Biological Forum – An International Journal **7**(1): 1529-1536(2015)

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Response of some Maize Hybrids to Water Stress at Pollination Phase

Jamileh Seyedzavar and Amir Fayaz Moghadam
Department of Agronomy and Plant Breeding,
Faculty of Agriculture, University of Uremia, IRAN

(Corresponding author: Jamileh Seyedzavar)
(Received 29 March, 2015, Accepted 15 May, 2015)
(Published by Research Trend, Website: www.researchtrend.net sjamileh@gmail.com)

ABSTRACT: In order to evaluation the response of some maize hybrids to water deficit stress, a field experiment in 2010 with maize hybrids was conducted using a split-plot plan with complete randomized block design in four replications at the agricultural research station, university of Tabriz (Khalatpoushan). Main plots included three different irrigation regimes (Non-Stress, Milddle-stress and Severe-stress) and sub plots included 14 maize hybrids. Results showed significant differences among hybrids and irrigation regimes for all studied traits. Analysis of variance revealed significant differences between Hybrids and also irrigation levels for all traits. In the present study, grain yield had a positive-significant correlation with number of tassel branches and number of leaves per ear. This research suggests that there is considerable variation among studied hybrids in water stress at pollination stage. Since anthesis was found as the highest sensitive stage to water stress, to avoid high grain yield reduction, favorable soil water condition must be provided in irrigation schedual.

Keywords: water stress, pollination stage, maize, grain yield.

INTRODUCTION

Corn (*Zea mays* L.) is one of the important cereal crops in the world and Iran after wheat and rice (Alvi *et al.*, 2003; Gerpacio and Pingali, 2007). Maize crop plays an important role in the world economy and is valuable ingredient in manufactured items that affect a large proportion of the world population (Alvi *et al.*, 2003).

Corn is produced primarily for animal feed and industrial uses and it is portioned as follow; about 35% for human nutrient requirement and about 65% for animal feed (Kusaksiz, 2010). Corn is used as food and feed for livestock and meets the requirements of material in different industries such as food, medicine and textile (Ali *et al.*, 2011).

Selection is a widely used and successful method in plant breeding. Response to selection depends on many factors such as the interrelationship of the characters. Plant breeders work with some yield components related to yield in the selection programs and it is very important to determine relative importance of such characters contributing to grain yield directly or indirectly (Joshi, 2005).

Grain yield is a complex trait that is influenced by a large number of physiological processes. These processes are manifested in growing, morphological and physiological traits, and these traits are measurable (Hobbs and Mahon, 1982). Studies evaluating direct and indirect effects on yield components associated with the heritability, can significantly improve the efficiency of breeding programs through the selection indices (Kashiani *et al.*, 2010).

It is a "single most common cause of severe food shortage" (FAO) in developing countries and predicted global warming in XXI century will increase drought impact on crop production. Drought can be defined as the absence of adequate moisture necessary for normal plant growth and to complete the life cycle (Zhu, 2002). Estimations of Intergovernmental Panel on Climate Change (IPCC, www.ipcc.org) are that between 1990 and 2100, globall increase of temperature will be 1.4 to 5.8 °C. Although the effect of this warming will be regionally distributed, it is assumed that increase in temperature, reduction in rainfalls, together with increase of incidents of insects and pests will reduce crops grain yield, particularly in tropical and subtropical area (Ribaut, 2006).

Drought stress is considered one of the most common factors of limiting plant growth in arid and semiarid regions (Turhan and Baser, 2004). Drought pressure was classified as one of the most deleterious environmental stresses which restrict crop production (Alahdadi *et al.*, 2011; Khodarahmpour, 2011; Oraki *et al.*, 2011; Song *et al.*, 2010; Sinaki *et al.*, 2007) and 20-25 percent of the planting area of maize is affected by drought pressure in the world (Golbashy *et al.*, 2010).

