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VARIATION OF WATER-SOLUBLE CARBOHYDRATES AND GRAIN YIELD IN IRANIAN COLD BARLEY PROMISING LINES UNDER WELL-WATERED AND WATER STRESS CONDITIONS

ABSTRACT

In order to evaluate promising lines in terms of grain yield and water-soluble carbohydrates remobilization, an experiment with fifteen promising lines and two checks was carried out under full irrigation and terminal water stress conditions at Miyandoab Agricultural Research and Natural Resources Station. Mobilized dry matter content and remobilization percentage from shoot to grain under water deficit (177mg)(11.2%) were greater than those under well watering condition. The lowest (110 mg) and the highest (260mg) mobilized dry matter to grain were obtained for C-79-18 and C-83-15lines, respectively. Water deficit reduced grain yield of barley genotypes by 200-1600 kg/ha, and mean grain yield reduction was 800 kg/ha. Line 14 with 5.880and 5.300t/ha grain yield in favorable and water stress conditions was superior to the other lines. Under water deficit condition, line 14 had greater grain yieldby20% and 38% than the Bahman and Makouee cultivars, respectively. The results showed that greater grain yield in tolerant lines under water deficit was due to remobilization of unstructured carbohydrates from shoot to grain.Thus, it seems that selection of lines with higher translocated dry matter and contribution of pre-anthesis assimilate in grain filling under water stress, the suitable way for achieving genotypes with high grain yield under water stress condition.

Key words: barley, water-soluble carbohydrate, grain yield, water stress

INTRODUCTION

Barley with higher tolerance to drought in comparison with the other crops, high ecological compatibility, and cultivation capability in different latitudes, utilization in human and animal food, high malt food value and

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usage in beverage industry has specific importance in agriculture and economy. Grain growth and filling is supplied from three photo-assimilate sources including photosynthesis of leaves and stem, ear and remobilization of carbohydrates from green organs to ear (Plawet*et al.* 2004). Current photo-assimilate production may reduce due to environment stresses. In this situation storage carbohydrate is one of the important sources for supplying photo-assimilate. When production of photo-assimilate was higher than storability of sink, these carbohydrates will be stored in different parts of plant such as stem internodes and in late stage of growth when demand for photoassimilate was higher than current photosynthesis, carbohydrates will transfer to kernels (Yang and Zeng, 2006).

Grain filling depends on two major sources of carbon, namely, photosynthesis that occurs during the grain filling period and remobilization of stored water-soluble carbohydrates from the stem into the mature grains. Remobilization of water soluble carbohydrates stored temporarily in the stem maintains the supply of carbon to the grain when the rate of photosynthetic production is less than the needs of the grain or other organs (Van Herwaarden *et al.* 1998a). Consequently, remobilized carbohydrate can make a significant contribution to grain weight and final grain yield. Under relatively non-stressed conditions water-soluble carbohydrates can contribute 10–20% of final grain yield (Gebbing*et al.* 1999), but under conditions where photosynthesis is reduced (e.g. disease, high temperature and terminal drought stress) this may increase to 50% or more (Ehdaie*et al.* 2008; Rebetzke*et al.* 2008; Rattey*et al.* 2009).Thus, this research was carried out to investigate the grain yield and stress tolerance indices of barley lines and selection of tolerant lines for cultivation in environments with limited water availability.

MATERIALS AND METHODS

The field experiment with fifteen promising lines and two checks were conducted at the Miyandoab Agricultural and Natural Resource Research Station (Latitude 36˚58’ N, Longitude 46˚6’ E, Altitude 1314 m) in 2006-7. Soil texture at the 30Cm depth was clay loam with pH=7.5-8 and EC= 2 ds × -^{2}. Seeding rates for all genotypes was 400 seed/m2 and each genotypes was planted in 6 rows with 20 cm apart and 5 m long. The experiment was arranged in RCB design with three replications, and two different conditions of full-irrigation and terminal water stress (stopped irrigation at anthesis stage) conditions. Seedbed preparation, fertilizers used, and weed control for all treatments were the same. In order to determine the remobilized dry matter to grain, 10 full stems with leaves and ears were harvested randomly from each plot during anther appearance and physiological maturity. Then, total dry weight, dry weight of ear, leaf and stem for both harvest stages and grain dry weight (just in physiological maturity) were measured. Dry matter translocated (DMT) and contribution of pre-anthesis assimilation in grain filling (CPAAG) were estimated using following equations (Papakosta and Gagianas, 1991):

