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Assessment of remobilization variation of bread wheat cultivars under different irrigation and nitrogen fertilizer treatments

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Abstract
In order to investigate the effect of water treatment and nitrogen fertilizer application on remobilization and grain yield of bread wheat cultivars, an experiment was carried out as split-split plot design based on randomized complete blocks with three replications. Three levels of irrigation (full irrigation, withholding irrigation at heading, withholding irrigation at anthesis) were assigned to main plots, different times of nitrogen fertilizer application (application of 120 kg/ha nitrogen in four different times: 20 kg at sowing + 100 kg/ha at tillering, 20 kg at sowing + 100 kg/ha at bolting, 20 kg at sowing + 50 kg at tillering + 50 kg at bolting, 20 kg at sowing + 50 kg at tillering + 50 kg at heading) were randomized in sub-plots and five bread wheat cultivars (Zarrin, Pishgam, Urum, Zare, Mihan) were assigned to sub-sub-plots. Withholding irrigation at different developmental stages of wheat increased remobilization percentage of all cultivars. However, application of nitrogen at the heading stage reduced remobilization. The highest and lowest remobilization were recorded for Urum and Zarrin with 62.13% and 20.33%, respectively. Grain yield was significantly reduced with the reduction of water availability. Mean grain yield of all cultivars was 7.500 ton/ha under full irrigation, which reduced to 6.500 ton/ha when irrigation was withheld. Nitrogen fertilizer application improved the grain yield of wheat cultivars. The highest grain yield was obtained for Mihan by 9.39 ton/ha under full irrigation and nitrogen application at sowing + tillering + heading. The higher grain yield of tolerant cultivars under water deficit treatments was attributed to remobilization of unstructured carbohydrates from shoot to grain. It seems that selection of cultivars with higher translocation of dry matter and contribution of pre-anthesis assimilates in grain filling under water stress, can be a suitable strategy to produce high yielding cultivars under water deficit stress condition.

Keywords: Fertilizer; Grain yield; Remobilization; Water treatment; Wheat

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Introduction

Water deficit is the most important limiting factor for crop production (Boyer 1982). A common effect of water deficit stress on crop plants is the reduction of dry biomass production. Plant productivity under water deficit stress is highly related to the processes of dry matter partitioning and temporal root distribution (Kage *et al*. 2004). The sensitivity of crop plants such as wheat (*Triticum aestivum* L.) to soil drought is particularly critical during the grain-filling period because the reproductive phase is extremely sensitive to plant water status (Saini and Westgate 1999).

Carbon requirements for grain growth in wheat are mainly provided from current assimilation by photosynthesis and remobilization of reserves from the stems (Yang *et al*. 2000). One of the best approaches to achieve an acceptable wheat grain yield under drought conditions is to use the potential of carbohydrate remobilization to the growing grains. When the photosynthesis decreases after anthesis, assimilates produced prior the flowering, become more important. Carbohydrates are stored in the wheat stem when photosynthetic production is greater than the needs of the plant (Schnyder 1993). Consequently, remobilized carbohydrate can make a significant contribution to final grain yield and grain weight. Under relatively non-stressed conditions water soluble carbohydrates can contribute 8–27% of final grain yield (Gebbing *et al*. 1999), but under conditions where photosynthesis is reduced (e.g. disease, high temperature and terminal drought) this may increase to 50% or more (Pietragalla and Pask 2012).

Due to extensive changes in environmental conditions and use of different wheat cultivars, the amount of stem reserves that contribute to formation of grain yield, differs in different studies (Ehdaie *et al*. 2006). Plaut *et al*. (2004) reported that under suitable conditions, acceptable amount of carbohydrates accumulate in the stem before anthesis. Some drought tolerant cultivars which have the high potential for storage of photosynthetic assimilates in stem, also have high efficiency in translocation of these assimilate to the growing grains in stress condition (Gavuzzi *et al*. 1997). Stress condition that caused by water deficit, lead to early maturing of plant. In such circumstances stem carbohydrate remobilization significantly decreases (Yang *et al*. 2001). With respect to the role of carbohydrate remobilization in grain yield stability under water deficit, these traits were used for the selection of resistant cultivars in conditions with terminal water deficit. This study was carried out to determine the amount of remobilization and translocation of stem reserves in some cultivars of bread wheat under terminal drought stress.

Materials and Methods

The field experiment was conducted at the Miyandoab Agricultural and Natural Resources Research Station (Latitude 36˚58' N, Longitude 46˚6' E, Altitude 1314 m) in 2013-2014 to investigate the effects of water deficit stress and nitrogen fertilizer application on grain yield and remobilization of bread wheat cultivars. This experiment was arranged as a split-split plot based on randomized complete block design with three replications. Different levels of limited irrigation (I1= full irrigation, I2= withholding irrigation at heading (Zadox 59), I3= withholding irrigation at anthesis (Zadox 69)) were assigned to main plots and timing and methods of nitrogen fertilizer application (including 120 kg ha^{-1} nitrogen at four levels: F1= 20 kg at sowing + 100 kg at tillering, F2= 20 kg at sowing + 100 kg at booting, F3= 20 kg at sowing + 50 kg at tillering + 50 kg at booting, F4= 20 kg at sowing + 50 kg at tillering + 50 kg at heading) were randomized in subplots and five wheat bread cultivars (Zarrin, Pishgam, Urum, Zare, Mihan) were assigned to sub-sub plots. Soil texture at the 30 cm depth was clay loam with pH= 7.5-8 and EC = 2 ds/m. Seeding rates for all cultivars were 400 seeds ds/m and each cultivar was planted in 6 rows of 20 cm apart and 5 m long. Seedbed preparation and weed control for all treatments were similar.

