International Journal of Plant Production 3 (1), January 2009
ISSN: 1735-6814 (Print), 1735-8043 (Online)
This is a refereed journal and all articles are professionally screened and reviewed.
GUASNR
www.ijpp.info

The Effects of Drought Stress on Improved Cotton Varieties in Golesatn Province of Iran

O. Alishah[a], A. Ahmadikhah[b,*]

[a] *Breeding Department of Cotton Research Institute of Iran, Beheshti Street, P.O.Box 49175-483, Gorgan, Iran.*
[b] *Department of Plant Breeding and Biotechnology, Faculty of Agriculture, Gorgan University of Agricultural & Natural Resources, Beheshti Street, P.O Box 386, Gorgan, Iran.*
[*] Corresponding author. E-mail: ahmadikhah_a@gau.ac.ir

Received 15 December 2007; Accepted after revision 12 September 2008; Published online 15 January 2009

Abstract

Drought stress is one of the most important abiotic stresses influencing performance of crop plants. Therefore, the identification or development of tolerant genotypes is of high importance for incorporating in cotton production. In this study to evaluate the effect of drought stress on some cotton traits, 5 improved cotton varieties were studied in a split plot design with three replications in 2 years (2000-2001) at 2 locations (Hashemabad and Anbaroloom); one with Mediterranean climate and the other with drought-stress condition. Treatments were irrigation as main plot in 3 levels (I_0=without irrigation, I_1=one time irrigation; that carried out 70 days after sowing, and I_2=at least 3 times irrigation) and varieties as subplot in 5 levels (5 genotypes). In the basis of combined variance analysis significant differences were detected among varieties for yield, boll number, boll weight, length and number of sympodial and monopodial branches. Drought stress decreased yield, boll number, boll weight, and induced earliness. With increasing irrigation frequency, earliness lightly reduced in the former climate probably because of inducing vegetative growth and retarding in generative phase. In latter climate increased irrigation frequency had a positive effect on the yield. It seems that water deficiency has reduced yield via decreasing boll number. The number of formed bolls in stressful conditions was less than that of in non-stressful conditions. Stress tolerance index (STI) revealed that Siokra-324 and Tabladila were more tolerant and stable varieties.

Keywords: Cotton; Drought; Irrigation; Stable Yield; STI; Golesatn

Introduction

Water is one of the key factors in crop production. Although water is the most abundant molecule on the earth surface, the availability of water strongly restricts terrestrial plant production (Pospisilova et al., 2000). Environmental stress limits the overlay productivity of world plant production to %50 of its potential (Boyer, 1982). Since water resources are limited, efficient use of water volume unit (WVU) is necessary in crop production. Water deficit, the major factor limiting plant growth and crop productivity worldwide, is expected to increase with the spread of arid lands (Saranga et al., 2001). Global climatic trends may accentuate this problem (Le Houerou, 1996). Iran is considered as an arid area with 240 mm rainfall per year, so large areas are located in arid and semi-arid region (Farshadfar et al., 2004). Of one million ha surface of Golestan Province in Northern Iran, only ~650 000 ha are under different crop plants, from them 450 000 ha can be irrigated. However, only 250 000 ha are irrigated because of limited water resources (Sohrabi, 2005). Cotton is one of the most important crop plants in Golestan County, but today its cultivation surface decreased because of some problems emerged in the trade and economy, and high costs of production, presence of competent crops, water deficient etc, and now it is cultivating in low-efficient areas with lower fertility. One of desirable ways to compensate the production costs and to economy cotton production is introduction of new varieties, and development of the drought tolerant varieties is a confidential approach to increase the economic efficiency of cotton production in water deficient conditions. In these cases either in relatively dry or water availability conditions the objective is the development and releasing of varieties capable to maximally use from water. In the arid regions, however, the objective is the development of drought tolerant varieties so that they need lower water, and in the water availability conditions breeding objective is to develop plants that have higher yield with adaptability to environment.

