INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 6, No. 2, p. 366-374, 2015

RESEARCH PAPER OPEN ACCESS

Evaluation of the relationship between gas exchange variables with grain yield in barley genotypes under terminal drought stress

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Key words: Barley, Grain yield, Photosynthetic rate, Stomatal conductance, Drought stress.

http://dx.doi.org/10.12692/ijb/6.2.366-374 Article published on January 27, 2015

Abstract

Drought stress is one of the major abiotic stresses in agriculture worldwide. This study was carried out to investigate the effect of drought stress at grain filling period on photosynthesis, gas exchange parameters and grain yield in twelve varieties of barley. To this end, an experiment was laid out in a split-plot arrangement based on randomized complete blocks design with three replications during 2010 to 2011 seasons at the field research of Razi University, Kermanshah state in the west of Iran. The results showed that post anthesis water deficiency caused 22 percent reduction in grain yield and had not signification effect on plant height. In addition, drought stress at grain filling period can considerably decreased leaf photosynthesis rate (Pn), stomatal conductance (gs) and transpiration rate (Tr), and increased sub-stomatal CO_2 concentration (Ci). The results showed that by imposing water deficit, Pn, gs and Tr was reduced in all studied barley genotypes. Pn, gs and Tr were statistically higher in full irrigation treatment as compared to drought stress by an average of 32.3, 19 and 15%, respectively. The decrease in the net photosynthetic rate in the grain filling stage of drought stress was related to the closure of stomata and decreased stomatal conductance. Our data revealed the better performance of 'Karoun' than 'Nosrat', 'Sararud' and other genotypes in the reduction rate of grain yield at maturity and photosynthetic features against soil water deficit conditions

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Introduction

Barely (*Hordeum vulgare* L.) is one of the five important crops that commonly used as human and animal feed and also malt production (FAOSTAT, 2010). Among all the factors limiting barley productivity, drought remains the single most important factor affecting the world security and sustainability in agricultural production. Drought is undoubtedly one of the most important environmental stresses limiting the productivity of crop plants around the world (Bohnert *et al.*, 1995; Farooq *et al.*, 2009).

The typical first response of all plants to water deficit is osmotic adjustment that is by synthesizing and accumulating compatible osmolyte such as proline, glycine betaine (GB) and reducing soluble sugars including monosaccharaides, disaccharides and oligosaccharides (Chaves *et al.*, 2003; Ashraf and Foolad, 2007). Also up-regulating of enzymatic antioxidant as superoxide dismutase (SOD), catalase (CAT) and peroxidase (POX) and also non-enzymatic antioxidants as vitamin E, carotenoids (carotene and xanthophyll) and soluble antioxidant including ascorbate and glutathione can is in order to overcome oxidative stress due to drought conditions (Esfandiari *et al.*, 2009; Gill and Tuteja, 2010; Liu *et al.*, 2011; Sarafraz-Ardakani *et al.*, 2014). In drought stress environment, some of plant uses drought escape mechanism and therefore, reduces vegetative and reproductive stages (Mohammadi *et al.*, 2006; Sabeti, 2011). Drought stress can influence on the procedure of cell expansion via physical and metabolic changes. For instance, a change in the slope of water potential can directly influence the cell's expansion (Kramer and Boyer, 1995). Along with the increasing of humidity stress, plant height decreases (Neilson and Nelson, 1998). Also, drought stress reduces plant height (Soler *et al.*, 2007), leaf area (Pandey *et al.*, 2000), shoot growth and grain yield (Zand-Parsa and Sepaskhah, 2001).

Photosynthesis, which is the most significant process influence crop production, is also inhibited by drought stress (Shangguan *et al.*, 2000). Water deficit inhibits photosynthesis by causing stomatal closure (stomatal factor) and metabolic damage (non-stomatal factor). Stomatal closure is one of the earliest responses of plants to water deficit that limits transpirational water loss and helps plants to retain water status under drought. However, closure of stomata in turn, results in reduction of CO_2 availability for photosynthetic carbon metabolism, depresses net CO_2 assimilation rate and inhibits plants ability for dry matter accumulation (Chaves *et al.*, 2009). In addition, declines in the CO_2 availability to the Calvin cycle enzymes result in lower regeneration of $NADP^+$ and production of excess excitation energy that damages photosystems (Hajiboland, 2014). Kirnak *et al.* (2001) have found that water stress results in significant decreases in chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth; and plants grown under high water stress have less fruit yield and quality. The present study aims to determine water deficit effects on photosynthesis and gas exchange parameters in leaves of twelve barley (*Hordeum vulgare* L.) genotypes and to determine the relationship between some morphological traits with grain yield under water deficit.