In order to determine the internodes weight in each plot, 20 stems together with leaves and spikes were harvested randomly from the two middle rows of each plot during anthesis and physiological maturity stages. Main tillers were immediately dried in a forced-air drier at 70 ºC for 48 h. Then, total dry weight, spike dry weight, peduncle and other internodes at both times, and grain weight (at physiological maturity) were measured. Dry matter translocated (DMT) and remobilization percentage (R%) were estimated as follows (Papakosta and Gagianas 1991):

$$DMT = DMA - (DMM - GW)$$
$$R\% = (DMT/GW)*100$$

where DMT is the amount of translocated dry matter, DMA is dry matter at anthesis, DMM is dry matter at physiological maturity and GW is grain weight. Remobilization efficiency (RE) was estimated according to the following equation (Donaldson 1996):

$$RE\ \% = DMT/DMA*100$$

Grain yield for each cultivar was measured by harvesting 6 m^2 of each plot. Analysis of variance of data and comparison of means by LSD method were done, using MSTATC and SPSS statistical programs.

Grain yield

Grain yield was significantly affected by irrigation, nitrogen and cultivar. The irrigation × cultivar, nitrogen × cultivar and irrigation × nitrogen × cultivar interactions were significant for grain yield (table not shown). In general, grain yield of wheat cultivars decreased with declining water availability (Figure 1). The response of wheat cultivars to nitrogen application was different under various watering treatments. Grain yield improvement as a result of nitrogen application at different stages (F_2, F_3, F_4) was observed for all cultivars especially under irrigation withholding treatments. The highest grain yield was recorded for Mihan (9.3 t ha^{-1}) under I1 and F4. Under I1 the lowest grain yield was obtained for Zarrin at F_3 and F_4 levels of nitrogen application (Figure 1).

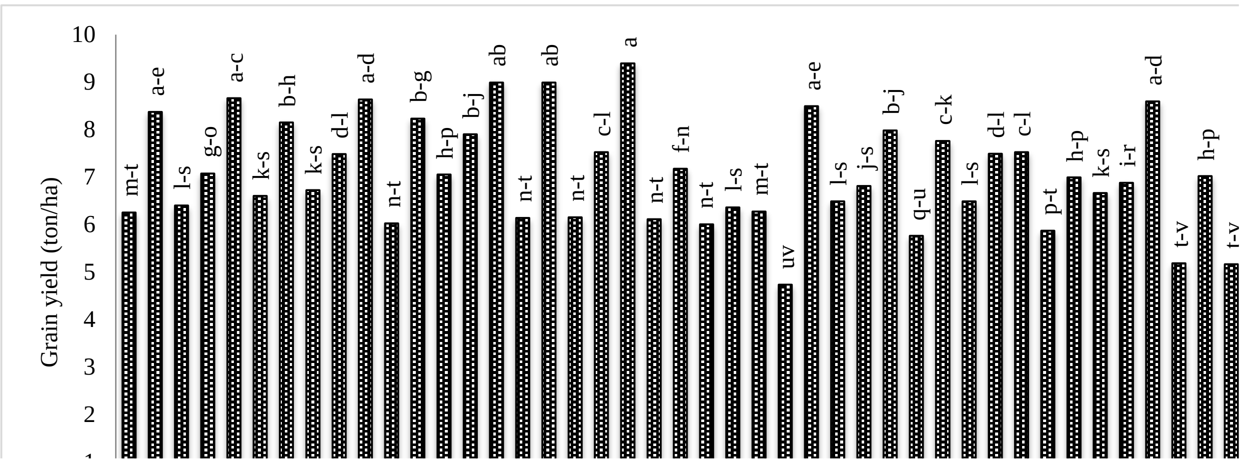

Figure 1. Mean grain yield of bread wheat cultivars affected by irrigation treatments and timing of nitrogen application; Different letters indicate significant difference at $p \leq 0.05$; I_1, I_2 and I_3 represent full irrigation, withholding irrigation at anthesis and withholding irrigation at heading, respectively. F_1, F_2, F_3 and F_4 indicate nitrogen fertilizer application of 120 kg/ha at four timings: 20 kg at sowing + 100 kg/ha at tillering, 20 kg at sowing + 100 kg/ha at bolting, 20 kg at sowing + 50 kg at tillering + 50 kg at bolting and 20 kg at sowing + 50 kg at tillering + 50 kg at heading, respectively; G_1, G_2, G_3, G_4 and G5 represent wheat cultivars of Zarrin, Pishgam, Urum, Zare and Mihan, respectively.