The effect of drought on growth, yield and yield component and quality characters are very different and serious. The turgor decrease is the first effect of drought stress that influences cell growth rate and its final volume. The phenomenon probably is the most sensitive drought-related process, resulting in decreasing the development rate, stem growth, leaf growth and also decreasing the stomatal diameter. The drought stress affect directly or indirectly photosynthesis via affecting the carbohydrate metabolism. Due to drought stress the photosynthesis decreases, flower and bud fall increases and competition between vegetative and reproductive for obtaining carbohydrates increases. Leaf area development in cotton in the response to drought stress is more sensitive than stomatal photosynthesis and any changes in terms of decrease or increase of carbon uptake by change in photosynthesis rate, is resulted in the decrease of boll maintenance on plants.

Availability of adequate water for normal plant growth and development is of high importance in cotton culture (Radin et al., 1992; Marani et al., 1985). In drying soil, nutrient availability and uptake to the root system may decrease and, in turn, alter the physicochemical properties of the xylem sap (Chapin, 1991; Bacon et al., 1998; Schurr and Schulze, 1996). Mild drought stress may increase the xylem pH due to reduced nitrate uptake before it reaches the leaves, causing an increase in apoplastic pH (Gollan et al., 1992; Schurr et al., 1992). Drought stress influences leaf water content, photosynthesis, and water-use efficiency (Egilla et al., 2005).

Different mechanisms were developed during plant evolution to prevent water loss, and to tolerate a mild one. Shoot desiccation is avoided mainly by stomatal regulation of transpiration rate. In response to water stress a shift in a relationship between water and pressure potential has been observed. This can be reached by osmotic adjustment (accumulation of osmotically active substances), increased cell wall elasticity, and/or increased apoplastic water fraction (Pospisilova et al., 2000). Water stress affects many metabolic pathways, mineral uptake, membrane structure, etc. Therefore it is not surprising that also hormone content can be changed. It is very important because plant hormones are considered as main signals in root-to-shoot communication and vice versa (Davies and Zhang, 1991; Tardieu and Davies, 1993; Davies, 1995; Naqvi, 1995). In consequence, the change of hormonal balance might play the key role in the sequence of events induced by stress (Itai, 1999). Despite of this, the mechanism of induction of a hormonal shift by an environmental change is unknown (Pospisilova et al., 2000). In many cases, water deficit reduces growth, and leaf area development and duration. Stomatal closure decreases the CO_2 influx which limits photosynthesis under mild water stress and supports photoinhibition under high irradiance. The severe water stress directly affects photosynthetic capacity of the mesophyll causing decrease in carboxylation as well as electron transport chain activities, and/or induces ultrastructural changes in chloroplasts (Pospisilova et al., 2000).

Genomic tools and approaches may expedite breeding of genotypes that respond favorably to specific environments, help test roles of additional physiological factors, and guide the isolation of genes that protect crop performance under arid conditions toward improved adaptation of crops to arid cultivation (Saranga et al., 2001). The interaction of genotype with environment is of primary importance in many aspects of genomic research and is a special priority in the study of major crops grown in a wide range of environments. A merger of physiology and genetics may improve basic understanding of complex genotype×environment interactions, such as plant response to arid conditions, offering new avenues for crop improvement. On the other hand, knowledge of the nature of drought at a particular site could be an important consideration when making decisions related to soil fertilization. Thus, if we want to increase productivity of agriculture we need to understand controls over plant water relations and consequences of water stress. Our objective in this research was to study the effect of drought stress on the performance and stability of recently improved varieties and to identify more tolerant and stable varieties for incorporating in cotton production programs in areas faced with drought stress.

