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Dry matter accumulation and remobilization in grain sorghum genotypes (*Sorghum bicolor* L. Moench) under drought stress

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Abstract

A field experiment was conducted during growing season of 2007-2008 at Khorasan Agricultural and Natural Resource Research Center, Mashhad-Iran, to study dry matter accumulation and remobilization in grain sorghum genotypes under water stress and normal conditions. The main plots were allocated to two levels of moisture regimes, including water deficit after anthesis and normal condition (no water stress) and the subplots were disturbance photosynthesis with potassium iodide and non disturbance on current photosynthesis and three grain sorghum genotypes (Sepideh, M5 and M2 promising lines). The results showed that water stress significantly ($p \leq 0.01$) increased amounts of remobilized dry matter (ARDM), remobilization efficiency (REE), remobilization percentage (REP) by 11.21%, 32.37 % and 14.20%, respectively, compared with normal condition over all treatments. However it significantly ($p \leq 0.05$) decreased biological and grain yield. Disturbance in current photosynthesis caused 57.79 % and 21.20 % increase in remobilization percentage and remobilization efficiency compared to non disturbance status across all treatments. M5 genotype had the highest remobilization percentage and remobilization efficiency as compared with the two other genotypes in all experimental plots. The stepwise linear multiple regression indicated that grain yield would be properly predicted by biological yield and harvest index ($R^2=0.99$, $p \leq 0.01$).

Keywords*:* photosynthesis; remobilization efficiency; remobilization percentage, water deficit

Introduction

Drought stress is a major constraint factor affecting crop production in arid and semi arid climates. It has been shown that stem and leaf sheath of small grain cereals are the organs that reserve photosynthetic assimilates (Slafer and Savin, 1994; Yang et al., 2007). During grain filling, occurrence of different biotic and abiotic stress factors such as water deficit decreases current photosynthesis (Bdukli et al., 2007). Under this condition demand rate for utilization of the stem accumulation increases and remobilization of stem reserves is an important supporting process that can largely compensate grain yield decrease (Palta et al., 1994). Moreover, leaf photosynthesis is decreased as a result of various stresses such as drought, heat stress, and leaf diseases (Bdukli et al., 2007) and consequently, grain filling becomes largely dependent on the vegetative source or photosynthesis of ear tissue (Paponov et al., 2005). One of the appropriate ways to achieve reasonable yield is to assess remobilization rate of carbohydrates and protein that are produced under stressful condition and considered as an effective physiological index in yield formation. The decrease of photosynthetic capacity is a fundamental yield limiting factor, thus, lower photosynthetic capacity of canopy leads to decreased yield by shortening duration of grain filling period (Blum et al., 1994). The best-known agents to stimulate leaf senescence are chlorate magnesium (Blum et al., 1983), potassium iodide (Nikolas and Turner, 1993) and potassium chlorate (Bdukli et al.,2007) that are used in field to screen drought-tolerant genotypes at post-anthesis stage. These compounds are highly efficient and have low toxic effects. By applying chemical substances involved in leaf senescence, current photosynthesis is disturbed, resulting in significant decrease in yield and yield components. Genetic variation for assimilation and remobilization under drought stress as well as disturbance in current photosynthesis has been reported (Royo and Blanco, 1999). A simple and effective method for determining the amount of remobilized dry matter is to measure the differences in stem weight between anthesis and maturity stages (Ehdaie et al., 2007). Sorghum (*Sorghum bicolor* L. Moench) is an important summer season crop in low rainfall areas. Sorghum is better able to tolerate drought stress compared with other crops and is known as an index for drought resistance of agronomic crops (Beheshti, 1997). A better understanding of the perform- ance of sorghum cultivars in terms of dry matter accumulation and remobilization of photosynthetic assimilates under optimal and stressful condition will assist to select new varieties, which are suitable for cultivation in semiarid areas.