Materials and methods

Plant material and treatments

This research carried out during 2010 to 2011 growing season in the field research of Campus of Agriculture and Natural Resources, Razi University, Kermanshah state in the west of Iran (34° 20' N latitude, 47° 20' E longitude, elevation 1351 m above sea level) in the moderate-cold and semi-arid zone. The soil was a clay loam (39.1% clay, 37.7% silt and 23.2% sand) and the experiment was laid out in a split-plot arranged as a randomized complete blocks design with three replications. Two levels of moisture regimes i.e., well water (irrigation in all stages of plant growth normally) and drought stress (post anthesis water deficiency with withholding of irrigation) as the main-plot and different improved barley genotypes i.e., 'Aras', 'Afzal', 'Jonub', 'Reihan', 'Zarjo', 'Sararud', 'Sahra', 'Fajr-30', 'Karoun', 'Gorgan-4', 'Makuei' and 'Nosrat' as sub-plot were considered.

Some growing characteristics of genotypes used in the experiments are shown in Table 1. The seeds of barley genotypes were obtained from Seed and Plant Improvement Institute, Agricultural and Natural Resources Research Center of Kermanshah, Iran. Each plot included 6 rows 20 cm apart, 2 meters long, 3 and 1 meters distances were taken between test plots and replicates, respectively. Fertilizers were applied to the field according to the soil analysis. Seeds were sown at a density of 400 seeds m^{-2} on 12th October 2010. The experimental plots received similar management practices such as land preparation, weed control and etc. Date of anthesis was determined from middle rows in each plot when 50% of the spikes had extruded anthers (Ehdaie *et al*., 2006). Humidity and moderate temperatures during the crop season is presented in Table 2.

Gas exchange measurements

The net photosynthesis rate (Pn), stomatal conductance (gs), transpiration rate (Tr) and sub-stomatal CO_2 concentration (Ci) were measured using a portable photosynthesis system LI-6400 (LI-COR, Lincoln, USA) on the flag leaves on midday (09:00-12:00) at 14 day after anthesis. Photosynthetically-active radiation (PAR) of 1200-1600 μmol (photon) m^{-2} s^{-1} was provided at each measurement by the ambient CO_2 concentration of 380-400 ppm and full sunlight.

Grain yield and some agronomic traits

Grain yield for each genotype were measured by harvesting 1 m^2 of the central part of each plot at crop maturity. In order to measuring plant height, 10 plants randomly selected and measurement were performed.

Statistical analyses

Statistical analyses were performed using SAS statistical software (version 9.0). The significant differences between treatments were compared with the critical difference at 5% probability level by the Duncan's test. The figures were drawn using Excel software (version 10).

Results and discussion

Leaf photosynthetic rate and gas exchange

The main effects of moisture and genotype were highly significant for all the measured traits (Figure 1). Also, the interaction between genotype by moisture was also significant for all gas exchange traits. Leaf gas exchange parameters indicated that under soil moisture stress net photosynthesis rate (Pn), stomatal conductance (gs) and transpiration rate (Tr) declined in all genotypes tested. The mean decreases were 32.3%, 19% and 15%, respectively (Figures 1A, B, C). The results in this experiment confirmed several previous studies showing that water deficit stress significantly affects gas exchange, water relations and physiology in wheat, tomato and other plant (Srinivasa Rao *et al*., 2001; Tahi *et al*., 2007; Saeidi *et al*., 2010; Ghaderi *et al*., 2011; Nguyen *et al*., 2012; Abdoli and Saeidi, 2013).

Table 1. Characteristics of genotypes used in the experiments.