Material and methods

In this study four recently improved varieties of cotton research institute of Iran, namely as Siokra-324, Tabladila, Nazili84 and Mehr along with a standard control variety (Sahel) were evaluated in a split plot design (as randomized complete block) in three replications, for two years in two regions (Hashemabad (with Mediterranean climate) and Anbaroloom (with warm & dry climate), Golestan Province, Gorgan, Northern Iran). Irrigation treatment was selected as a main plot in 3 levels (I_0= without irrigation, I_1= one time irrigation; that carried out 70 days after sowing, and I_2= at least 3 times irrigation) and varieties as subplot in 5 levels (5 genotypes). The varieties were cultivated in plots of 6 rows of 11 m length. For irrigation management, the distance between main plots was 3 m and between subplots was 2 m. To measure and control the used water for each treatment, meteorological information, 20-year rainfall average, distribution of rainfall in different months of year were collected and the used water in each time of irrigation was measured using a counter. The time of Irrigation were adjusted based on water-need curve and the evaporation volume. Different traits were evaluated including yield (Kg/ha), plant height (cm), boll number, boll weight (gr), length and number of sympodial and monopodial branches (cm), earliness (%), stress tolerance index (STI), and percent of yield loss due to stress. Stress tolerance index (STI) was calculated as follows (Fernandes et al., 1992):

STI= $\frac{(Yp)(Ys)}{(\bar{Y}p)^2}$ where Yp represents each genotype yield in non-stress condition, Ys represnts each genotype yield in stress condition and $\bar{Y}p$ shows mean yield of all genotypes in non-stress condition.

Analysis of simple and combined variance was carried out on the collected data. Comparison of means was carried out using Dauncan multiple tests in SAS program. For the analysis, year was considered as a random effect, and location and treatments as a fixed effect.

Results and discussion

The results of combined variance analysis of different traits in different years and locations are presented in Table 1. This analysis showed that year effect (Y) was significant on some traits such as total yield, length and number of sympodial and monopodial branches and the effect of locations (L) was significant on total yield, plant height, boll number, length and number of sympodial and monopodial branches and percent of earliness at 1% level. The interaction of L x Y also was significant on total yield, plant height, length of sympodial and monopodial branches and boll number at 1% level, but was non significant on earliness, and number of sympodial and monopodial branches. Therefore, it can be concluded that in this study the expression and quantity of morphological traits were affected by year and location, indicating the importance of identification or improvement and introduction of compatible varieties for each climate.

The effect of irrigation was significant (at 1% level) on all studied traits. The interaction of irrigation x year was not significant on all traits (except earliness at 5% level). However, the interaction of irrigation x location was significant on all traits (except length of sympodial and monopodial branches). Tertiary interaction of year x location x irrigation was not significant on most traits (except earliness at 5% level). Since the interaction of location x irrigation on quantity and expression of different traits was larger than the interaction of year x irrigation; it may be suggested the necessity of the study and precise estimation of water requirement of cotton varieties and irrigation management in different regions.

The genotype effect on the traits such as total yield (at 1% level) and boll number (at 5% level) was significant, but it was not observed significant differences between varieties in plant height, length and number of sympodial and monopodial branches, and earliness. In addition, it was not observed significant morphological differences between varieties, and they differed only in boll number. Therefore, this variable can be considered as the most important component of yield in selection and improvement of drought tolerant varieties for such regions.

The interaction of genotype x year was significant on yield, length of sympodial and monopodial branches, and earliness at 1% level, but was not on other traits. It is obvious that yield and linter quality of studied varieties which are less affected by year's effect, are of more agronomical importance. Furthermore, the interaction of genotype x location, also was significant on yield (at 5% level), and on boll number and earliness (at 1% level), indicating the effect of regional conditions on these traits and the necessity of site-specific adaptability in the selection and introduction of new cotton varieties. The interaction of genotype x irrigation on yield was significant, indicating differentially response of cotton varieties to water availability. The selection of these varieties with desirable and stable yield in different water conditions allows improving the cotton production efficiency for water-deficient and drought conditions.

Table 1. Compound variance analysis (ANOVA) of different cotton varieties in 2 years (2000-2001) at 2 locations (Hashemabad and Anbaroloom).