Results

Spike, peduncle and lower internodes weight

The results showed that dry weight of spike, peduncle and lower internodes were significantly affected by irrigation treatments. There were significant differences among cultivars in terms of dry weight of spike and lower internodes. Interaction of irrigation × cultivar was significant for dry weight of spike and peduncle. Interaction of nitrogen application × cultivar was significant for lower internodes' dry weight. Interaction of irrigation × nitrogen application × cultivar was significant for peduncle weight (table not shown).

Spike weight of all cultivars decreased by withholding water at heading stage. Zarrin showed the highest dry weight of spike under all irrigation treatments as compared with other wheat cultivars. The lowest dry weight of spike weight was recorded for Urum under all irrigation conditions (Figure 2). Withholding irrigation at anthesis had no significant effect on peduncle weight. However, withholding irrigation after heading stage considerably increased the peduncle weight of all cultivars. Peduncle's dry weight varied from 250 mg under I1 for Urum to 527 mg under I2 for Zarrin and Mihan cultivars (Figure 3). Dry weight of the lower internodes ranged from 930 mg for Pishgam to 1220 mg for Mihan cultivars (Table 1). Significant differences were observed among cultivars for their response to different nitrogen treatments in terms of lower internodes' weight. The highest dry weight of lower internodes was achieved for Mihan under F_1 and F_2 nitrogen application treatments (Figure 4).

Table 1. Mean internodes, dry matter and grain weight of wheat affected by irrigation treatments and cultivars

Treatment	Lower internodes' weight (mg)	Dry matter (mg/plant)	Grain weight (mg)
Irrigation			
I_1	1210a	4550a	2570a
I_2	1100a	4200a	2570a
I_3	820b	3610b	2200b
Cultivar			
G_1	1050b	4150b	2410bc
G_2	930c	4590a	2840a
G_3	950c	3880c	2350c
G_4	1050b	3650c	2040d
G_5	1220a	4330b	2620b

Different letters indicate significant difference at p ≤0.05; I1: full irrigation, I2: withholding irrigation at anthesis and I3: withholding irrigation at heading. G1, G2, G3, G4 and G5 were wheat cultivars: Zarrin, Pishgam, Urum, Zare and Mihan, respectively.

Photo-assimilate accumulation and remobilization

DMA, DMM, GW, DMT, R% and RE% were significantly affected by irrigation treatments (table not shown). DMA of all cultivars significantly declined under I2. The highest and lowest reduction in DMA were recorded for Pishgam and Zare, respectively (Figure 5).

DMM of plants under I_3 was significantly lower than other irrigation treatments. Pishgam and Zare cultivars had the highest (4590 mg) and the lowest (3650 mg) dry matter, respectively

(Table 1). GW reduced under I3 treatment. Pishgam cultivar had the highest GW (2840 mg) among cultivars (Table 1).

There was significant difference among cultivars for DMT in response to different irrigation and nitrogen application treatments. Maximum DMTs were recorded for Zare (766 mg) at F_4, Zarrin (970 mg) at F_1 and Zarrin (784 mg) at F_2 nitrogen treatments (Figure 6).

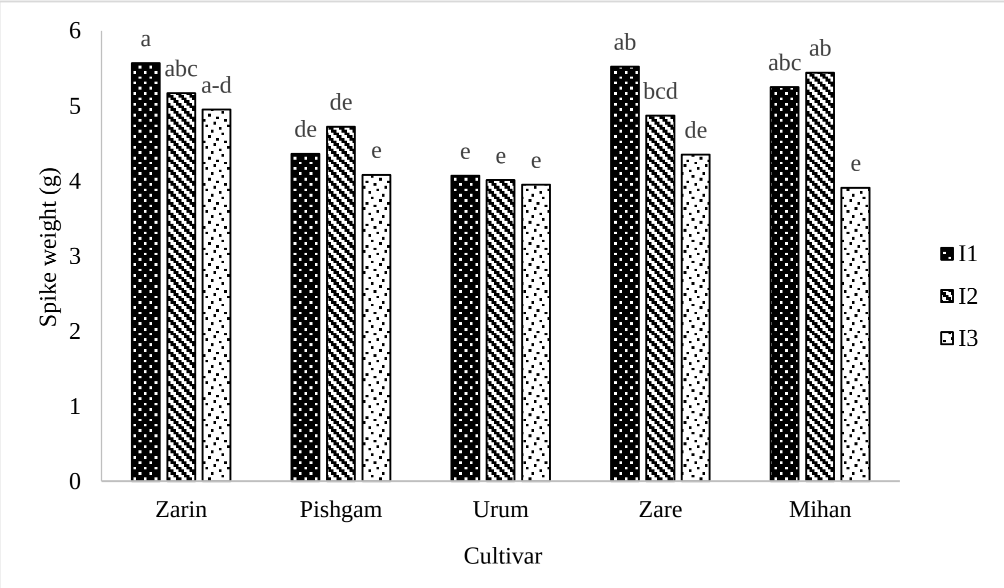

Figure 2. Mean spike weight of bread wheat cultivars under different irrigation treatments; Different letters indicate significant difference at p ≤0.05; I_1, I_2 and I_3 represent full irrigation, withholding irrigation at anthesis and withholding irrigation at heading, respectively.