$$DMT = (DMM - GW)$$

$$CPAAD_{\%} = \frac{DMT}{GW} \times 100$$

Where DMT is content of dry matter translocated, DMA is dry matter in anther appearance stage, DMM is dry matter in physiological maturity stage, GW is grain weight .Remobilization efficiency (RE) was estimated according to Donaldson (1996):

$$RE_{\%} = \frac{DMT}{DMA} \times 100$$

Finally, grain yield for each plot were recorded. Analysis of variance of data and comparison of means at $p \leq 0.05$ were done, using MSTATC, SPSS and MINITAB programs.

RESULTS AND DISCUSSION

Photo assimilate accumulation and remobilization

The results showed that dry matter in maturity stage (DMM), grain weight (GW), dry matter translocated (DMT), contribution of pre-anthesis assimilate in grain filling (CPAAG %) and remobilization efficiency (RE) were significantly affected by irrigation treatments ($p \leq 0.01$).

Drymatter weight in maturity stage (DMM)

The greatest dry matter weight under favorable irrigation was obtained from C-38-4 (line13) line. However, there is no significant difference between line13 and lines 1,2,4,5,9,12,13,14,15, 16 and 17 (Table1). Under late water stress condition, the greatest DMM was achieved from C-83-4 (line 13), which significantly was different from the other lines and checks (Table1).

Table1

Means comparison of dry matter weight (DMM) and grain weight (GW) of barley genotypes under well-watering and water stress conditions

Lines	Dry matter weight [g]		Grain weight [g]	
	Well watering	Water stress	Well watering	Water stress
C-79-10	3.29 ab	3.10 ab	1.67 ab	1.56 ad
C-79-13	3.17 ac	3.00 ac	1.57 ac	1.56 ad
C-79-18	2.93 bc	2.90 ac	1.49 bc	1.46 ae
C-80-7	3.09 ac	3.00 ac	1.58 ac	1.55 ad
C-80-11	3.18 ac	3.06 ac	1.65 ab	1.65 a
C-80-13	2.74 c	2.72 c	1.37 c	1.34 e
C-81-11	2.74 c	2.76 bc	1.35 c	1.40 ce
C-81-13	2.94 bc	2.80 ac	1.43 bc	1.43 be
C-81-15	3.09 ac	2.93 ac	1.52 ac	1.47 ae
C-82-5	2.94 bc	2.81 ac	1.50 bc	1.48 ae
C-82-10	2.78 bc	2.77 bc	1.39 c	1.37 de
C-82-11	3.04 ac	2.91 ac	1.54 ac	1.54 ae
C-83-4	3.47 a	3.14 a	1.76 a	1.61 ab
C-83-15	3.05 ac	3.02 ac	1.56 ac	1.59 ac
C-83-17	3.00 ac	2.77 bc	1.50 bc	1.38 de
Makouee	3.02 ac	2.88 ac	1.56 ac	1.46 ae
Bahman	2.98 ac	2.90 ac	1.58 ac	1.59 ac

Different letters indicating significant difference at $p < 0.05$

Grain weight

The greatest grain weight under both favorable and water stress conditions were obtained for lines 13 and 5, respectively (Table 1).The significant and positive correlation between dry matter weight before anthesis (DMA) and grain weight (GW)(0.78**) showed the importance of dry matter accumulation before anthesis and its effect on grain weight in maturity stage (Table 1).