		Mean squares					
S.O.V	df	Yield	Plant height	Boll number	Reproductive branch number	Reproductive branch length	Earliness
Y	1	1513502.7**	0.002	44.3	57.4	557.2**	251.1
L	1	76885836.5**	29506.6**	1854.0**	345.9**	1409.5**	872.6**
Y*L	1	282235.0**	11236.9**	725.2**	1.16	1213.2**	20.3
Ee	8	201886.6	861.2	40.1	10.0	117.8	245.7
A factor	2	14092871.7**	14110.9**	402.3**	325.5**	1026.5**	617.4**
Y*A	2	297323.3	993.7	21.6	10.3	156.6	275.1*
L*A	2	3579888.8**	1992.8*	68.7*	69.7**	77.6	1197.3**
Y*L*A	2	180611.0	1021.7	34.8	9.4	2.8	318.9*
E_a	16	165905.1	4414.7	15.2	7.9	81.6	74.3
B factor	4	1432361.4**	178.7	26.1*	1.5	16.3	152.9
Y*B	4	243030.7**	145.4	16.9	4.3	49.8**	289.1**
L*B	4	174581.5*	60.7	32.7**	1.0	22.9	376.7**
Y*L*B	4	418961.9**	274.0*	21.4	3.8	25.4	42.4
A*B	8	128075.8*	56.2	10.4	3.1	17.2	72.5
Y*A*B	8	89775.4	94.3	5.3	3.8	4.4	80.6
L*A*B	8	98775.9	40.3	2.2	1.2	15.0	77.2
Y*L*A*B	8	70952.1	53.6	7.7	2.8	17.1	36.5
E_b	96	60560.8	90.5	9.2	2.1	14.3	58.5
C.V. (%)	-	15.5	11.6	25.5	12.8	21.1	8.7

*,** significant differences at %5 and %1 levels, respectively. Ee: environmental error; Ea: A factor error; Eb: B factor error.

Cotton is a very susceptible plant to the quantity of irrigation water, and therefore, irrigation management is very complicated, so that the results obtained in each location and for each variety are useable only for the same or similar locations. In lower-irrigation or over-irrigation conditions the yield loss could be large, so that in lower-irrigation, the plants would be stunted and try to finish their growth through dropping of flowers and reducing yield. In over-irrigation conditions, however, plant vegetative growth is induced and flower production and yield are strongly reduced and plant finished its life period as soon as possible (Marani et al., 1985; Radin et al., 1992). Therefore, the involvement of these varieties showing least fluctuations in yield by regulating vegetative and generative phases in stressful and non-stressful conditions are of high importance in production programs. For example, variety Sahel (which was used as control in this study), one of cotton commercial varieties cultivated in northern Iran, is tolerant to wilt vertisillium disease and well adapted to wet and humid regions (Sohrabi, 2005). In this study it was observed that this variety had larger bolls compared to other studied varieties, but its boll number was more highly affected by environment. Also we observed that in warm and dry conditions its boll number, and subsequently, its yield decreased. In humid conditions and cloudy days with lower sunny times it seems that formation of bolls on the top parts of plant in autumn season is not completed due to occurrence of cold or rainfall. Therefore, these factors cause, directly or indirectly, yield loss of this variety.