Variation in water availability (interannual or intraseasonal) is the prevalent limitation to crop production systems in most regions of the world-over 80% of total global agricultural land is rain field (Easterling *et al.* 2007). Security of food in the world relies on growth and development of plants which are highly tolerated to abiotic stresses particularly drought (Ali *et al.*, 2011 and Jaleel *et al.*, 2009). Currently selection criteria are applied for good variety selection as compare to breeding techniques which are time consuming (Zhu, 2002). The effect of temperature (and drought) in reducing the length of the growth cycle, especially the grain filling phase, is the most important factor in explaining reduced yields at warmer temperatures (White & Reynolds 2003). It is a fact that when drought stress starts to affect the plant during the reproductive stage the plant reduces the demand of carbon by decreasing the size of sink. As a result of it tillers degenerate, flower may drop, pollen may die and ovule may abort (Blum, 1996).

The flowering and pod setting stages appear to be the most sensitive stages to water stress. Researches indicated that water deficit during reproductive growth was more effective than that during vegetative growth of rapeseed (Nayyar *et al.* 2006; Ghobadi *et al.* 2006).

Heat or drought stress during the maize silk-tasseling phase (flowering and pollination) have been observed to reduce yields by as much as 7% per day of stress, a greater yield reduction than for all other potential climatic stresses (Shaw 1977). Khodarahmpour and Hamidi (2012) showed that the grain yield reduced 15, 40, and 60 percent respectively due to stress during at the vegetative growth, pollination and grain filling.

Similarly, increased temperatures (and deficit of water) during a plant's reproductive period, when grain filling occurs, indirectly cause yield reductions. Yields are significantly correlated with the duration of the reproductive period (correlation of r = 0.81; Cross, 1975). Limited irrigation at critical stages of growth and development may be crucial for recognition of tolerant maize varieties. Thus, the objective of this research was to evaluate the performance of maize cultivars under water deficit stress at pollination stage.

MATERIALS AND METHODS

A split plot experiment (using RCB design) with four replications was conducted in 2010 at the Research Farm of the Faculty of Agriculture, University of Tabriz, Iran, in order to determine response of some corn hybrids to water stress. Irrigation treatments (NWS: non-water stress, MWS: middle water stress and SWS: severe water stress) were located in main plots and 14 corn hybrids were allocated to sub plots. The name of hybrids was:

SC700, SC704, KSC705, SC706, SC702, SC670, SC647, SC604, K166 × K18, DC370, K48 × K19, SC500, K3647 × K18 and SC400

Seeds of corn hybrids were sown by hand on 6 June 2010. Different water stress treatments (I1, I2 and I3; 40, 70 and 120 mm evaporation from class A pan, respectively) applied after completing the pollination. Several morphological traits were measured under control and water stress conditions. Data were recorded on 10 competitive plants of each plot and grain yield (kg ha^{-1}) and yield component was calculated for the entire plot. Some of the studied traits were:

Length of silk (LS), length of tassel (LT), number of tassel branches (NTB), number of leaves per ear (NLE), grain depth in cob (GDC), grain width (GW), cob diameter (CD) and grain yield per plant (GY).

All the data were analyzed on the bases of experimental design, using SAS 9.1 software. Duncan multiple range test was applied to compare means of each trait at 5% probability.

RESULTS AND DISCUSSION

Analysis of variance of the data for yield and yield components of maize cultivars showed that Length of silk ($p < 0.01$), length of tassel branches ($p < 0.01$), number of tassel branches ($p < 0.01$), number of leaves per ear ($p < 0.01$), grain depth in cob ($p < 0.01$), grain width ($p < 0.01$), cob diameter ($p < 0.05$) and grain yield per plant ($p < 0.01$) significantly affected by drought stress (Table 1).

Means of all traits except cob diameter were decreased under water stress. Because of water deficit cob diameters increased. (Table 2). Pandy *et al.* (2000) reported that, deficit irrigation in reproductive stage plenty reduced most of yield component traits.