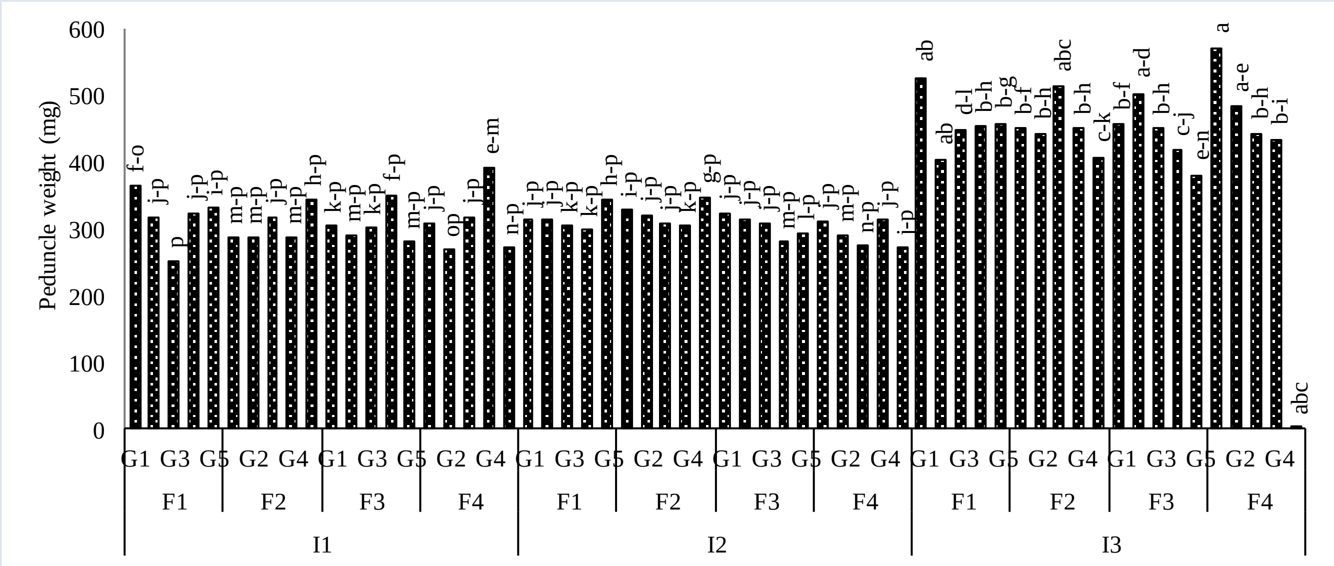

Figure 3. Mean peduncle weight of bread wheat cultivars affected by irrigation treatments and timing of nitrogen application; Different letters indicate significant difference at p ≤0.05; I_1, I_2 and I_3 represent full irrigation, withholding irrigation at anthesis and withholding irrigation at heading, respectively. F_1, F_2, F_3 and F_4 indicate nitrogen fertilizer application of 120 kg/ha at four timings: 20 kg at sowing + 100 kg/ha at tillering, 20 kg at sowing + 100 kg/ha at bolting, 20 kg at sowing + 50 kg at tillering + 50 kg at bolting and 20 kg at sowing + 50 kg at tillering + 50 kg at heading, respectively; G_1, G_2, G_3, G_4 and G5 represent wheat cultivars of Zarrin, Pishgam, Urum, Zare and Mihan, respectively.

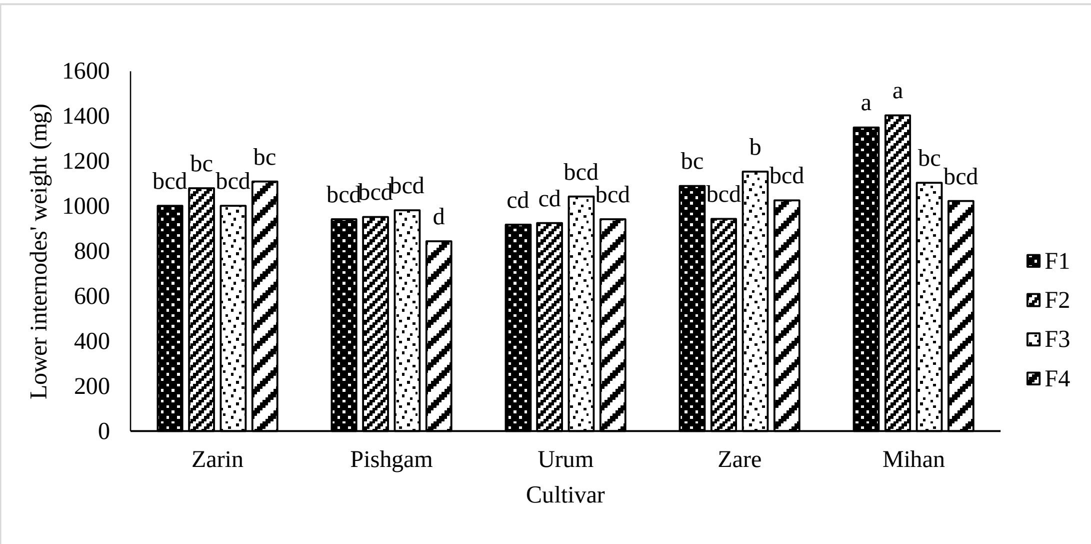

Figure 4. Mean lower internodes' weight of bread wheat cultivars affected by timing of nitrogen application; Different letters indicate significant difference at p ≤0.05; F_1, F_2, F_3 and F_4 indicate nitrogen fertilizer application of 120 kg/ha at four timings: 20 kg at sowing + 100 kg/ha at tillering, 20 kg at sowing + 100 kg/ha at bolting, 20 kg at sowing + 50 kg at tillering + 50 kg at bolting and 20 kg at sowing + 50 kg at tillering + 50 kg at heading, respectively

