INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2006/08–6–796–800
http://www.fspublishers.org

Characterization of Cotton (*Gossypium hirsutum* L.) Varieties for Growth and Productivity Traits Under Water Deficit Conditions

SEEMA MAHMOOD[1], MEZHAR IRFAN, FARAH RAHEEL AND ASMA HUSSAIN
Institute of Pure and Applied Biology (Botany Division) Bahaudin Zakariyya University, Multan, 60800, Pakistan
[1]Corresponding author's e- mail: drseemapk@yahoo.com

ABSTRACT

The present study was carried out to reveal drought tolerance of eight cotton varieties (BH-118, CIM-446, FH-900, FH-901, MNH-93, MNH-552, MNH-554 & NIAB Krishma) using various growth and productivity traits. These varieties were subjected to two and four water deficit cycles. The varieties showed distinct responses with respect to moisture deficit conditions. Certain growth and productivity traits provided some manifestation of drought resistance in these varieties. The MNH-93 and BH-118 appeared to be more drought tolerant for both growth and yield parameters as compared to other varieties under evaluation. MNH-552, MNH-554, CIM-446, FH-900 and NIAB-Krishma exhibited some potential to withstand drought intensities, although an affirmative relationship for growth and yield attributes can not be established in these varieties. The study suggested that intra-specific morphological diversity can further be exploited to acquire genetic information about traits which signify drought resistance using molecular markers.

Key Words: Cotton; Drought; Growth; Yield; Fiber

INTRODUCTION

The global climate is rapidly changing; the productivity of the agriculture is also being seriously affected as a consequence of major shifts in the pattern of temperature and rainfall (Giorgi, 2005). It is anticipated that such changes will affect water availability to the plants, especially those native to the arid and semi-arid tropics. Water availability is crucial for plant growth. Water is a major constituent (85 - 95%) of plant protoplasm. It provides turgidity to cells and tissues, which enables them to divide and differentiate. Moreover, it plays an important role in the translocation of salts and nutrients (Salisbury & Ross, 1992). Low rainfall and un-availability of sufficient irrigation water are major causes of limited water availability to crops in arid and semi-arid regions. The extreme spatial and temporal variability of water availability results in variable soil moisture. Thus water deficit cycles often occur during the life history of plants in such climatic zone (Belhassen & Monneveux, 1996; Passioura, 1996). It has also been reviewed that soil water scarcity, moisture deficit or drought may prove to be a critical constraint to agricultural productivity throughout the world (Fischer *et al*., 2001). Water un-availability can result crop losses and is considered as the second largest contributor to yield reduction after diseases (Khatri *et al.,* 2004). Plants show numerous physiological, metabolic and molecular responses to water stress (Hoekstra *et al*., 2001; Chaves *et al.,* 2002). All such changes are reflected by altered phenotype, where certain morphological traits can signify the abilities of plants to grow under water deficit conditions (Bray, 1997). Thus, the potential of the species for moisture deficit environment can be revealed by the variability of morphological expressions. Various species of cotton including (*Gossypium hirsutum* L.) are grown in different regions of the world. Cotton is an important commodity and backbone of textile industry of the country. Cotton growing countries earn foreign exchange from its finished products and raw material. In addition, it has 20 - 24% of oil content, which is mainly used in manufacturing of hydrogenated "ghee".

The traits, those might show some selective advantage for coping with water stress, would be of great significance for the economic utilization of areas with different periods of drought. Moreover, morphological characterization can be further exploited to acquire genetic information about traits that signify drought resistance using molecular markers. Thus stable varieties with desirable characteristics and vast genetic diversity can be developed. Keeping in view the importance of cotton in Pakistan's agriculture and aggravating water availability the present study was contemplated to assess relationship of various drought treatments with growth and productivity attributes as predictors.

MATERIALS AND METHODS

Eight cotton (*Gossypium hirsutum* L.) varieties (BH-118, CIM-446, FH-900, FH-901, MNH-93, MNH-552, MNH-554 & NIAB-Krishma) were obtained from Central Cotton Research Institute Multan, Pakistan. The choice of these varieties was made because there were no records for their drought tolerance. The study was conducted from June to November 2002 at the Botanic Garden, Bahauddin Zakariya University, Multan, Pakistan.