In the total SC702 had the lowest dimension of grain (Fig. 1 and Fig. 2) and had the highest cob diameter under average stress condition (Fig. 3).

Table 1: Analysis of variance for studied traits under water stress at pollination stage.

S.O.V	df	MS							
		LS (Cm)	LTB (Cm)	NTB	NLE	GDC (Cm)	GW (Cm)	CD	Grain yield (gr)
Replication	3	1.808 ns	41.505 ns	5.304**	2.122 ns	0.006ns	0.004 ns	0.007 ns	6405.96*
Stress	2	9.566**	129.701*	217.2**	20.76**	0.051*	0.033*	0.363**	60390.2**
Erorr1	6	1.404	17.662	0.179	4.79	0.005	0.005	0.011	717.67
Hybrid	13	19.471**	52.397**	45.83**	11.77**	0.030**	0.024 **	0.108*	6720.58**
Hybrid*Stress	26	1.052 ns	0.024 ns	4.128 ns	0.67 ns	0.001 ns	0.001 ns	0.026 ns	673.18 ns
Erorr2	117	1.429	5.545	5.78	0.609	0.005	0.008	0.056	797.15
CV (%)		12.22	5.61	13.51	8.21	7.08	6.62	8.68	18.19

ns . *,** : non-Significant, Significant at 0.05 and 0.01 probability level, respectively.

Table 2: Comparison of means of yield component and grain yield of maize under water stress at pollination stage.

Treats	LS (Cm)	LTB (Cm)	NTB	NLE	GDC (Cm)	GW (Cm)	CD (Cm)	GY (Gr)
Non-stress	10.141a	43.351a	19.735a	10.114a	1.041a	0.836a	2.683 b	188.655a
Middle stress	9.878 a	42.050b	17.855b	9.5108b	1.030 a	0.848a	2.721b	153.799b
Severe stress	9.331c	40.317c	15.798c	8.896c	0.984 b	0.815b	2.838 a	123.020c