Dry mattertranslocation content (DMT)

The greatest DMT (107 mg) under favorable condition was obtained from Bahman. However, line 14 in comparison with other lines under limited water had the greatest DMT (260 mg). Difference among lines in terms of DMT in normal and water limitation conditions were 78 and 150 mg, respectively. Cultivar 3 under both conditions had the lowest DMT (Fig. 1). There was significant difference among barley cultivars in terms of ability in production, accumulation and translocation of dry matter to grains. Allocation of photo-assimilate to barley grain may be due to current photosynthesis and remobilization of photo-assimilate from vegetative organs such as leaf, stem and ear components to grain (Van Sanford and MacKown, 1987). Carbon was accumulated as soluble carbohydrates in vegetative organs (Kuhbauch and Thome, 1989). Accumulation of photoassimilate before anthesis in vegetative organs depends on growth situation and was higher under favorable growth condition (Blum, 1998)

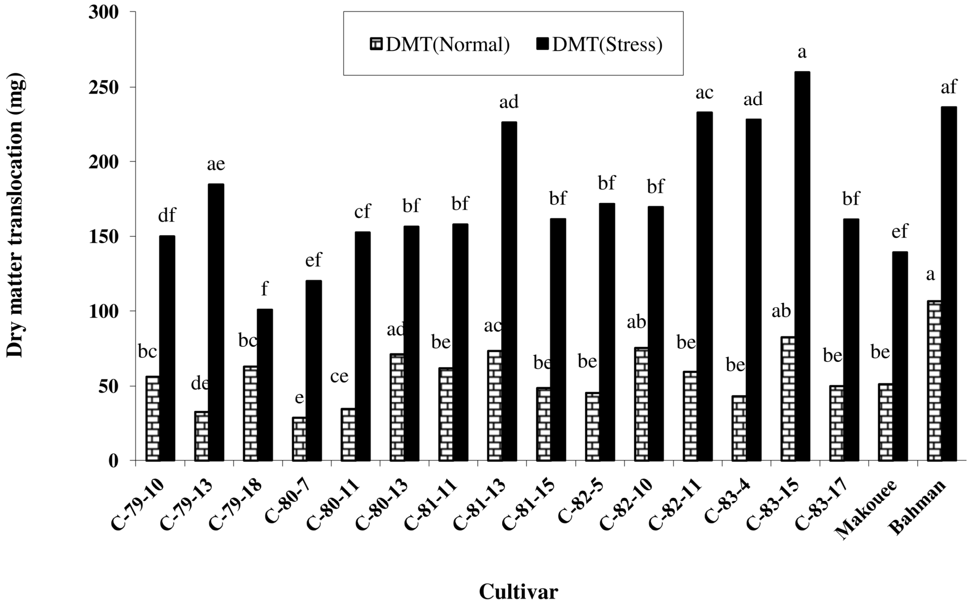

Fig. 1. Mean comparison of dry matter translocation content of different barley lines under different water treatment

Content and contribution of pre-anthesis assimilate in grain filling (CPAAG%)

Results showed CPAAG% normal condition varied from 1.4% (line 4) to 6.9% (line 17). Under late water stress condition, the lowest and greatest CPAAG% belonged to line 3 (7%) and line 14 (16.3%), respectively (Fig. 2). Mean of CPAAG% under favorable and water stress conditions was 4.2 and 11.8, respectively (Fig. 4). Positive and significant correlation between DMT and CPAAG% indicate that increasing dry matter translocated causes increased remobilization percentage (Tables 2 and 3).