Dry matter remobilization of all cultivars increased with decreasing water availability. However, nitrogen application at heading stage resulted in the reduction of remobilization. There was considerable difference among wheat cultivars in terms of R% in response to nitrogen treatments. Under I_1 and F_4, Zare and Pishgam showed the maximum and minimum R% (44.09% and 10%), respectively. Under I3, the highest (70.46%) and the lowest (12.7%) R% were obtained for Zarrin and Mihan cultivars under F_1 and F_2 nitrogen treatments. Urum and Zarrin had the highest and lowest R% under I2 (Figure 7). RE% showed similar trends as R% (Figure 8).

Discussion

In the present study, the dry matter accumulation started approximately at anthesis, then declined, indicating some remobilization at grain filling stage, and mostly was localized within the sheath-enclosed peduncle and lower internodes (Figures 2, 3 and 4). Accumulation of dry matter in the peduncle tissues is started during early reproductive development, reaching a maximum after anthesis, and is subsequently remobilized to provide carbon for grain filling (Gebbing 2003). Changes in peduncle and lower internodes' weight under different irrigation treatments (Figure 3 and 4) demonstrated their significant role in remobilization of carbohydrates to grains. Diminishing lower internodes' weight at maturity can be attributed to active sink (grains) needs for utilization of stored carbohydrates and higher contribution of these internodes to grain filling under water deficit condition. By increasing drought stress greater remobilized dry matter, remobilization efficiency and remobilization percentage were observed in the wheat cultivars (Figures 3 and 4). Crops rely on remobilization of stored carbohydrates from the pre-anthesis stage when drought stress occurs (Grewal 2010).

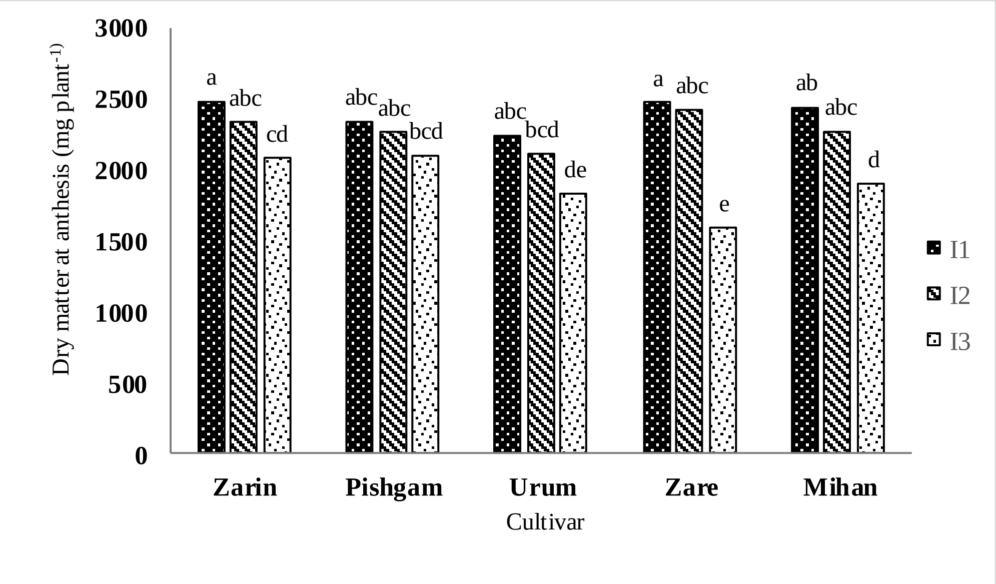

Figure 5. Dry matter weight of wheat cultivars at anthesis under different irrigation treatments; Different letters indicate significant difference at p ≤0.05; I_1, I_2 and I_3 represent full irrigation, withholding irrigation at anthesis and withholding irrigation at heading, respectively.