The mean yield of cotton varieties in different conditions and locations are represented in Table 2. As seen, in Hashemabad region, variety Siokra-324 in two years in different conditions of water availability, had the highest yield (1715.6, 2996.5 and 3176.7 Kg/ha (in the complete stress, relative stress and full irrigation, respectively; Table 2) followed by variety Tabladila with 1507.6, 2718 and 2842 Kg/ha, respectively. Also, in 2000 in the region Anbaroloom, variety Siokra-324 and in 2001 variety Tabladila were superior varieties. In the relative stress condition, in 2000, variety Tabladila had the highest yield followed by variety Siokra-324 and in 2001, variety Siokra-324 was superior. However, in the full irrigation condition, variety Siokra-324 had higher yield compared to other varieties in two years in two regions (Table 2). In region Anbaroloom, we recorded lower rainfall with undesirable distribution (Table 3). In two years of study, experimental fields received maximum two times irrigation, which was ~50 percent of normal consumed water in Hashemabad. Some regions of northern Iran and some areas in many other countries have similar environmental conditions like this region and, hence are faced to drought or hot stress, relative salinity and water deficient, which influence directly or indirectly on root growth, and water / mineral uptake, resulting in decreased yield and linter quality. Therefore, selection or development of compatible varieties with stable higher yield is of high importance for incorporating in cotton - growing fields of the region or similar regions. Variety Siokra-324 has small leaves, open canopy and potential high performance of flowers and bolls. These traits are desirable characters for better adaptability and producing higher yield in different conditions of water availability, which induce reduced evaporation and better light entrance. Quisenberry and McMichal (1991) also have emphasized the selection of compatible and tolerant varieties under field conditions based on yield performance and agronomical traits.

Our study showed that with increasing irrigation frequency, plant height increases, but this increase in Mediterranean climate is higher than that of in warm-dry climate (~1.12 fold; Figure 1). Furthermore, with increasing irrigation frequency, earliness lightly reduced in the former climate probably because of inducing vegetative growth and retarding in generative phase (Figure 2A). However, in latter climate it was not observed such phenomenon probably because of warm and dry conditions; in Anbaroloom region increased irrigation frequency had a positive effect on the yield (Figure 2B).

Table 2. The average of yield and stress tolerance index (STI) of cotton varieties in different conditions of irrigation stress in Hashemabad and Anbaroloom regions in 2000-2001.

Varieties	Yield (Kg/ha)						STI	Yield loss due to stress (%)
	Hashemabad (Mediterranean climate)			Anbaroloom (warm&dry climate)				
	I_0	I_1	I_2	I_0	I_1	I_2		
Sahel	1152.5i	2175.6e	2477.2c	672.8f	892.6de	1045.5d	0.34	53.5
Mehr	1332.4h	2310.0de	2338.3d	829.6e	1100.8cd	1198.7cd	0.54	44.7
Nazili84	1422.0h	2696.1cd	2606.2c	1053.9d	1244.0c	1364.6bc	0.71	43.5
Tabladila	1507.2g	2718.0c	2848.0b	1158.9d	1363.8bc	1690.0ab	0.71	41.9
Siokra-324	1715.6f	2996.5a	3176.7a	1203.7c	1433.7b	1856.1a	0.86	37.5

I_0= without irrigation, I_1= one time irrigation (70 days after sowing), and I_2= at least 3 times irrigation.

Table 3. The consumed water volume (m^3) for irrigation of cotton varieties in different drought conditions at given locations.

		Hashemabad			Anbaroloom		
		I_0	I_1	I_2	I_0	I_1	I_2
Year	2000	1530	2290	3926	535	955	1555
	2001	1332	2232	3632	587	1235	1822

I_0= without irrigation, I_1= one time irrigation (70 days after sowing), and I_2= at least 3 times irrigation.

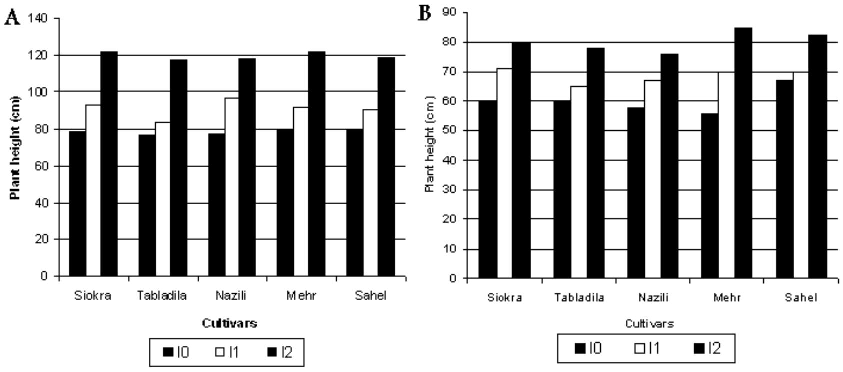

Figure 1. The effect of drought stress on plant height of cotton varieties in Hashemabad (A) and Anbaroloom (B).