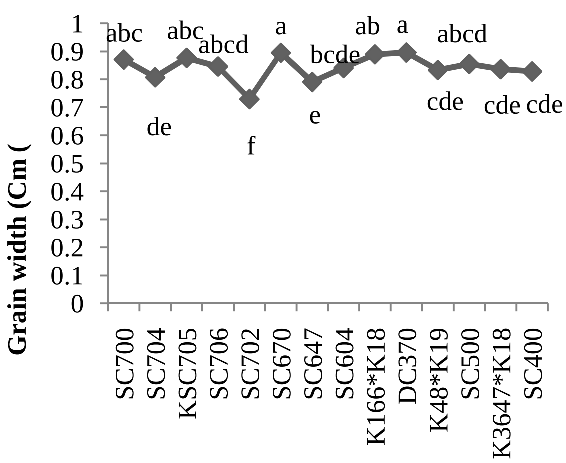

Fig. 1. The comparison of the grain width in the average levels of water deficit

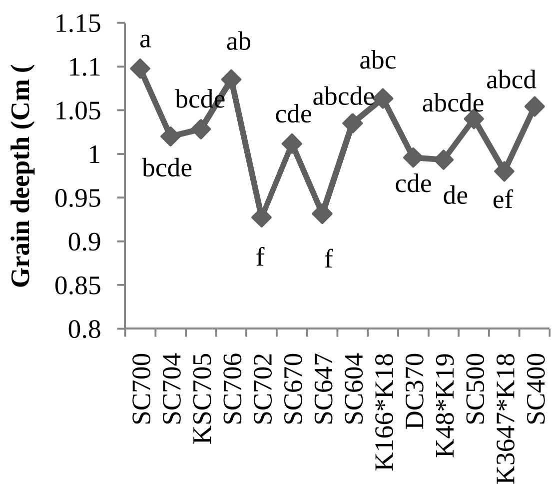

Fig. 2. The comparison of grain deepth in the average levels of water deficit

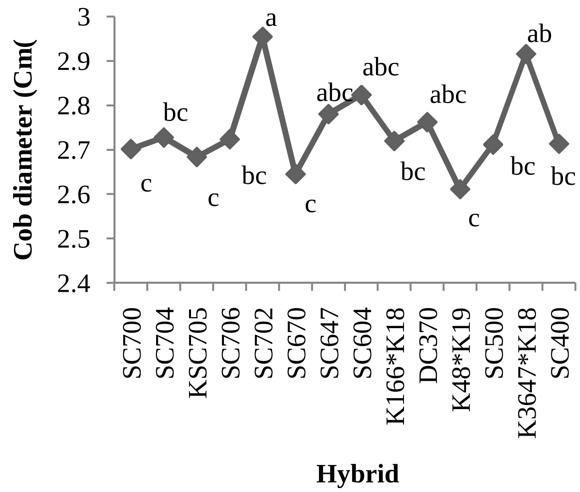

Fig. 3. The comparison of the cob diameter in the average levels of water deficit

Removal of leaf and tassel reduces yield and grain number. Corn tassel is an organ that after pollination absorbs 20-40% of intercepted radiation at high densities and decreases the radiation intercepted by leaves (Dungan and Hatfield, (1965)). In the present study hybrids K166xK18 and SC500 had the maximum number of tassel branches and hybrids SC704, SC702 and SC647 had the minimum of that (Fig. 4).

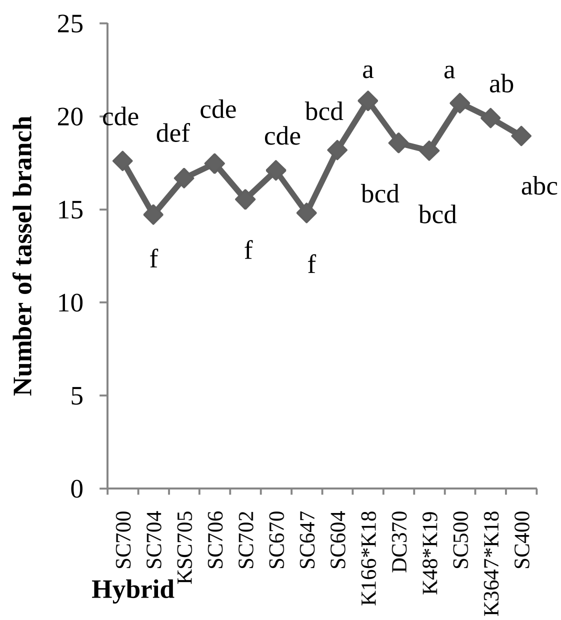

Fig. 4. The comparison of the number of tassel branches in the average levels of water deficit.

Optimal leaf area establishment is vital criterion for photosynthesis maintenance and dry matter production. Photosynthetic pigments are used specially for capturing light and reducing powers production (Farooq *et al.*, 2009). Photosynthesis directly depends on relative water contents and leaf water potential. Decrease in relative water contents and leaf water potential decreases the speed of photosynthesis (Lawlor and Cornic, 2002). In this study hybrids SC500, K3647xK18 and SC400 had the highest number of leaves per ear and hybrids SC700, SC704 and KSC705 had the lowest of that (Fig 5).

Due to shortage of water to maize crop grain yield reduced if water deficit occurs during the critical growth stages from tasseling to grain filling. Drought stress before one week to silking and two weeks after silking decreased the grain yield (53% of the non-drought stressed) (Classen and Shaw 1970). Maximum grain yield under average stress condition was showed in SC500 against of SC704, KSC705, SC702, SC647 (Fig. 6).