The aim of this study was to evaluate some eco-physiological parameters of sorghum genotypes such as dry matter accumulation, amount of remobilized dry matter, remobilization efficiency, remobilization perce-

Table 1. Analysis of variance of the effects of water condition, photosynthesis status, genotype and their interactions on eco-physiological traits of sorghum

		Mean square				
S.O.V.	df	ARDM	REP	REE	Grain yield	Biological yield
Replication	2	7.056^{ns}	20.626^{ns}	16.504^{ns}	1.255^{ns}	1.76^{ns}
Water condition (WC)	1	23.393*	1403.251*	73.245*	17.417*	9.703*
Error$_a$	2	2.365	42.071	1.925	2.893	0.218
Photosynthesis status (PS)	1	58.982**	3637.296**	152.976**	19.097**	8.113**
WC × PS	1	6.334*	71.91**	5.313^{ns}	10.028**	9.09**
Genotype (G)	2	211.211**	546.047**	239.79**	2.851**	61.506**
G×WC	2	9.82**	121.926**	14.89**	0.63^{ns}	5.127**
G×PS	2	22.009**	94.763**	37.552**	0.094^{ns}	1.52*
G×PS×WC	2	14.193**	84.83**	16.537**	0.034^{ns}	6.58**
Error$_b$	20	1.21	6.648	1.819	0.479	0.321

ns, * and **: Non significant, significant at 5 % and 1 % levels of probability, respectively.

ntage, biological yield, and grain yield under water limited condition.

Materials and methods

A field experiment was conducted using split plot design based on a randomized complete block design with three replications during growing season of 2007-2008 at Khorasan Agricultural and Natural Resource Research Center (36° 13´11″ N, 59° 38 ´ 19″ E, 1029 m above sea level) located in Mashhad, Iran. The main plots consisted of two levels of moisture regimes, including water deficit after anthesis and normal condition (no water stress). The subplots consisted of photosynthesis status (non desiccation and chemical desiccation with potassium iodide) in factorial combinations with three grain sorghum genotypes (Sepideh conventional cultivar, M5 and M2 promising lines, released from sorghum breeding program in Mashhad which the last two genotypes had recorded the maximum adaptability with the area). In order to disturb current photosynthesis, potassium iodide with 0.4 % of active substance was applied at the post-anthesis stage or simultaneously with commencement of linear growth after lag phase. For non-disturbance treatment of current photosynthesis, normal condition was maintained. Soil preparation was performed in accordance to conventional approaches at Research Station, including moldboard plow followed by double disk and leveler. Fertilizers were applied based on the results of the soil test analyses and on the nutrient requirement of the crop. The fertilizers of urea, ammonium phosphate and potassium sulfate were broadcasted and incorporated into the soil at the rates of 50, 250, and 200 kg ha^{-1}, respectively. The urea fertilizer (50 kg ha^{-1}) was top-dressed at the 6-leaf stage and at the panicle initiation stage to the side of the crop stands at a depth of 5 cm below the soil surface. Each genotype was sown in six rows of 6 m length, with a spacing of 62.5 cm between rows. The plants were thinned at the 4-leaf stage to a density of 16.5 plant m^{-2}. Weeds were hand weeded during the growth season. Pesticide applications were made to control aphids and agrotis. To determine above-ground dry matter of plant parts at anthesis stage, five plants were randomly taken from each sub plot. The plants were separated into stem, leaves and panicle at each stage and were dried in an oven at 75 $^{\circ}$C for 48 h.

To measure the amount of remobilized dry matter in above-ground plant parts the following equations were used (Cox et al., 1986; Papakosta and Gagianas , 1991 and Arduini et al., 2006).

ARDM (g/plant) **=** DMSHT (Ant) – DMSHT (Mat)
REE (%) **=** (ARDM (g/plant) / DMSHT (Ant)) × 100
REP (%) **=** (ARDM (g/plant) / GY (g/plant)) × 100

Where, ARDM is amount of remobilized dry matter (g/plant); DMSHT(Ant) is above-ground dry matter of plant parts at anthesis stage (g); DMSHT(Mat) is above-ground dry matter of plant parts at maturity stage (g), except grain weight (g); REE is remobilization efficiency (%); REP is remobilization percentage; and GY is grain yield (g/plant). A random sample of five plants at physiological maturity was selected to measure total above-ground biomass and yield components. The samples were dried following the same procedure as for the anthesis stage. The final harvest was done in a plot area of 10 m^{2} after removing guards for measuring economical yield and harvest index. The analysis of variance was performed using SAS statistical software (version 9.0). The stepwise multiple linear regression was computed between grain yield and other traits. The significant differences between treatments were compared with the critical difference at 5% probability level by the Duncan's test.