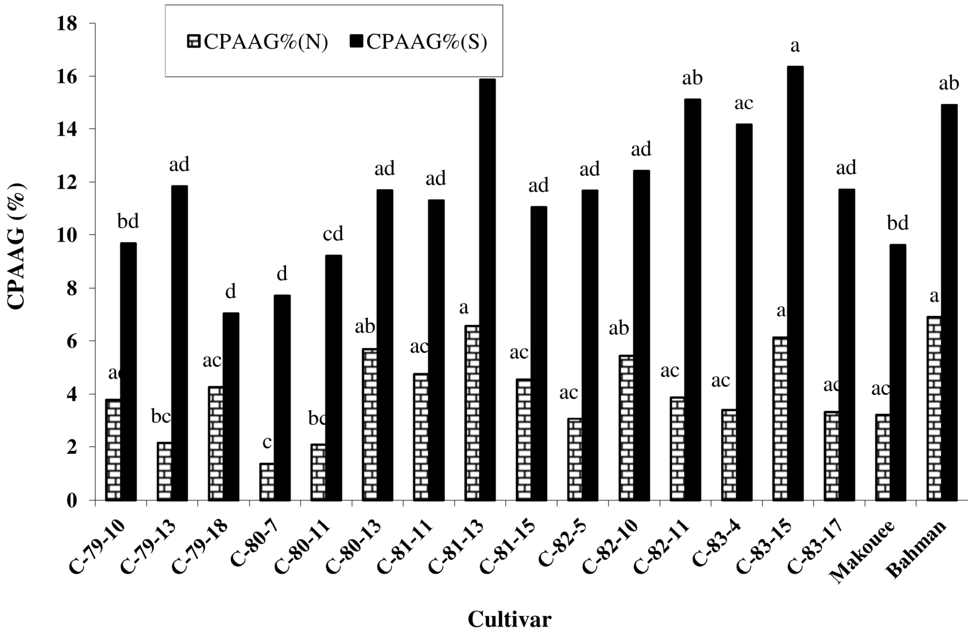

Fig. 2.CPAAG% Mean comparison of different barley lines under different water treatment

Table 2

Correlation coefficients between different parameters of accumulation and translocation of photoassimilate under full irrigation condition

Parameters	DMA	DMM	GW	DMT	CPAAG%	RE%
DMA	1					
DMM	0.92 **	1				
GW	0.78**	0.95**	1			
DMT	-0.33ns	-0.46ns	-0.36ns	1		
CPAAG%	-0.23 ns	-0.47ns	-0.46ns	0.94**	1	
RE%	-0.24ns	-0.42ns	-0.37ns	0.97**	0.98**	1
Yield	0.31ns	-0.01ns	-0.01ns	0.26ns	0.32ns	0.29ns

ns, **: no significant and significant at p≤0.01, respectively

Table 3

Correlation coefficients between different parameters of accumulation and translocation of photoassimilate under limited irrigation condition

Parameters	DMA	DMM	GW	DMT	CPAAG%	RE%
DMA	1					
DMM	0.76 **	1				
GW	0.55*	0.90**	1			
DMT	0.48**	0.16 ns	0.36 ns	1		
CPAAG%	0.35 ns	-0.08ns	0.10ns	0.97**	1	
RE%	0.31 ns	0.01ns	0.26ns	0.98**	0.97**	1
Yield	0.38ns	0.13ns	0.13ns	0.48*	0.46 ns	0.44ns

ns, *, **: No significant and significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Under limited water condition, CPAAG% was considerably greater than well watered condition. This result showed that current photosynthesis was diminished under water stress condition and plant for grain filling was utilized stem reserves. Photosynthetic reserves contribution before anthesis in barley yield was estimated up to 74% (Gallagher *et al.*, 1975). Remobilization percentage among barley cultivars were changed between 4-24.2% (Przulj and Momcilovic, 2001).

Remobilization efficiency (RE)

Under wellwatered condition, the lowest remobilization efficiency was obtained from cultivar 4 (1.37) and the highest was observed in cultivar 17 (Bahaman) with 6.9%. Under late water limited condition, the greatest remobilization efficiency was achieved from cultivars 14 and 17 (15.4). In both water limited and favorable watering, the lines with high DMT and CPAAG% had greater RE% (Fig. 3). Existence of significant Positive correlation of DMT and CPAAG% with RE% in both irrigation conditions, confirm the above results mentioned (Tables 2 and 3).