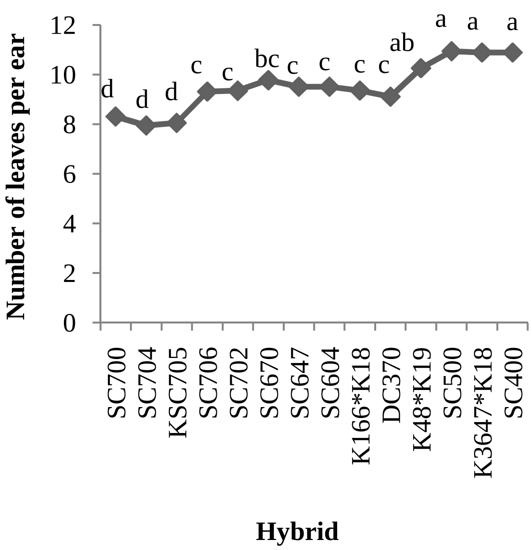

Fig. 5. The comparison of the number of leaves per ear in the average levels of water deficit

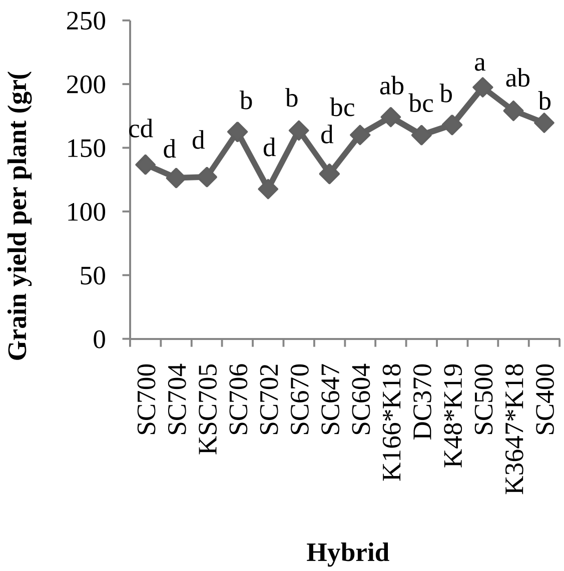

Fig. 6. The comparison of grain yield in the average levels of water deficit

Obviously reducing the grain width and depth leads to reduction in size and weight of the grain. Water stress in maize because of the leaves wilting, cause to reduced photosynthesis and photosynthetic material transfer. This action by prevent from grain development, finally reduced grain weight (Nelson, 2003). Mojadam (2006) concluded that grain yield, dry matter of ear, cob, stem, leaves, plant height, and ear length significantly reduced in response to water deficit stress. Alavi Fazel and Lak (2011) reported that the highest grain yield was obtained at the optimum irrigation and grain yield reduced up to 35 percent due to stress at the pollination. Payero et al. [26] showed that drought stress significantly decreases the maize grain yield. Frederick et al. (2001) reported that, drought stress happening between initial flowering and grain fill decreases total grain yield primarily by reducing branch vegetative growth, which reduces branch grain number and branch grain yield.

In the present study, grain yield had a positive-significant correlation with number of tassel branches (0.888) and number of leaves per ear (0.765) (Table 3). Setter *et al.*, (2001) stated that water stress at pollination stage affected grain formation process in the corn through reducing leaves photosynthesis and reduced the number of grain per ear due to increasing the production of sterile pollen which was resulted from assimilate deficiency. Dry weight loss and reduce of photosynthetic materials due to water limitation have also been reported by other researchers such as Osborne et al. (2002). The increment of dry mater is because of higher use of light due to expansion of leaf area under normal irrigation (irrigation after 70 mm evaporation) condition. Lak et al. (2007) also emphasized that reduction in plant dry matter production under irrigation after 130 mm evaporation due to the negative impact of drought stress on ear dry weight (51% reduction) because in corn, cob is an important component of the plant. Scarisbrick and Daniels (1986) showed that 20% of total dry matter weight could be reduced because of drought stress during flowering period.

Water stress around flowering and pollination delays silking, reduces silk length, and inhibits embryo development after pollination. Moisture or heat stress interferes with synchronization of pollen shed and silk emergence (Valliyodan and Nguyen, 2006).