Results and discussion

The results of this study showed significant main effects of genotypes, water deficit stress, and photosynthesis status for grain yield, biological yield, harvest index, ARDM, REP, and REE. There were also significant interaction effects of the above-mentioned factors for some investigated traits (Table 1).

Genotype

There were significant differences among sorghum genotypes for DMSHT (Mat), ARDM, REE, REP, biological yield, and grain yield ($P \leq 0.01$) (Table 1). M5 promising line had the highest average grain yield (3.69 kg/ha), REP (51.68), and REE (26.46) compared with the two other genotypes over all investigated factors (Table 2). Ehdaie et al. (2007) reported that these traits

Table 2. Mean comparison of genotype, water stress and photosynthesis status on some investigated traits

Treatment	DMSHT (MAT)(g)	ARDM (g)	REE (%)	REP (%)	Grain yield (t/ha)	Biological yield (t/ha)
Genotype						
Spideh	62.94^{a}[1]	13.62^{b}	17.79^{c}	44.63^{b}	2.88^{b}	20.79^{a}
M2	47.04^{c}	11.94^{c}	20.24^{b}	38.19^{c}	2.83^{b}	16.43^{c}
M5	55.24^{b}	19.90^{a}	26.46^{a}	51.68^{a}	3.68^{a}	19.69^{b}
Water condition						
Normal	56.57^{a}	14.35^{b}	20.07^{b}	38.58^{b}	3.82^{a}	19.5^{a}
Stress	53.57^{b}	15.96^{a}	22.92^{a}	51.07^{a}	2.43^{b}	18.44^{b}
Current photosynthesis						
Normal	56.71^{a}	13.87^{b}	19.43^{b}	34.78^{b}	3.86^{a}	19.44^{a}
Disturbance	53.43^{b}	16.43^{a}	23.55^{a}	54.88^{a}	2.40^{b}	18.49^{b}

[1] Means with similar letters within a column are not significantly different at 5 % level according to DMRT

Table 3. Effect of water condition and genotypes on some investigated traits

Water condition	Genotype	REE (%)	REP (%)	ARDM (g)	Harvest ndex (%)
Normal	Sepideh	15.87^{e}[1]	36.18^{d}	64.82^{a}	18.65^{ab}
	M2	18.03^{d}	30.50^{e}	48.48^{e}	19.42^{ab}
	M5	26.31^{a}	49.09^{b}	56.41^{c}	21.00^{a}
Stress	Sepideh	19.71^{c}	53.08^{a}	61.06^{b}	9.27^{c}
	M2	22.45^{b}	45.89^{c}	45.60^{f}	15.06^{b}
	M5	26.61^{a}	54.27^{a}	54.06^{d}	16.07^{b}

[1] Means with similar letters within a column are not significantly different at 5 % level according to DMRT

are influenced by genetic and environmental factors. Interaction effects of genotype × current photosynthesis status and genotype × water condition on ARDM, REE, and REP, were significant ($P \leq 0.01$) (Table 1). The comparison of means for these traits also showed that genotypes response to varying water and photosynthesis condition was different. The maximum ARDM, REE, and REP were obtained from the interactions of M5 promising line × water deficit condition (Table 3) and M5 promising × disturbance on current photosynthesis (Table 4).Sepideh cultivar had the lowest REE and REP in normal current photosynthesis, while the lowest ARDM was observed in M2 promising line (Table 4). Additionally, the minimum values of REE and ARDM were obtained with Sepideh cultivar in normal water condition, while the lowest REP was found in M2 promising line (Table 3).

Results of this study demonstrated that significant genetic variation exists for reserve accumulation and utilization, as well as partitioning of assimilates among sorghum cultivars under both deficit water and well watered conditions. Under drought stress condition, M5 promising line produced the highest grain yield (3.11 ton/ha), indicating that this line could tolerate drought stress better than other genotypes through using stored reserves at pre- and post anthesis via remobilization.