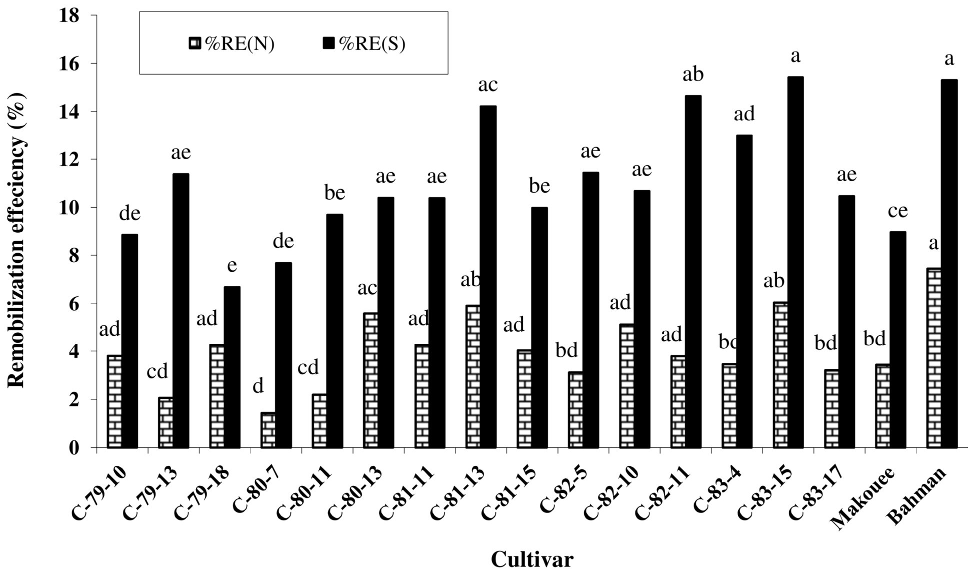

Fig. 3. Remobilization efficiency mean of barley lines under different irrigation conditions

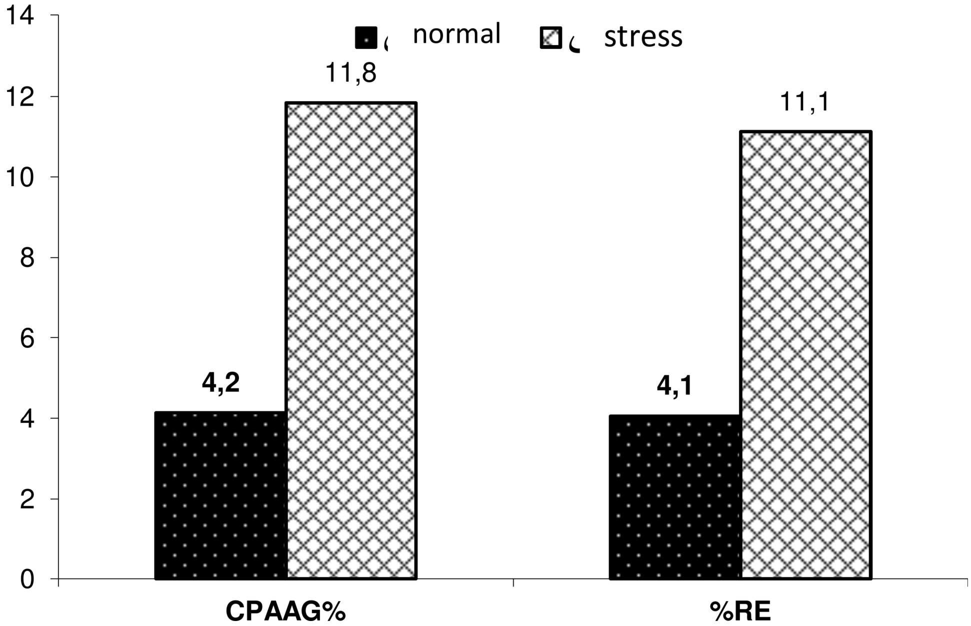

Fig. 4.Rates of CPAAG% and RE% under full irrigation and water stress conditions

Grain yield

Among lines in terms of grain yield under favorable irrigation condition there was no significant difference ($p \le 0.01$), but in late water stress condition, significant difference among lines was observed ($p < 0.05$). The greatest grain yield under limited irrigation condition was obtained from cultivars 2 and 14 by 5.317 and 5.305 t × ha^{-1}, respectively. Cultivars 16 and 11 with 3.278 and 3.417 t × ha^{*1} showed the lowest grain yield under water stress condition (Table 4).

Table 4

Comparison of means of grain yield of barley genotypes under well-watering and water stress conditions

Lines	Grain yield [t × ha^{-1}]	
	Well watering	Water stress
C-79-10	4.45a	3.66 de
C-79-13	5.54a	5.31a
C-79-18	4.92a	3.99ce
C-80-7	4.08a	3.72de
C-80-11	4.29a	3.55de
C-80-13	4.50a	3.94ce
C-81-11	4.43a	4.05 be
C-81-13	5.47a	4.58ad
C-81-15	4.61a	3.55 de
C-82-5	4.52a	3.51de
C-82-10	4.97a	3.42de
C-82-11	4.98a	3.58de
C-83-4	5.22a	4.58ad
C-83-15	5.88a	5.30ab
C-83-17	5.74a	5.08ac
Makouee	4.633a	3.27e
Bahman	4.811a	4.22ae