Abdelmula and Sabiel (2007) showed that Plant height, leaf area and number of leaves per plant were positively correlated with grain yield. They found that Plant height, number of leaves per plant and stem diameter might best selection criteria for improvement in maize.

Yield reduction in hot and dry condition is due to physiological stress, rather than the sensitivity of plant phenology to temperature. Fertilization necessitates a temporal overlap between the shedding of pollen by tassel and the emergence of silks (to intercept the pollen). Hot and dry weather both hastens pollen shed and delays silk emergence, narrowing the duration of co-occurrence. In addition, the ability of pollen to germinate on silks is greatly reduced at temperatures above 32°C (Basra 2000). The result is fewer grains available for filling during the reproductive period that directly follows (Herrero & Johnson 1980). Although climatic factors can cause severe yield reductions, their effects on silk-tasseling are difficult to identify because of the short duration of the period (Porter & Semenov 2005).

Considering the results of this research which are consistent with those of Oktam (2008), deficit irrigation reduced the yield, so that deficit irrigation and supplying 80 and 60 percent of full irrigation. In severe stress, stomata were closed which in turn reduced the uptake of carbon dioxide and the dry matter production, and the continuance of stress led to drastic reduction of photosynthesis. It seems that the reason of dry matter reduction under deficit irrigation, is mainly due to less leaf area expansion which did not provide a sufficient physiological source for absorbing more light and dry matter producing. These findings confirmed the researches of other researchers who reported that drought stress reduced the biological yield (Classen and Shaw, 1970; Alizadeh *et al.,* 2008; Alavi Fazel and Lak 2011).

Table 3: Correlation coefficients between the traits of maize hybrids in moderate levels of water stress

Traits	LS(Cm)	LTB (Cm)	NTB	NLE	GDC(Cm)	GW(Cm)	CD(Cm)
LTB (Cm)	0.826**						
NTB	0.136 ns	0.265 ns					
NLE	0.703**	-0.316 ns	0.599*				
GDC(Cm)	0.560*	0.606 *	0.432 ns	0.156 ns			
GW(Cm)	0.535*	0.800 **	0.539 ns	-0.174 ns	0.609*		
CD(Cm)	-0.575*	-0.737**	-0.093 ns	0.126 ns	-0.515 ns	0.598 *	
GY(Gr)	-0.163 ns	0.264 ns	0.888 **	0.765 **	0.601 *	0.482 ns	-0.213 ns

ns . *,** : non-Significant, Significant at 0.05 and 0.01 probability level, respectively.

CONCLUSION

According to the results of this research deficit irrigation based on 80% of full corn water requirement could be recommended under dry year's condition with lower grain yield reduction. Since anthesis was found as the highest sensitive stage to water stress, to avoid high grain yield reduction, favorable soil water condition must be provided in irrigation schedule.

REFERENCES

Abdelmula AA, Sabiel SAI. (2007). Genotypic and differential responses of growth and yield of some maize (Zea mays L.) genotypes to drought stress. *International conference on impact of agricultural research*, 1: 1-6.

Alahdadi I, Oraki H, Parhizkar khajani F. (2011). Effect of water stress on yield and yield components of sunflower hybrids. *African Journal of Biotechnology*, **10**: 6504-6509.

Alavi F, Lak Sh. (2011). Effects of irrigation-off at different growth stages, planting patterns and plant population on grain and biological yields and water use efficiency of grain corn hybrid SC.704. *World Applied Sciences Journal*, **15**: 253-260.

Ali, Q, Elahi M, Ahsan M, Nadeem Tahir, MH, Basra SMA. (2011). Genetic evaluation of maize (*Zea mays* L.) genotypes at seedling stage under moisture stress. *International Journal for Agro Veterinary and Medical Sciences*, **52**: 184-193.

