401.7jk
		Juanillo	22.6l	22.8k	567.7n	586.3m	218.2j	200.4m
	cutting off irrigation at dough development	Sanabad	26.5k	26.7ij	994.6lm	1001.9k	371.2hi	364.3kl
		Juanillo	26.1k	26.3ij	885.1m	876.2l	338.1i	317.9l

In each column, means followed by similar letter are not significantly different at the 5% probability level using Fisher's Least Significant Difference (LSD) test.