Number	Name	Characteristics		
		Number or rows per spike	Growth habit	Source
No. 1	Aras	Two rows	Winter	SPII †
No. 2	Afzal	Six rows	Winter	SPII
No. 3	Jonub	Six rows	Winter	SPII
No. 4	Reihan	Six rows	Winter	SPII
No. 5	Zarjo	Six rows	Winter	SPII
No. 6	Sararud	Two rows	Winter	SPII
No. 7	Sahra	Six rows	Winter	SPII
No. 8	Fajr-30	Six rows	Winter	SPII
No. 9	Karoun	Six rows	Winter	SPII
No. 10	Gorgan-4	Two rows	Winter	SPII
No. 11	Makuei	Six rows	Winter	SPII
No. 12	Nosrat	Six rows	Winter	SPII

† Seed and Plant Improvement Institute of Iran.

Under well-watered conditions, 'Fajr-30' and 'Sahra' had the highest Pn (14.2 and 12.2 µmol(CO_2) m^{-2} s^{-1}, respectively) and 'Zarjo' and 'Karoun' the lowest (9.5 and 9.3 µmol(CO_2) m^{-2} s^{-1}, respectively). Under drought stress 'Sahra' and 'Afzal' had the highest (9.2 µmol(CO_2) m^{-2} s^{-1}) and lowest (5.8 µmol(CO_2) m^{-2} s^{-1}) Pn values, respectively (Figure 1 A). Results revealed that Pn and gs in 'Karoun', 'Makuei' and 'Reihan' was lower influenced by drought stress in comparison to other genotypes (Figure 1). Azizian and Sepaskhah (2014) reported that Pn and gs were statistically decreased in water deficit by an average of 30 and 43% as compared to full irrigation treatment, respectively. Abdoli and Saeidi (2013) reported that net photosynthesis rate generally decreased with chlorophyll content and also this was paralleled by a lower stomatal conductance. Stomatal closure is one of the earliest responses of plants to water deficit that limits transpirational water loss and helps plants to retain water status under drought. However, closure of stomata in turn, results in reduction of CO_2 availability for photosynthetic carbon metabolism, depresses net CO_2 assimilation rate and inhibits plants ability for dry matter accumulation (Chaves *et al.*, 2009; Zoubeir *et al.*, 2012).

Table 2. Mean of minimum (T min) and maximum (T max) air temperature, minimum (RH min) and maximum (RH max) relative humidity and also total rainfall at the site of experiment during 2010-2011.

Characteristic	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
T min (°C)	10.6	4.5	-1.5	-2.2	-2.7	0.6	4.5	9.5	12.8
T max (°C)	30.3	21.9	16.8	9.6	8.0	15.4	20.1	23.6	33.8
Rainfall (mm)	1	31	24	50	65	21	47	128	0
RH min (%)	13.2	22.8	26.5	47.1	52.1	28.1	24.6	33.6	11.3
RH max (%)	46.4	66.8	62.4	91.0	94.2	82.0	78.8	87.4	51.1

Source: Meteorological Office, Iran.

Drought conditions, as expected, reduced stomatal opening and in consequence, decreased net transpiration rates. In general, resistant genotypes performed higher Pn, gs and Tr than susceptible ones under either conditions (Figure 1). Under controlled conditions, 'Afzal' and 'Gorgan-4' had the lowest stomatal conductance (0.073 mol m^{-2} s^{-1}) and 'Sahra' and 'Makuei' the highest (0.130 mol m^{-2} s^{-1}) (Figure 1 B). Minimum and maximum gs under drought stress was observed in 'Afzal' and 'Makuei' (0.063 and 0.113 mol m^{-2} s^{-1}, respectively). Plants respond to drought primarily by closing stomata for minimizing water loss (Yordanov *et al.*, 2003; Chaves *et al.*, 2009). The decrease in stomatal conductance may be derived from the decrease in hydraulic conductivity between soil and plant or from the shortage in the oxygen supply to the root system (Vartapetian and Jackson, 1997; Mohd *et al.*, 2010).

The averages of sub-stomatal CO_2 concentration (Ci) of different genotypes in controlled condition were 166 µmol(CO_2)/mol air, while under water deficiency stress these values significantly increased to 208 µmol(CO_2)/mol air (Figure 1C). Aghaee and Ehsanzadeh (2011) reported that water deficit led to decreases in Pn and gs, but it led to increases in Ci. Also, reported it seems that water deficit stress leaves negative impacts on all components of photosynthesis in oilseed pumpkin (*Cucurbita pepo* L.), including photosynthetic surfaces, stomatal closure and mesophyll cell activities. For genotypes, Ci was increased significantly under water deficits (Figure 1C); the increase percentage in 'Aras' and 'Afzal' (52.4% and 64.8%, respectively) was higher than 'Jonub' and 'Sararud' (9.1% and 9.5%, respectively) under drought stress condition. But, under mild or moderate drought stress stomatal closure (causing reducted leaf internal CO_2 concentration) is the major reason for reduced rates of leaf photosynthetic (Chaves, 1991; Cornic, 2000; Flexas *et al.*, 2004).