The evaluation of boll number in different varieties shows that water deficiency has reduced yield more probably via decreasing boll number. The number of formed bolls in stressful conditions was less than that of in non-stressful conditions. The average formed boll number in Hashemabad was 1.8 fold of Anbaroloom (data not shown), probably due to reduced growth, reduced number and length of sympodial and monopodial branches.

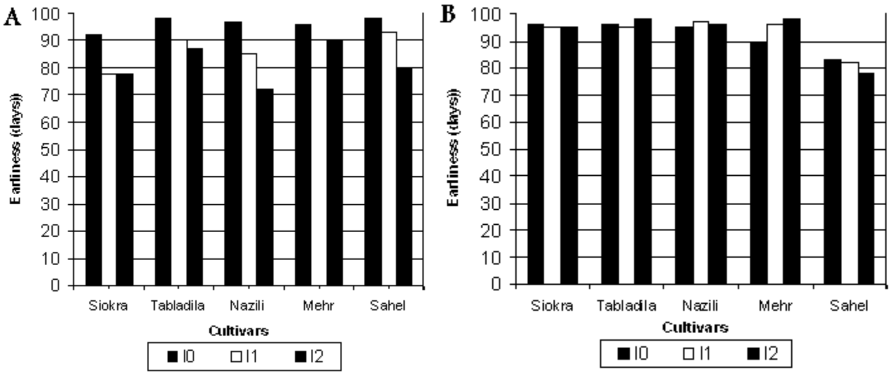

Figure 2. The effect of drought stress on earliness of cotton varieties in Hashemabad (A) and Anbaroloom (B).

Marani et al. (1985) and Wanjura et al. (2004) with regard to the pattern of boll formation and its conservation in cotton suggested that formed bolls in the first nod of sympodial branches have a higher probability of survival. In stressful conditions (warm & dry climate) the elongation rate of branches and main stem is usually lower, and hence not only the locations of boll formation are reduced but also most bolls are formed on the nods nearer to the main stem (on the sympodial branches) (Pettigrew, 2004).

The evaluation data of stress tolerance index (STI) of the studied varieties are given in Table 2. This criterion might help the identification of compatible and stable varieties with higher degree of stress tolerance and lower loss of yield during drought stress. As seen in the table, Siokra-324 is a more tolerant variety among the studied varieties with 2-year STI average of 0.86 and the least yield loss (37.5%) followed by variety Tabladila with 2-year STI average of 0.71 and relatively low yield loss (41.9%). Therefore, between studied varieties, Siokra-324 and Tabladila (with slight difference in yield) are identified as drought tolerant varieties for northern Iran and areas with similar environmental conditions.

References

Bacon, M.A., Wilkinson, S., Davies, W.J., 1998. pH-regulated leaf cell expansion in droughted plants is abscisic acid dependent. Plant Physiol. 118, 1507–1515.

Boyer, J.S., 1982. Plant productivity and environment. Sci. 218, 443–448.

Chapin, S.A., 1991. Effects of multiple environmental stresses on nutrient availability and use. In: Mooney, H.A., Winner, W.E., Pell, E.J. (Eds.), Response of plants to multiple stresses. San Diego. Academic Press, pp: 67–88.

Davies, P.J., 1995. The plant hormone concept: concentration, sensitivity and transport. In: Davies, P.J. (Ed.), Plant Hormones. Dordrecht, Boston, London. Kluwer Academic Publishers, pp:13–38.

Davies, W.J., Zhang, J., 1991. Root signals and the regulation of growth and development of plants in drying soil. Annu. Rev. Plant Physiol. Plant mol. Biol. 42, 55–76.