Alizadeh O, Majede E, Nadian HA, Normohamade GH, and Amerian MR. (2008). Effect of water stress and different nitrogen rate on phenology, growth and development of corn. *Journal of Agricultural sciences and natural resources*, **14**: 24-32.

Alvi MBM, Rafique M, Tariq S, Hussain A, Mahmood T, Sarwar M. (2003). Character association and path coefficient analysis of grain yield and yield components maize (*Zea mays* L.). *Pakistan Journal Biology Science*, ***6:*** 136-138.

Basra AS. (2000). Crop responses and adaptations to temperature stress. Food Products Press, New York.

Blum A, (1996). Crop responses to drought and the interpretation to adaptation. *Plant Growth Regulation*, **20**:135-148.

Classen MM, Shaw RH. (1970). Water deficit effects on corn II. Grain components. *Agronomy Journal*, **62**: 652-655.

Cross, H.Z. 1975. Diallel analysis of duration and rate of grain filling of seven inbred lines of corn: Crop Science, 15: 532-535.

Dungan WG, Hatfield JL. (1965). The daily growth and yield of corn kernels. *Agronomy Journal*, **57**: 221-223.

Easterling WE, Aggrawal PK, Batima P, Brander KM. (2007). Food, fiber, and forest products. In: Parry ML, Canziani OF, Palutikof JP, Hanson CE, van der Linden PJ (eds) Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge pp. 273-313.

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.

Frederick JR, Camp CR, Bauer PJ. (2001). Drought-stress effects on branch and mainstem seed yield and yield components of determinate soybean. *Crop Sciences*, **41**: 759-763.

Gerpacio VR, Pingali PL. (2007). Tropical and subtropical maize in Asia: production systems, constraints and research priorities CIMMYT, Mexico, PP. 93.

Ghobadi M, Bakhshandeh M, Fathi G, Gharineh MH, Alamisaeed K, Naderi A, Ghobadi V. (2006). Short and long periods of water stress during different growth stages of canola (*Brassica napus* L.). *Agronomy Journal,* **5**: 336-341.

Golbashy M, Ebrahimi M, Khavari Khorasani S, Choukan R. (2010). Evaluation of drought tolerance of some corn (Zea mays L.) hybrids in Iran. *African Journal of Agricultural Research*, **5**: 2714-2719.

Herrero MP, Johnson RR. (1980). High temperature stress and pollen viability of maize. *Crop Science,* **20**: 796-800.

Hobbs SLA, Mahon JD. (1982). Variation, heritability and relationship to yield of physiological characters in peas. *Crop Science,* **22**: 773- 779.

Jaleel CA, Manivannan P, Wahid A, Farooq M, Somasundaram R, Paneerselvam R. (2009). Drought stress in plants: a review on morphological characteristics and pigments composition. *International Journal of Agricultural and Biological*, **11**: 100-105.

Joshi BK. (2005). Correlation, regression and path coefficient analyses for some yield components in common and Tartary buckwheat in Nepal. *Fagopyrum*, **22**: 77-82.

Khodarahmpour Z. (2011). Effect of drought stress induced by polyethylene glycol (PEG) on germination indices in corn (Zea mays L.) hybrids. *African Journal of Biotechnology,* **10**: 18222-18227.

Khodarahmpour Z, Hamidi J. (2012). Study of yield and yield components of corn (*Zea mays* L.) inbred lines to drought stress. *African Journal of Biotechnology*, **11**: 3099-3105.

Kusaksiz T. (2010). Adaptability of some new maize (*Zea mays* L.) cultivars for silage production as main crop in Mediterranean environment. *Turkish Journal of Field Crops*, **15**: 193-197.

Lak S, Naderi N, Siadat SA, Aynehband A, Noormohammadi G, (2007). Effects of water deficiency stress on yield and nitrogen efficiency of grain corn hybrid KSC 704 at different nitrogen rates and plant population. *Iranian journal of agricultural sciences and natural resources,* **14**: 63- 76. (In Persian)

Lawlor DW, Cornic G. (2002). Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. *Plant Cell Environ*, **25**: 275-294.