Mean comparisons showed that 'Fajr-30' with 4.80 mol(H_2O) m^{-2} s^{-1} and 'Aras' with 2.55 mol(H_2O) m^{-2} s^{-1}, respectively had the highest and the lowest transpiration rate under non-stress condition (Figure 1 D). But, under drought stress environment 'Sahra' and 'Makuei' genotypes with 3.38 and 3.55 mol(H_2O) m^{-2} s^{-1} and also, 'Jonub' with 1.99 mol(H_2O) m^{-2} s^{-1}, respectively had the highest and the lowest transpiration rate (Figure 1 D). The decrease in the transpiration rate per leaf area of drought stress was related to the closure of stomata and decreased stomatal conductance (Abdoli and Saeidi, 2013). According to Chaves *et al.* (2003) discrepancies in results concerning the contribution of stomatal and non-stomatal factors in photosynthesis inhibition may be explained by differences in the rate of imposition and severity of stress, developmental stage and plant condition, species studied and superimposition of other stresses.

In full irrigation and water-withholding at anthesis conditions, a positive correlation was found between Pn and transpiration rate. Also, a positive correlation was found between gs and transpiration rate (Figure 3). Tavakoli *et al.* (2011) reported that the correlation of photosynthesis and stomatal conductance showed that the stomatal limitation was very important than non-stomatal limitation.

Grain yield and agronomic traits

The results obtained from mean comparison analysis of grain yield and plant height are shown in Figure 2. Showed that post anthesis water deficiency stress caused 22% reduction in grain yield. The averages of grain yield of different genotypes in well watered condition were 6130 kg ha^{-1}, while under water deficiency stress these values significantly reduced to 4783 kg ha^{-1}. Closure of stomata and decrease in CO_2 concentration as an initial response to water stress inhibited dry mater production due to limitation of photosynthesis (Ready *et al.*, 2004) and so that decreased of grain yield. Gupta *et al.* (2001) evaluated two spring wheat genotypes, Kalyansona and C-306, for yield and yield attributes and noted that water stress caused significant reduction in plant height, leaf area, number of grain per spike, test weight and yield.