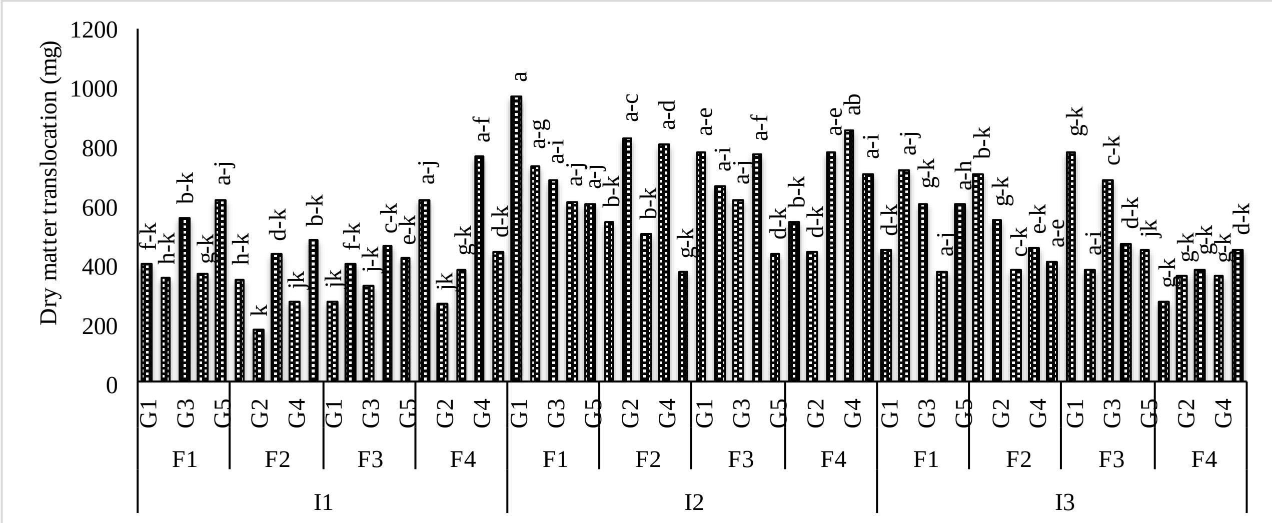

Figure 6. Dry matter translocation of wheat cultivars affected by irrigation treatments and timing of nitrogen application; Different letters indicate significant difference at p ≤0.05; I_1, I_2 and I_3 represent full irrigation, withholding irrigation at anthesis and withholding irrigation at heading, respectively. F_1, F_2, F_3 and F_4 indicate nitrogen fertilizer application of 120 kg/ha at four timings: 20 kg at sowing + 100 kg/ha at tillering, 20 kg at sowing + 100 kg/ha at bolting, 20 kg at sowing + 50 kg at tillering + 50 kg at bolting and 20 kg at sowing + 50 kg at tillering + 50 kg at heading, respectively; G_1, G_2, G_3, G_4 and G5 represent wheat cultivars of Zarrin, Pishgam, Urum, Zare and Mihan, respectively.

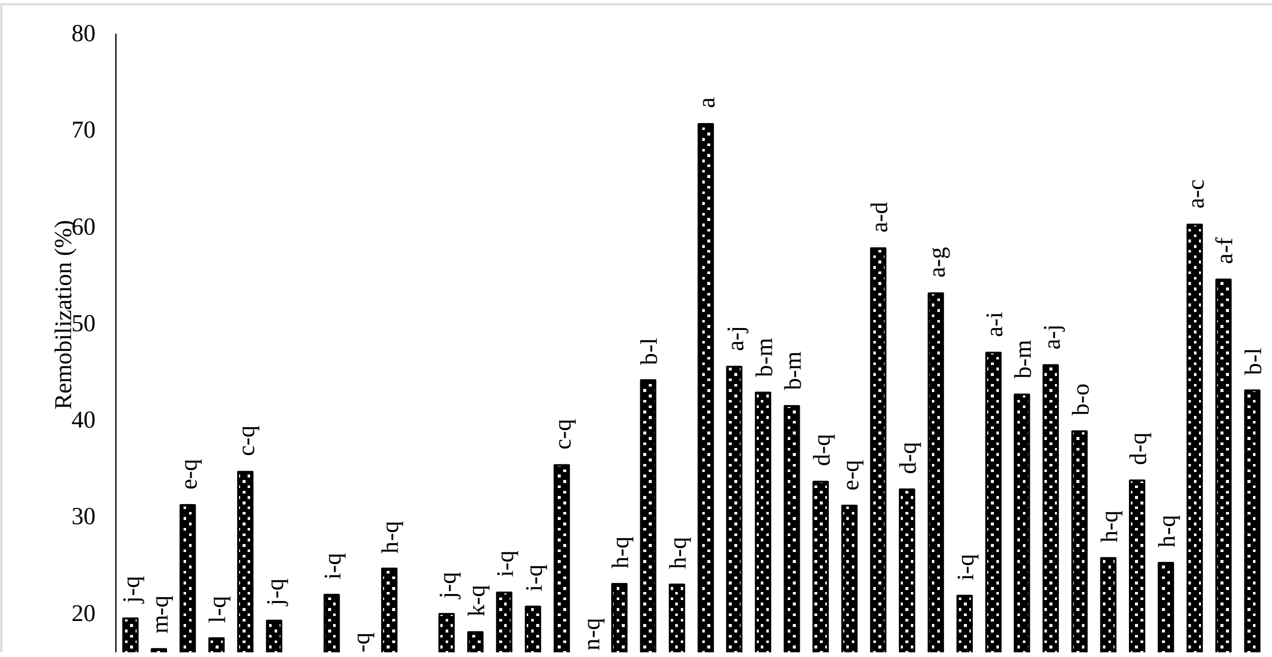

Figure 7. Remobilization of wheat cultivars affected by different irrigation treatments and timing of nitrogen application; Different letters indicate significant difference at p ≤0.05; I_1, I_2 and I_3 represent full irrigation, withholding irrigation at anthesis and withholding irrigation at heading, respectively. F_1, F_2, F_3 and F_4 indicate nitrogen fertilizer application of 120 kg/ha at four timings: 20 kg at sowing + 100 kg/ha at tillering, 20 kg at sowing + 100 kg/ha at bolting, 20 kg at sowing + 50 kg at tillering + 50 kg at bolting and 20 kg at sowing + 50 kg at tillering + 50 kg at heading, respectively; G_1, G_2, G_3, G_4 and G5 represent wheat cultivars of Zarrin, Pishgam, Urum, Zare and Mihan, respectively.