Mojaddam M. (2006). Ph.D. Thesis. Effects of water deficiency Stress and Nitrogen consumption management on agro-physiological Traits and yield of Grain corn (*Zea mays* L.) Hybrid SC704 in Khuzestan climate conditions. Islamic Azad University of Khuzestan. Iran pp. 222

Nayyar H, Singh S, Kaur S, Kumar S, Upadhyaya HD. (2006). Differential sensitivity of macro carpa and microcarpa types of chickpea (*Cicer arietinum* L.) to water stress: association of contrasting stress response with oxidative injury. *Journal of Integrative Plant Biology,* **48**: 1318-1329.

Nelson RL. (2008). Tassel emergence & pollen shed. Corny news network.

Oktam A. (2008). Effects of deficit irrigation on some yield characteristics of sweet corn. *Bangladesh Journal of Botany*, **37**: 127-131.

Oraki H, Alahdadi I, Parhizkar khajani F. (2011). Investigation of the effect of water deficit stress on yield and yield components in sunflower hybrids. *African Journal of Agricultural Research*, **6**: 2358-2363.

Osborne SL, Schepers DD, Francis JS, Schlemmer MR. (2002). Use of spectral radiance to estimate in-season biomass and grain yield in nitrogen and water stress on corn. *Crop Science*, **42**: 165-171.

Pandy RK, Maranvill JW, Chetima MM. (2000). Deficit irrigation and nitrogen effects on maize in a Sahelian environment. II. Shoot growth. *Agricultural Water Management*, **46**: 15-27.

Payero JO, Melvin RS, Irmak S, Tarkalson D. (2006). Yield response of corn to deficit irrigation in a semiarid climate. *Agricultural Water Management*, **84:** 101-112.

Porter JR, Semenov MA. (2005). Crop responses to climatic variation. Philosophical Transactions of the Royal Society B: *Biological Sciences,* **360:** 2021-2035

Ribaut J. 2006. Drought adaptation in cereals. Food Products Press, New York, USA.

Scarisbrick D, Daniels RW. (1986). Oil seed rape first published in Great Britain by Collins Professional and Technical Books.

Setter TL, Brain A, Lannigan F, Melkonian J. (2001). Loss of kernel set due to water deficit and shade in maize: Carbohydrate supplies, ABA and cytokinin. *Crop Sciences*, **41**:1530-1540.

Shaw RH. (1977). Water use and requirements of maize-a review. Agro-meteorology of the maize crop. WMO Publication 481, World Meteorological Organization, Geneva. pp. 119-134.

Sinaki MJ, Majidi Heravan E, Shiranirad H, Noormohammadi G, Zarei GH. (2007). The effects of water deficit during growth stages of canola (*Brassica napus* L.). *American-Eurasian Journal of Agricultural & Environmental Sciences*, **2**: 417-422.

Song Y, Birch CQuS, Doherty A, Hanan J. (2010). Analysis and modelling of the effects of water stress on maize growth and yield in dryland conditions. *Plant Production Science*, **13**: 199-208.

Turhan H, Baser I. (2004). In vitro and in vivo water stress in sunflower (*Helianthus annuus* L.). *HELIA*, **27**: 227-236.

Valliyodan B, Nguyen HT. (2006). Understanding regulatory networks and engineering for enhanced drought tolerance in plants. *Current Opinion in Plant Biology*, **9**: 189-195.

White JW, Reynolds MP. (2003). A physiological perspective on modeling temperature response in wheat and maize crops. In: White JW (ed) Modeling temperature response in wheat and maize. Proceedings of a Workshop, CIM MYT, El Batán, Mexico, 23-25 April 2001. CIMMYT, Mexico City pp. 8-17.Zhu JK, 2002. Salt and drought stress signal transduction in plants. Annual Review of Plant Biology, **53**: 247-257.