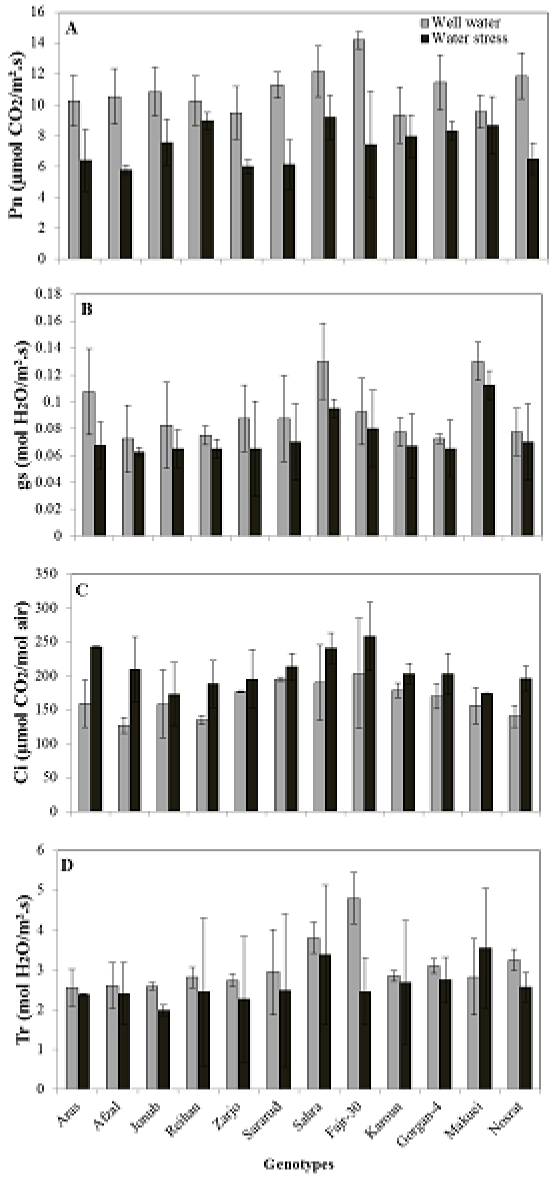

Fig. 1. Influence of drought stress on net photosynthetic rate, Pn (A), stomatal conductance, gs (B), sub-stomatal CO_2 concentration, Ci (C) and transpiration rate, Tr (D) of flag leaf (14 days after anthesis) of barley genotypes. Vertical bars represent ± standard deviation (SD).

The results showed that there were significant differences among genotypes in respect to grain yield under non-stress condition. Also, significant differences were observed among genotypes under stress condition (Figure 2). These results demonstrate high diversity among genotypes that enable us to select genotypes under non-stress and stress environments. Mean comparisons showed that 'Nosrat', 'Karoun' and 'Jonub' genotypes with 8383, 7777 and 7483 kg ha^{-1}, respectively had the highest and 'Afzal' with 3919 kg ha^{-1} had the lowest grain yield under non-stress condition (Figure 2 A). But, under drought stress environment 'Nosrat', 'Karoun' and 'Sararud' genotypes with 6959, 6561 and 6300 kg ha^{-1} and also, 'Afzal', 'Sahra' and 'Aras' genotypes with 3393, 3268 and 3219 kg ha^{-1}, respectively had the highest and the lowest grain yield (Figure 2 A).

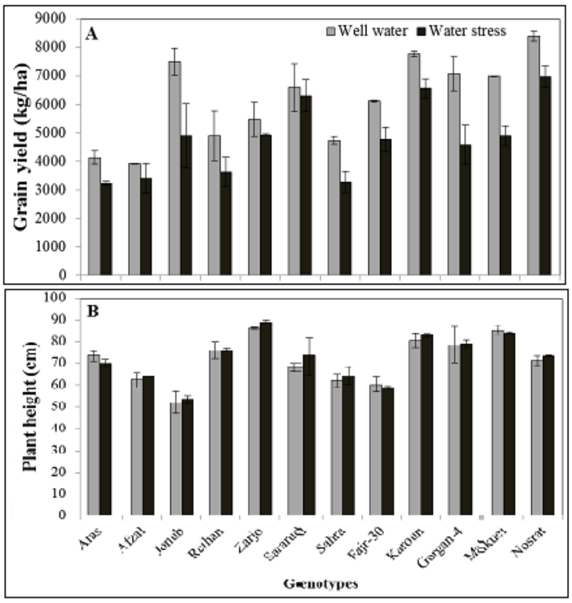

Fig. 2. Influence of drought stress on grain yield (A) and plant height (B) of barley genotypes. Vertical bars represent ± standard deviation (SD).

Blum and Pnuel (1990) reported that the final grain yield and its associated traits of bread wheat were significantly decreased due to water stress. Reduction in kernel weight of wheat was also reported by various other researchers (Anjum *et al.*, 2011; Abdoli and Saeidi, 2012). Kar *et al.* (2007) observed that under water deficit condition, supplemental irrigation during reproductive phases had a significant effect on increasing seed yield. Water stress at flowering negatively influenced the formation of grain, grain size, resulting in lower final grain yield.

The results showed that, plant height was no significantly affected by water deficit after anthesis stage (Figure 2 B). 'Zarjo', 'Makuei' and 'Karoun' had the longest stem (87.5, 84.4 and 81.6 cm, respectively) and 'Jonub' lower stem length (52.6 cm) (Figure 2 B). Richards *et al.* (2001) have reported that one of the major effects of water stress is to decrease plant height, which also caused a reduction in dry matter accumulation and subsequently plant production.