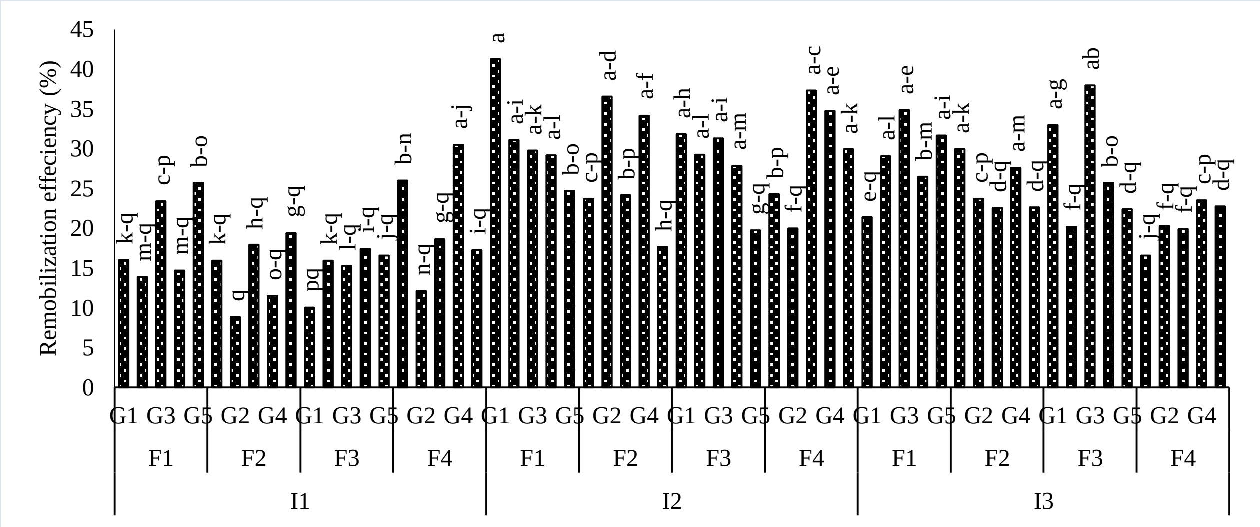

Figure 8. Remobilization efficiency of wheat cultivars affected by irrigation treatments and timing of nitrogen application; Different letters indicate significant difference at $p \leq 0.05$; I_1, I_2 and I_3 represent full irrigation, withholding irrigation at anthesis and withholding irrigation at heading, respectively. F_1, F_2, F_3 and F_4 indicate nitrogen fertilizer application of 120 kg/ha at four timings: 20 kg at sowing + 100 kg/ha at tillering, 20 kg at sowing + 100 kg/ha at bolting, 20 kg at sowing + 50 kg at tillering + 50 kg at bolting and 20 kg at sowing + 50 kg at tillering + 50 kg at heading, respectively; G_1, G_2, G_3, G_4 and G5 represent wheat cultivars of Zarrin, Pishgam, Urum, Zare and Mihan, respectively.

Significant differences among cultivars in terms of dry mater remobilization from spike and internodes may have resulted from different potential of these cultivars in utilizing the stored dry matters and consequently can be attributed to their differential tolerance to water deficit stress. The findings of the current study are consistent with those of Ehdaie *et al.* (2006) who discussed that the lower internodes should have appropriate length to reach their potential for carbohydrates accumulation before anthesis and a major source for carbohydrates mobilization after anthesis.

Dry matter accumulation and partitioning into different plant parts varied under different timings of nitrogen. Reduction of remobilization due to nitrogen application at bolting stage can be related to the effect of nitrogen on increasing of plant growth duration, photosynthesis and diminishing the needs to stem stored carbohydrates. It has been established that N fertilization profoundly affects dry matter accumulation and partitioning in wheat (Sieling and Beims, 2007). Increasing the rate of current photosynthesis with increasing nitrogen flow has been attributed to the positive effect of nitrogen on leaf area index (LAI) and leaf area duration (Gholinezhad and Sajedi, 2012) and production and accumulation of dry matter under optimum irrigation conditions (Figures 5, 6 and 7). Drdas and Sioulas (2008) reported that nitrogen fertilizer increased rate of current photosynthesis but decreased rate of remobilization.