Inoue et al. (2004) and Royo and Blanco (1999) observed similar phenomena in some crop varieties, which was associated with drought tolerance. Among the genotypes, M5 promising line had the highest harvest index under drought stress (16.07%), normal condition (21.00%), non photosynthesis disturbance (21.99%), and photosynthesis disturbance (15.08%) (data not showed). These results suggest that this genotype had superior drought tolerance. Genetic variation for this trait has been reported in different crop types (Slafer and Savin, 1994; Kumudini et al., 2002; Papakosta and Gagianas, 1991; Royo and Blanco, 1999; Bonnett and Incoll, 1993).

Water- limited condition

The result of this experiment showed that the effect of water deficit on grain yield, biologic yield, ARDM, REP, and REE was significant ($p \leq 0.05$) (Table 1). Mean comparison of water stress showed that it could cause 53.61 and 5.43 % reduction in grain and biological yield, respectively across all treatments (Table 2). Drought stress caused 11.21%, 32.37%, 14.20% increase in ARDM, REP, and REE, respectively, as compared to normal condition (Table 2). Anthesis is the most sensitive phonological stage to water stress in sorghum and other cereals (Blum et al., 1997; Hammer and Broad, 2003; Borras et al., 2002). Drought occurrence in relation to anthesis stage causes a drastic reduction in yield and yield components. (Araus et al., 2002; Blum et al.,1983; Blum et al 1994; Blum et al., 1989; Borras et al.,2002; Hammer and Broad, 2003; Papakosta and Gagianas, 1991, Seghatoleslami et al., 2008; Yadav and Bhatnagar, 2001). Crops rely on remobilization of stored carbohydrates from pre-anthesis stage when drought stress occurs. This becomes more important under terminal drought stress that is coincident with grain filling period and inhibits current photosynthesis. Papacosta 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. It may be postulated that when sorghum genotypes encounter water deficit at reproductive stage, although yield is decreased compared to normal condition, the rate of dry matter transfer and remobilization efficiency and percentage

Table 4. Effect of current photosynthesis status and genotype on some investigated traits

Current Photosynthesis status	Genotype	REE (%)	REP (%)	ARDM (g)	Harvest index (%)
Non-disturbance	Sepideh	15.18^{d1}	31.35^{d}	11.59^{d}	17.40^{bc}
	M2	16.75^{d}	29.43^{d}	9.85^{e}	20.73^{ab}
	M5	26.38^{a}	43.56^{c}	19.62^{a}	21.99^{a}
Disturbance	Sepideh	20.40^{c}	57.90^{a}	15.65^{b}	10.52^{d}
	M2	23.74^{b}	46.96^{b}	14.04^{c}	13.74^{cd}
	M5	26.55^{a}	59.80^{a}	20.19^{a}	15.08^{c}

[1] Means with similar letters within a column are not significantly different at 5 % level according to DMRT

Table 5. Effect of water condition and photosynthesis status on some investigated traits

Water condition	Photosynthesis status	DMSHT (MAT)	ARDM (%)	REE (%)	REP (%)	Grain yield (t/ha)	Biological yield (t/ha)
Normal	Disturbance	54.87^{b}	16.05^{ab}	22.52^{b}	47.23^{b}	2.572^{b}	19.52^{a}
	Non-disturbance	57.28^{a}	12.65^{c}	17.63^{c}	29.95^{d}	5.084^{a}	19.46^{a}
Stress	Disturbance	55.15^{b}	16.82^{a}	24.60^{a}	62.54^{a}	2.237^{b}	17.47^{b}
	Non-disturbance	52.00^{c}	15.10^{b}	21.25^{b}	39.61^{c}	2.638^{b}	19.43^{a}

[1] Means with similar letters within a column are not significantly different at 5 % level according to DMRT

increases. These traits could be selected to screen sorghum genotype for yield potential under water-limited conditions.