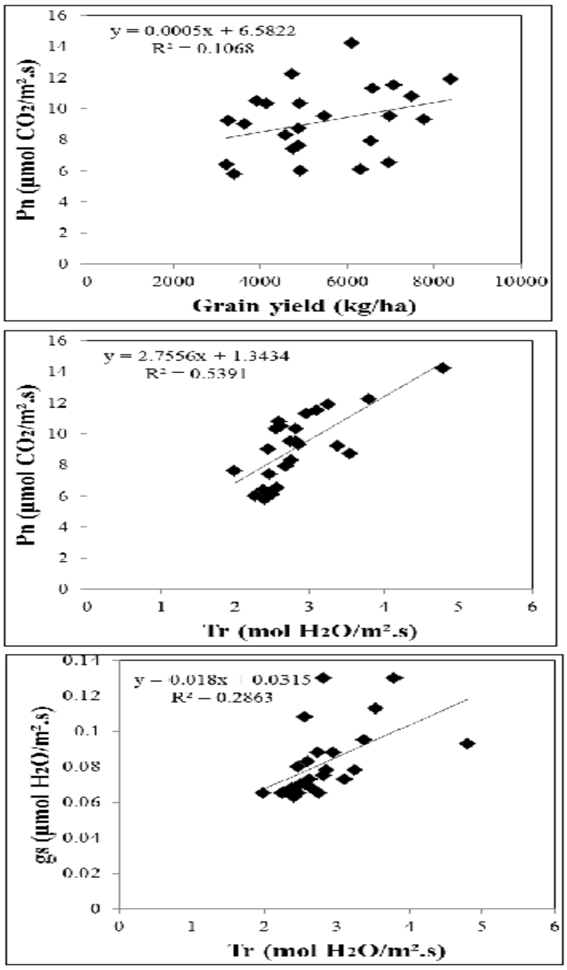

Fig. 3. Relationship between the grain yield (GY), net photosynthesis rate (Pn), stomatal conductance (gs) and transpiration rate (Tr) of barley genotypes under drought stress.

Conclusion

In conclusion, results of this study indicated that drought stress at grain filling period can considerably decrease grain yield of barley, as well as significantly reduced gas exchange parameters such as Pn, gs and Tr, and increased sub-stomatal CO_2 concentration, but had not signification effect on plant height. Overall, 'Karoun' genotype was less affected by water deficit in comparison with other genotypes in terms of photosynthetic function as indicated by less reduction in gas exchange and agronomic traits. The results of present research may contribute toward choosing parents for stress tolerance breeding in Iranian barley genotypes.

Acknowledgments

The authors would like to thank their Colleagues in Campus of Agricultura and Natural Resources, Razi University, Kermanshah, Iran. Also, we are extremely thankful to Mrs. Maryam Khas-Amiri for excellent technical assistance in some phases of this study.

References

Abdoli M, Saeidi M. 2012. Using different indices for selection of resistant wheat cultivars to postanthesis water deficit in the west of Iran. Annals of Biological Research **3,** 1322-1333.

Abdoli M, Saeidi M. 2013. Evaluation of water deficiency at the post anthesis and source limitation during grain filling on grain yield, yield formation, some morphological and phonological traits and gas exchange of bread wheat cultivar. Albanian Journal of Agricultural Sciences **12(2),** 255-265.

Aghaee AH, Ehsanzadeh P. 2011. Photosynthetic attributes of oilseed pumpkin (*Cucurbita pepo* L.) under different irrigation and nitrogen regimes. 2nd Iranian Conference on Plant Physiology, Yazd, p 18.

Anjum SA, Wang LC, Farooq M, Hussain M, Xue LL, Zou CM. 2011. Brassinolide application improves the drought tolerance in maize through modulation of enzymatic antioxidants and leaf gas exchange. Journal of Agronomy and Crop Science **197(3),** 177-185.
http://dx.doi.org/10.1111/j.1439-037X.2010.00459.x

Ashraf M, Foolad MR. 2007. Roles of glycine betaine and proline in improving plant abiotic stress resistance. Environmental and Experimental Botany **59,** 206-216.
http://dx.doi.org/10.1016/j.envexpbot.2005.12.006

Azizian A, Sepaskhah AR. 2014. Maize response to water, salinity and nitrogen levels: physiological growth parameters and gas exchange. International Journal of Plant Production **8(1),** 131-162.