Egilla, J.N., Davies, Jr.F.T., Boutton, T.W., 2005. Drought stress influences leaf water content, photosynthesis, and water-use efficiency of *Hibiscus rosa-sinensis* at three potassium concentrations. Photosynth. 43, 135–140.

Farshadfar, E., Mohamady, R., Maroufi, A., 2004. Chromosomal location of drought tolerance genes in Shayan wheat cultivar. 8th Agronomy and Plant Breeding Conf. Rasht, Iran.

Fernandes, C.J., 1992. Effective selection criteria for assessing plant stress tolerance. In: Kuo, C.G. (Eds.), Adaptation of food crops to temperature and water stress. Shanhua, Taiwan. AVRDC, pp: 257-270.

Gollan, T., Schurr, U., Schulze, E.D., 1992. Stomatal response to drying soil in relation to changes in the xylem sap concentration of *Helianthus annuus*. 1. The concentration of cations, anions, amino acids in, and pH of, the xylem sap. Plant, Cell and Environ. 15, 551-559.

Itai, C., 1999. Role of phytohormones in plant responses to stresses. In: Lerner, H.R. (Ed.), Plant Responses to Environmental Stresses. From Phytohormones to Genome Reorganization. New York-Basel. Marcel Dekker, pp: 287-301.

Le Houerou, H.N., 1996. Climate changes, drought and desertification. J. Arid Environ. 34, 133-185.

Marani, A., Baker, D.N., Reddy, V.R., McKinion, J.M., 1985. Effect of water stress on canopy senescence and carbon exchange rates in cotton. Crop Sci. 25, 798-802.

Naqvi, S.S.M., 1995. Plant/crop hormones under stressful conditions. In: Pessarakli, M. (Ed.), Handbook of Plant and Crop Physiology. New York, Basel, Hong Kong. Marcel Dekker, pp: 645-660.

Pettigrew, W.T., 2004. Physiological Consequences of Moisture Deficit Stress in Cotton. Crop Sci. 44,1265–1272.

Pospisilova, J., Synkova, H., Rulcova, J., 2000. Cytokinins and water stress. Biologia Plantarum 43(3), 321-328.

Quisenberry, J.E., McMichael, B.L., 1991. Genetic variation among cotton germplasm for water use efficiency. Envir. Exp. Bot. 31, 453-460.

Radin, J.W., Reaves, L.L., Mauney, J.R., French, O.F., 1992. Yield enhancement in cotton by frequent irrigations during fruiting. Agron. J. 84, 551–557.

Saranga, Y., Menz, M., Jiang, C.-X., Wright, R.J., Yakir, D., Paterson, A.H., 2001. Genomic Dissection of Genotype × Environment Interactions Conferring Adaptation of Cotton to Arid Conditions. Genome Res. 11, 1988-1995.

Schurr, U., Gollan, T., Schulze, E.-D., 1992. Stomatal response to soil drying in relation to changes in the xylem sap composition of *Helianthus annuus*. II. Stomatal sensitivity to abscisic acid imported from the xylem sap. Plant, Cell and Environ. 15, 561–567.

Schurr, U., Schulze, E.-D., 1996. Effects of drought on nutrient and ABA transport in *Ricinus communis*. Plant, Cell and Environ. 19, 665–674.

Sohrabi, B., 2005. Impact of drip irrigation on water use efficiency and quantitative and qualitative traits in cotton. Final Rep. Res. Cotton Research Inst. Iran.

Tardieu, F., Davies, W.J., 1993. Root-shoot communication and whole-plant regulation of water flux. In: Smith, J.A.C., Griffiths, H. (Eds.), Water Deficits. Plant Responses from Cell to Community. Oxford. Bios Scientific Publishers, pp:147-162.

Wanjura, D.F., Upchurch, D.R., Maas, S., 2004. Spectral reflectance estimates of cotton biomass and yield. Proc. Beltwide Cotton Conf., San Antonio. National Cotton Council of America, Memphis, TN.