Drought occurrence at the anthesis stage causes a drastic reduction in grain weight and yield (Seghatoleslami *et al.* 2008). Water deficit through decreasing photosynthesis capacity caused the reduction of grain yield (Figure 1) as it was reported also by Fathi *et al.* (1997). Reduction of plant growth, leaf expansion and grain filling duration due to water deficit at later growing stages has caused the reduction of grain yield (Sabchez-Diaz *et al.* 2002). Under favorable watering, current photosynthesis as an important carbon source for grain filling depends on the effective light absorption by the green area of the plant after pollination stage (Blum, 1996). In most studies, it was determined that stems and leaf sheaths contained most of the stored assimilates (Yang *et al*. 2007). Papakosta and Gagianas (1991) reported that stem reserves are important source of carbon for grain filling during terminal drought and remobilization percentage was 6 to %73 in bread wheat. During reproductive stage, occurrence of different biotic and abiotic stress factors such as water deficit decreases current photosynthesis (Bdukli *et al*. 2007). Under this condition the demand for utilization of stem accumulation increases and remobilization of stem reserves is regarded as an important process that can compensate grain yield decline (Palta *et al.* 1994).

The response of a plant to environmental stress is demonstrated by its nutritional status. Increasing nitrogen application resulted in the elevation of the grain yield. The use of larger quantities of N fertilizer at the optimum irrigation condition resulted in considerable increase in grain yield whereas at the severe drought stress condition using higher amounts of nitrogen did not affect grain yield (Figure 1). It seems that this condition results from the declined absorption and increased nitrogen waste due to water deficit in soil. Nitrogen consumption by a strong sink and active source (higher LAI) can increase grain yield. In a study, chlorophyll content and leaf area index increased by increasing nitrogen fertilization which eventually improved the biomass production (Sieling and Beims, 2007).

In general, lower yield reduction of Pishgam and Mihan under sever water stress can be attributed to genetic differences among wheat cultivars in utilizing stored dry matter under water deficit stress condition. Tolerant cultivars had greater ability to remobilize the carbohydrates to grains and had higher grain weight under limited irrigation conditions. Therefore, selection of tolerant cultivars with higher capacity of dry matter translocation and remobilization under water deficit stress is regarded as a suitable strategy to increase grain yield in wheat.

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ارزیابی تغییرات انتقال مجدد ارقام گندم نان تحت تیمارهای مختلف آبیاری و کود نیتروژن

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چکیده

به منظور بررسی اثر تیمارهای آبیاری و مصرف کود نیتروژن بر انتقال مجدد و عملکرد دانه ارقام گندم نان، آزمایشی به‌صورت طرح کرت‌های دو بار خرد شده بر پایه بلوک‌های کامل تصادفی با سه تکرار اجرا شد. سطوح مختلف آبیاری (آبیاری کامل و قطع آبیاری در مراحل ظهور سنبله و مرحله گلدهی) در کرت‌های اصلی، زمان و نحوه مصرف کود نیتروژن (شامل ۱۲۰ کیلوگرم در چهار سطح: ۲۰ و ۱۰۰ کیلوگرم در هکتار به ترتیب در مراحل کاشت و پنجه‌دهی، ۲۰ و ۱۰۰ کیلوگرم در هکتار به ترتیب در مراحل کاشت و گلدهی، ۲۰، ۵۰ و۵۰ کیلوگرم در هکتار به ترتیب در مراحل کاشت، پنجه‌دهی و گلدهی، ۲۰، ۵۰ و۵۰ کیلوگرم در هکتار به ترتیب در مراحل کاشت، پنجه‌دهی و ظهور سنبله) در کرت‌های فرعی و پنج رقم گندم نان (زرین، پیشگام، اروم، زارع، میهن) در کرت‌های فرعی فرعی به طور تصادفی قرار گرفتند. قطع آبیاری در مراحل مختلف نمو، سبب افزایش درصد انتقال مجدد در کلیه ارقام گندم شد. کوددهی نیتروژن در مرحله ظهور سنبله موجب کاهش انتقال مجدد شد. بیشترین و کمترین میزان انتقال مجدد برای ارقام گندم اروم و زرین به ترتیب با ۶۲/۱۳ و ۲۰/۳۳ درصد ثبت شد. عملکرد دانه به طور معنی‌دار با کاهش مقدار آب قابل دسترس کاهش یافت. متوسط عملکرد دانه کلیه ارقام گندم تحت شرایط آبیاری کامل ۷/۵ تن در هکتار بود که به ۶/۵ تن در هکتار در شرایط قطع آبیاری کاهش یافت. مصرف کود نیتروژن منجر به بهبود عملکرد دانه شد. در شرایط آبیاری کامل، بیشترین عملکرد دانه با ۹/۴ تن در هکتار متعلق به رقم میهن تحت تیمار کوددهی ۲۰ ، ۵۰ و۵۰ کیلوگرم در هکتار به ترتیب در مراحل کاشت، پنجه‌دهی و ظهور سنبله بود. نتایج نشان داد که عملکرد دانه بیشتر در ارقام متحمل به خشکی تحت تیمارهای کم‌آبی ناشی از انتقال مجدد کربوهیدرات‌های غیرساختمانی از ساقه به دانه بوده است. بنابراین، به نظر می رسد که انتخاب ارقام گندم با ماده خشک منتقل شده بیشتر و مشارکت مواد فتوسنتزی قبل از گلدهی در پرشدن دانه تحت شرایط کمبود آب، یک راه‌کار مناسب برای دستیابی به ارقام گندم با عملکرد دانه بالا در این شرایط باشد.

واژه‌های کلیدی: انتقال مجدد؛ تیمار آبیاری؛ عملکرد دانه؛ کود نیتروژن؛ گندم نان