Blum A, Pnuel Y. 1990. Physiological attributes associated with drought resistance on wheat cultivars in a Mediterranean environment. Australian Journal of Agriculture Research **41,** 799-810.
http://dx.doi.org/10.1071/AR9900799

Bohnert HJ, Nelson DE, Jensen RG. 1995. Adaptations to environmental stress. Plant Cell **7,** 1099-1111.
http://dx.doi.org/10.1105/tpc.7.7.1099

Chaves MM, Flexas J, Pinheiro C. 2009. Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. Annals Botany **103,** 551-560.
http://dx.doi.org/10.1093/aob/mcn125

Chaves MM, Maroco JP, Pereira JS. 2003. Understanding plant responses to drought - from genes to the whole plant. Function Plant Biology **30,** 239-264.
http://dx.doi.org/10.1071/P9930639

Chaves MM. 1991. Effects of water deficits on carbon assimilation. Journal of Experimental Botany **42,** 1-16.
http://dx.doi.org/10.1093/jxb/42.1.1

Cornic G. 2000. Drought stress inhibits photosynthesis by decreasing stomatal aperture – not by affecting ATP synthesis. Trends in Plant Science **5,** 187-188.
http://dx.doi.org/10.1016/S1360-1385(00)01625-3

Ehdaie B, Alloush GA, Madore MA, Waines JG. 2006. Genotypic variation for stem reserves and mobilization in wheat: II. Post anthesis changes in internode water-soluble carbohydrate. Crop Science **46,** 2093-2103.
http://dx.doi.org/10.2135/cropsci2006.01.0013

Esfandiari E, Shakiba MR, Mahboob SA, Alyari H, Baradaran Firozabadi M. 2009. Effect of water stress on antioxidant enzymes activities and lipid peroxidation of wheat seedlings. Journal of Agriculture Knowledge **19(2),** 129-138.

FAO. (Food and Agriculture Organization of the United Nations). 2010. FAOSTAT. http://faostat.fao.org/

Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA. 2009. Plant drought stress: effects, mechanisms and management. Agronomy for Sustainable Development **29,** 185-212. http://dx.doi.org/10.1051/agro:2008021

Flexas J, Bota J, Loreto F, Cornic G, Sharkey TD. 2004. Diffusive and metabolic limitations to photosynthesis under drought and salinity in C_3 plants. Plant Biology **6,** 1-11. http://dx.doi.org/10.1055/s-2004-815737

Ghaderi N, Talaie AR, Ebadi A, Lessani H. 2011. The physiological response of three Iranian grape cultivars to progressive drought stress. Journal of Agricultural Science and Technology **13,** 601-610.

Gill SS, Tuteja N. 2010. Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. Plant Physiology and Biochemistry **48,** 909-930. http://dx.doi.org/10.1016/j.plaphy.2010.08.016

Gupta NK, Gupta S, Kumar A. 2001. Effect of water stress on physiological attributes and their relationship with growth and yield of wheat cultivars at different stages. Journal of Agronomy and Crop Science **186,** 55-62. http://dx.doi.org/10.1046/j.1439-037x.2001.00457.x

Hajiboland R, Sadeghzadeh N. 2014. Effect of selenium supplementation on CO_2 and NO_3^- assimilation under low and adequate N supply in wheat (*Triticum aestivum* L.) plants. Photosynthetica In press, http://dx.doi.org/10.1007/s11099-014-0058-1

Kar G, Kumar A, Martha M. 2007. Water use efficiency and crop coefficients of dry season oil seed crops. Agricultural Water Management **87,** 73-82.. http://dx.doi.org/10.1016/j.agwat.2006.06.002

Kirnak H, Kaya C, Tas I, Higgs D. 2001. The influences of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. Bulgarian Journal of Plant Physiology **27(3-4),** 34-46.

Kramer PJ, Boyer JS. 1995. Water Relations of Plants and Soils. Academic Pres, New York.

Liu C, Liu Y, Guo K, Fan D, Li G, Zheng Y, Yu L, Yang R. 2011. Effect of drought on pigments, osmotic adjustment and antioxidant enzymes in six woody plant species in karst habitats of south western China. Environmental and Experimental Botany **71,** 174-183. http://dx.doi.org/10.1016/j.envexpbot.2010.11.012

Mohammadi AA, Eslam Majidi H, Bi Hamta MR, Heydari Sjharif Abad H. 2006. The evaluation of drought stress for morphological characteristics of agriculture in some cultivars of rice. Journal of Research and Constructing in Husbandry **73,** 184-192.