Different letters indicating significant difference at $p < 0.05$

Mean grain yield under favorable and unfavorable irrigation conditions was 4.88 and 4.08 t × ha^{-1}, respectively (Fig. 5). Water deficit caused 16.5% reduction in grain yield of barley lines. Tolerant line (14) under water deficit condition had greater grain yield than the check cultivars (Makouee and Bahman) by 38% and 20%, respectively (Table 4). Under well watering there was no significant difference in comparison with control cultivars, but grain yield of lines 2, 8, 13, 14 and 15 were greater than control cultivars under water deficit (Table 4). These results showed that under well watering condition all of the promising lines had high yield potential. But in Water deficit condition, there was difference in terms of grain yield production. Water deficit in grain filling stage through decreasing photosynthesis capacity caused to reduction in grain yield (Fathi and McDoand, 1997). Reduction plant growth, leaf expansion and grain filling duration due to water deficit in late growth season caused to reduction of barley grain yield (Gonzalez *et al.*, 1999;Sanchez*et al.*, 2002).

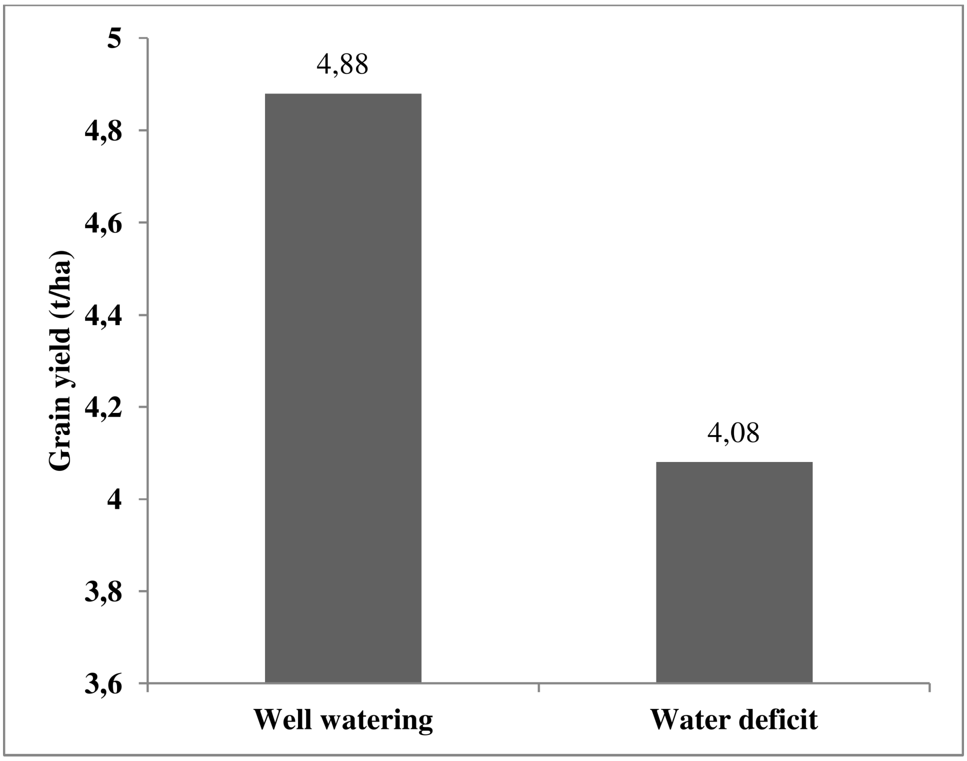

Fig. 5.Mean grain yield of barley under different irrigation treatments

CONCLUSIONS

Genetic differences among cultivars showed that CB-83-15 (line 14) has lower yield reduction than the other lines and produced suitable grain yield under both well and limited irrigation conditions. DMT and CPAAG% under limited irrigation increased. Tolerant lines had the DMT and CPAAG% in comparison with the other lines. It may be that the greater grain yield of tolerant lines under limited watering was due to greater carbohydrates re-mobilization to grains. So, selection of lines with higher DMT and CPAAG% under water stress is a suitable way for increasing grain yield.

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