Photosynthesis status

Photosynthesis disturbance significantly affected all the investigated traits (Table 1). Disturbance in current photosynthesis decreased grain yield, harvest index, and biological yield by an average of 37.82%, 34.58% and 4.88%, respectively across all sources of variation. Generally, photosynthesis is influenced by various biotic and abiotic stresses during grain-filling period Kumudini et al (2002) suggested that lower canopy capacity of current photosynthesis reduced yield via decreasing grain-filling duration. This is in agreement with our finding, which shows that decreasing photosynthesis capacity is a major limiting factor for yield and all yield components. Disturbance in current photosynthesis increased ARDM, REP, and REE by 18.45%, 57.79% and 21.20%, respectively, as compared to non disturbance status (Table 2). This indicates that when crop is exposed to drought stress during grain filling and current photosynthesis is not adequately able to support the sink, in turn, the crop tends to utilize stored assimilates from other the parts of the plant. Consistent with our results, decreased weight of stem under water stress during grain filling stage was observed by Nikolas and Turner (1993) and Papakosta and Gagianas (1991).

Current photosynthesis plays an important role in supplying necessary carbohydrates for sorghum during reproductive stage (Kiniry and Tischler,1992; Craufurda and Peacock ,1993; Gambin and Borras, 2007). Blum et al. (1991) mentioned that translocation of dry matter under drought stress condition is similar to transfer of dry matter in leaf removal condition or leaf desiccation by chemical substances. Therefore, this method can be used for breeding drought resistant crops. The interaction of water stress × photosynthesis status was significant for ARDM, REP, grain yield, and biological yield, except for REE (Table 1). The highest ARDM (16.82%), REP (62.54%), and REE (24.60%) were observed under water deficit and current photosynthesis disturbance treatments that showed significant differences compared with other treatments (Table 5). The highest grain yield was obtained from normal water condition and non-disturbance photosynthesis treatments and it had significant differences compared to other treatments (Table 5). The lowest grain yield was observed under photosynthesis disturbance and water stress condition that caused a 55% reduction in grain yield in comparison to normal water and photosynthesis condition. The three-way interaction effect revealed that under water deficit condition and disturbance in current photosynthesis M5 promising line had the highest yield when compared with other genotypes (data not shown), indicating that M5 promising line could be considered as a drought resistant cultivar and cultivated under stress condition. It seems that there is an interaction effect between sink size and demand for stem reserves and growth environment during grain-filling stage. Bonnett and Incoll (1993) also reported that both pre-anthesis and grain-filling stages in barley are affected by this interaction. The results from stepwise multiple linear regression (Table 6) indicated that biological yield and harvest index traits could be considered as independent variables that described and determined grain yield as dependent variable in the formula below:

$$Y= -3.412+ 0.21\ HI+ 0.16\ BY \quad (R^2= 0.99, P\leq 0.01).$$

Table 6. Results of stepwise multiple regression analysis for grain yield as dependent variable

	b	Std. Error	t	Sig.
Constant	-3.012	0.333	-9.053	.000
Harvest Index	0.198	0.006	32.731	.000
Biological Yield	0.151	0.016	9.228	.000

Adjusted R-Square=0.99

References

Araus JL, GA Slafer, Reynolds MP and Royo C (2002) Plant breeding and drought in C3 cereals: What should we breed for? Ann Bot. 89: 925-940.

Arduini I, Masoni A, Ercoli L and Mariotti M (2006) Grain yield, and dry matter and nitrogen accumulation and remobilization in durum wheat as affected by variety and seeding rate. Eur J Agron. 25: 309-318.

Bdukli E, Celik N, Turk M, Bayram G and Tas B (2007) Effects of post anthesis drought stress on the stem–reserve mobilization supporting grain filling of two-rowed barley cultivars at different levels of nitrogen. J Bio Sci. 7: 949-953.

Beheshti AR (1997) Yield comparison of grain sorghum hybrids and their compatibility under Mashhad climate. Seed and Plant J. Agri. Res. 13: 1-7.

Blum A, Mayer J, and Golan G (1983) Chemical desiccation of wheat plants as simulator of post-anthesis stress ll. Relation to drought stress. Field Crops Res.6:149-155.

Blum A, Golan G, Mayer J, Sinmena B and Burra J (1989) The drought response of landraces of wheat from the Northern Negev desert in Israel. Euphytica. 43:87-96.