Mohd I, Shamsul H, Qaiser H, Shaheena A, Aqil A. 2010. Physiological and biochemical changes in plants under waterlogging. Protoplasma **241,** 3-17. http://dx.doi.org/10.1007/s00709-009-0098-8

Neilson DC, Nelson NO. 1998. Black bean sensitivity to water stress at various growth stages. Crop Science **28,** 422-427. http://dx.doi.org/10.2135/cropsci1998.0011183X003800020025x

Nguyen TT, Fuentes S, Marschner P. 2012. Effects of compost on water availability and gas exchange in tomato during drought and recovery. Plant Soil Environmental **58(11),** 495-502.

Pandey RK, Maranville JW, Admou A. 2000. Deficit irrigation and nitrogen effects on maize in a Sahelian environment. I. Grain yield and yield

components. Agricultural Water Management **46,** 1-13.
http://dx.doi.org/10.1016/S0378-3774(00)00073-1

Richards RA, Condon AG, Rebetzke GJ. 2001. Traits to improve yield in dry environments. In: Application of Physiology in Wheat Breeding. (Eds): Reynolds, M.P. Ortiz Monasterio, J.I. and McNab, A. Mexico, CIMMYT. 88-100 p.

Sabeti A. 2011. The study of drought stress on morpho-physiological characteristics of rice in density and planting geometry in Khoram Abad region. Ph.D. Dissertation. Olum Tahghighat University. p. 190. Tehran Iran.

Saeidi M, Moradi F, Ahmadi A, Spehri R, Najafian G, Shabani A. 2010. The effects of terminal water stress on physiological characteristics and sink-source relations in two bread wheat (*Triticum aestivum* L.) cultivars. Iranian Journal of Crop Science **12(4),** 392-408.

Sarafraz-Ardakani MR, Khavari-Nejad RA, Moradi F, Najafi F. 2014. Abscisic acid and cytokinin-induced carbohydrate and antioxidant levels regulation in drought-resistant and -susceptible wheat cultivar during grain filling under field conditions. International Journal of Biosciences **5(8),** 11-24.
http://dx.doi.org/10.12692/ijb/5.8.11-24

Shangguan ZP, Shao MA, Dyckmans J. 2000. Nitrogen nutrition and water stress effects on leaf photosynthetic gas exchange and water use efficiency in winter wheat. Environmental and Experimental Botany **44,** 141-149.
http://dx.doi.org/10.1016/S0098-8472(00)00064-2

Soler CMT, Hoogenboom G, Sentelhas PC, Duarte AP. 2007. Impact of water stress on maize grown off-season in a subtropical environment. Journal of Agronomy and Crop Science **193,** 247-261.
http://dx.doi.org/10.1111/j.1439-037X.2007.00265.x

Srinivasa Rao NK, Bhatt RM, Sadashiwa AT. 2001. Tolerance to water stress in tomato cultivars. Photosynthetica **38,** 465-467.
http://dx.doi.org/10.1023/A:1010902427231

Tahi H, Wahbi S, Wakrim R, Aganchich B, Serraj R, Centritto M. 2007. Water relations, photosynthesis, growth and water-use efficiency in tomato plants subjected to partial root zone drying and regulated deficit irrigation. Plant Biosystems **141,** 265-274.
http://dx.doi.org/10.1080/11263500701401927

Tavakoli A, Ahmadi A, saeidi M, Madah Hossani S. 2011. Study of water relation and gas exchange in drought tolerant and susceptible wheat (*Triticum aestivum* L.) cultivars under post-anthesis drought stress condition. 2nd Iranian Conference on Plant Physiology, Yazd, 124.

Vartapetian BB, Jackson MB. 1997. Plant Adaptation to an Aerobic Stress. Annals of Botany **79 (Suppl. A),** 3-20.

Yordanov V, Velikova T, Tsonev V. 2003. Plant responses to drought and stress tolerance. Bulgarian Journal of Plant Physiology Special Issue, 187-206.

Zand-Parsa S, Sepaskhah AR. 2001. Optimal applied water and nitrogen for maize. Agricultural Water Management **52(1),** 73-85.
http://dx.doi.org/10.1016/S0378-3774(01)00106-8

Zoubeir B, Ali A, Mohammed S, Lamhamedi Mejda A, Mohamed H. 2012. Adaptation and morpho-physiology of three *Populus deltoides* Marsh. × *P. nigra* L. clones after preconditioning to prolonged waterlogging. Agroforestry Systems **86,** 433-442.
http://dx.doi.org/10.1007/s10457-012-9487-7