Germination. All seed samples were surface sterilized in 5% sodium hypochlorite solution for 5 min before sowing in order to avoid any fungal contamination that may reduce seed germination. A seedling cohort was developed in a wire netting house under natural light and temperature conditions (38.6 ± 9.6^{0}C day & 22.3 ± 7.6^{0}C night temperature with 14 h day length). One hundred seeds of each variety were separately sown in earthen pots (internal diameter 28 cm) filled with 8 kg of sandy loam soil. Pots were regularly irrigated and when seedlings were 3 - 4 cm long, they were further transplanted to bigger pots for growth.

Growth. Six healthy seedlings of comparable size from each variety were transplanted equidistant in seventy-two cemented pots (40 cm internal diameter) filled with 12 kg of garden compost. The experiment was placed in Completely Randomized manner in a wire netting green house with glass roof under natural growth conditions (42.6 ± 7^{o}C day & 25.8 ± 5.6^{o}C night temperature with 14 h day length). The experiment consisted of three treatments:

To = (Control) pots were regularly irrigated and moisture levels were maintained by using a moisture meter (Plant Care -Moisture Meter, Made in Taiwan).

T1 = (two cycles) pots were regularly irrigated for 4 weeks then watering was with held for 3 weeks. The pots were observed daily when lower leaves of the plants showed drooping they were watered again and moisture levels were maintained for one week with the help of moisture meter. This constituted one cycle of drought (one week watering & three weeks of drought). Thus, plants received two alternate cycles of watering and moisture deficit.

T2 = (four cycles). The cycles were repeated four times in the similar manner as described above.

Harvesting. Three plants from each pot were harvested after the completion of drought regimes when plants were 12 weeks old. Measurements for plant height (cm), number of leaves per plant, leaf area (cm^2) and leaf dry weight were taken, Specific leaf area (SLA) was calculated as a quotient of total leaf area (cm^2) and total dry weight.

The other three plants were allowed to grow until maturity (up to 24 weeks). Then various quantitative number of bolls per plant, boll diameter (cm) and qualitative [staple length (mm), fiber strength, ginning out turn (%) and fiber fineness] traits were recorded. Staple length was measured by Tuft method, while Pressley Tester was used for measuring strength [thousands of pounds per square inch (tppsi)] and fiber fineness was determined by Micronaire Apparatus following Elms *et al.* (2001). The data recorded for each parameter were subjected to a two-way analysis of variance using a COSTAT package (Cohort Software, Berkeley, USA) and the least significant difference (LSD) was calculated following Snedecor and Cochran (1980).

RESULTS

All varieties exhibited distinct responses to various drought regimes. There was a consistent decline in plant height when plants were given two water deficit cycles. However, after four cycles of drought, an increase in plant height was observed in all varieties (Table I). Drought intensities caused a significant influence on plant height and the maximum decline was observed for FH-900 after receiving two cycles of drought.

However, MNH-93 had the highest mean value for plant height when subjected to four cycles of drought. A considerable decline was observed for leaf production in all varieties after the application of two drought cycles ($P < 0.001$). However, BH-118 remained un-affected at both water deficit regimens. Although, MNH 552 produced significantly higher number of leaves but showed a significant contrast from FH-901, MNH-5526 and MNH-554. Similarly, the lowest leaf number of MNH-554 did not differ from all other varieties except MNH-93 (Table I).

Water deficit caused a significant ($P < 0.001$) influence on the leaf expansion (Table III) as a marked reduction of leaf area occurred in response to varying drought regimes. Varieties exhibited distinct but inconsistent responses, when subjected to two drought cycles. The MNH-552 produced more expanded leaves in response to various drought regimes as compared to the control. The maximum reduction of leaf area was observed for CIM-446 after receiving four cycles of drought. Although, MNH-93 and MNH-552 differed markedly from BH-118 and FH-901 after two drought cycles but these varieties did not maintain these differences after four cycles of drought (Table I).

A significant decrease in leaf biomass was observed in response to moisture stress. The responses of varieties were considerably variable (Table III). CIM-446 showed the maximum reduction of leaf biomass at various moisture regimes, however, FH-900 exhibited the highest value for this parameter after receiving 4 cycles of drought. The data clearly depicted that BH-118, FH-901, MNH-93, MNH-552, MNH-554 and NIAB Karishma, were adversely affected by the highest moisture deficit conditions (Table I).