Blum A, Shpiler L, Golan G, Mayer J and Sinmena B (1991) Mass selection of wheat for grain filling without transient photosynthesis. Euphytica. 54: 111-116.

Blum A , Sinmena B, Mayer J, Golan G, and Shpiler L(1994) Stem reserve mobilization supports wheat grain filling under heat stress. Aust.J.Plant physiol. 21: 771-781.

Blum A, Golan G, Mayer J and Sinmena B (1997) The effect of dwarfing genes on sorghum grain filling from remobilized stem reserves under stress. Field Crops Res. 52:43–54.

Bonnett GD and Incoll LD (1993) Effects on the stem of winter barley of manipulating the source and sink during grain-filling I.Changes in the composition of water-soluble carbohydrates of internodes. J.Exp. Bot. 44:83-91.

Borras L, Cura AJ and Otegui ME (2002) Maize kernel composition and post-flowering source-sink ratio. Crop Sci. 42:781-790.

Craufurda PQ and Peacock JM (1993) Effect of heat and drought stress on sorghum (*Sorghum Bicolor*). II. Grain yield. Exp Agr 29: 77-86.

Cox MC, Qualset CO and Rains DW (1986) Genetic variation for nitrogen assimilation and translocation in wheat.iii. Nitrogen translocation in relation to grain yield and protein. Crop Sci. 26:737-740.

Ehdaie B, Alloush GA and Waines JG (2007) Genotypic variation in linear rate of grain growth and contribution of stem reserves to grain yield in wheat. Field Crops Res. 106: 34-43.

Gambin BL and Borras L (2007) Plasticity of sorghum kernel weight to increased assimilate availability. Field Crops Res. 100: 272-284.

Hammer GL and Broad IJ (2003) Genotype and environment effects on dynamics of harvest index during grain filling in sorghum. J. Agron. 95:199-206.

Inoue TS, INANAGA Y, Sugimoto P and Eneji AE (2004) Effect of drought on ear and flag leaf photosynthesis of two wheat cultivars differing in drought resistance. Photosynthetica. 42: 559-565

Kiniry JR and Tischler CR (1992) Nonstructural Carbohydrate Utilization by sorghum and maize shaded during grain growth. Crop Sci 32: 131-137.

Kumudini S, Hume DJ and Chu G (2002) Genetic improvement in short-season soybeans: II. Nitrogen accumulation, remobilization, and partitioning. Crop Sci. 42:141-145.

Nikolas ME and Turner NC (1993) Use of chemical desiccants and senescing agents to select wheat lines maintaining stable grain size during post-anthesis drought. Field Crops Res. 31: 155- 171.

Palta JA, Kobata T, Turner NC and Fillery IR (1994) Remobilization of carbon and nitrogen in wheat as influenced by postanthesis water deficits. Crop Sci. 34:118-124.

Papakosta DK and Gagianas AA (1991) Nitrogen and dry matter accumulation, remobilization and losses for Mediterranean wheat during grain filling. Agron J. 83:864-870.

Paponov IA, Sambo P, Schulte G, Presterl T, Geiger HH and Engels C (2005) Grain yield and kernel weight on two maize genotypes differing in nitrogen use efficiency at various levels of nitrogen and carbohydrate availability during flowering and grain filling. J Plant and Soil. 272: 111-123.

Royo C and Blanco R (1999) Use of potassium iodide to mimic drought stress in triticale. Field Crops Res 59: 201-212.

Seghatoleslami M J, Kafiv M and Majidi E (2008) Effect of drought stress at different growth stages on yield and water use efficiency of five proso millet (*panicum miliaceum* L.) genotypes. Pak J Bot. 40: 1427-1432.

Slafer GA and Savin R (1994) Sink-source relationships and grain mass at different positions within the spike in wheat. Field Crops Res. 37: 39-49.

Yadav OP and Bhatnagar SK (2001) Evaluation of indices for identification of pearl millet cultivars adapted to stress and non- stress conditions. Field Crops Res. 70: 201-208.

Yang DL, Jing R, Chang XP and Li W (2007) Identification of quantitative trait loci and environmental interactions for accumulation and remobilization of water-soluble carbohydrates in wheat (*Triticum aestivum* L.) stems. Genetics. 176:571–584.