Significant varietal differences ($P < 0.01$) became evident under increasing ($P < 0.01$) drought intensities (Table III). The MNH-93 consistently showed greater SLA under all the drought regimes. The data clearly revealed that CIM 446, MNH 554 and NIAB Karishma exhibited greater SLA only at two drought cycles as compared with control, while MNH 552 and FH 900 could only produced greatest SLA at the highest drought intensity. Rest of the varieties showed an inconsistent response for this attribute (Table I) Drought treatments caused a considerable ($P < 0.001$) reduction in boll formation (Table III). Although a decline in boll formation was observed for all verities after receiving varying degrees of moisture stress but the response of varieties was insignificantly variable. Two

Table I. Mean values ± S.E. for various growth attributes of eight cotton varieties (*Gossypium hirsutum* L.) after 2 and 4 drough cycles (n = 3)

		Varieties								
		BH-118	CIM-446	FH-900	FH-901	MNH-93	MNH-552	MNH-554	NIAB-KARISHMA	LSD at 5%
Characters										
Plant height (cm)	T_0	33.0±1.73	43.5±0.86	35.5±0.29	40.5±2.59	37.5±2.50	37.0±1.73	37.0±2.31	35.0±2.31	5.71
	T_1	29.5±0.28	32.0±1.15	34.5±0.86	31.0±0.58	44.5±0.86	32.5±0.28	32.0±1.15	33.0±1.73	
	T_2	41.0±1.15	40.1±2.62	39.0±2.31	41.5±2.59	45.0±0.6	35.5±0.29	41.5±0.28	37.5±3.17	
Number of leaves	T_0	8.0±0.00	11.5±0.29	12.5±0.29	13.0±0.58	12.0±0.58	13.5±0.29	10.0±1.15	12.5±1.50	2.17
	T_1	8.5±0.29	11.5±1.73	5.5±0.29	8.5±0.29	8.0±0.58	6.0±0.00	6.0±0.58	7.0±1.15	
	T_2	9.0±1.15	8.5±0.29	8.0±0.75	7.5±0.29	10.0±0.58	7.5±0.29	7.0±0.58	9.0±1.15	
Leaf area (cm^2)	T_0	232.0±20.78	240.0±28.86	230.5±0.35	234.0±15.59	169.5± 5.48	282.0±20.20	241.0±5.20	207.0±16.17	37.94
	T_1	224.5±17.6	220.5± 6.64	234.5± 2.60	254.0± 1.73	172.0±12.7	324.0±15.59	289.0± 4.04	198.5± 9.81	
	T_2	178.5±3.75	149.0± 2.31	206.5±10.68	185.0±12.70	187.5± 2.02	204.0±5.77	180.5±17.32	160.0± 1.73	
Specific Leaf area	T_0	85.6	93.02	92.09	95.69	99.23	98.55	99.50	89.22	12.57
	T_1	90.89	110.8	96.10	93.86	132.30	121.80	113.77	102.84	
	T_2	80.30	97.38	88.24	101.64	138.20	88.69	114.24	87.91	
Plant dry weight (g)	T_0	2.86±0.26	5.17±0.29	3.71±0.08	4.73±0.41	3.43±0.78	4.77±0.43	3.10±0.35	4.52±0.59	0.94
	T_1	2.52±0.09	2.07±0.20	2.13±0.18	1.37±0.05	3.34±0.40	2.18±0.06	1.76±0.10	2.08±0.35	
	T_2	3.64±0.23	3.84±0.39	3.03±0.39	2.89±0.54	3.05±0.31	2.98±0.10	2.06±0.17	3.61±0.33	
Leaf dry weight (g)	T_0	2.71±0.23	2.58±0.12	2.31±0.13	2.08±0.70	1.59±0.02	2.77±0.24	2.26±0.03	2.32±0.11	0.35
	T_1	2.47±0.20	1.99±0.18	2.44±0.03	2.25±0.03	1.30±0.04	2.66±0.03	2.54±0.08	1.93±0.13	
	T_2	1.70±0.13	1.53±0.02	2.34±0.11	1.82±0.21	2.09±0.06	2.30±0.05	1.58±0.03	1.82±0.11	

To=Control, T_1=2 drought cycles, T_2=4 drought cycles.

cycles of drought did not influence this trait in MNH-554 and NIAB-Karishma. However at the maximum drought intensity, boll formation was lower for FH-900, FH-901 and MNH 554 but MNH-552 produced highest number of bolls (Table II).

Varying degrees of moisture stress had caused an adverse effect on boll diameter in all cotton varieties (Table III). The varieties also differed significantly for this trait. Reduction in boll diameter was observed after two cycles of drought in all varieties but reduction was more profound at the highest water deficit level. The NIAB- Karishma had greater boll size after having two cycles of drought but only FH-900 produced the maximum boll size after four cycles of drought as compared to all other varieties (Table II).

The study revealed a significant ($P < 0.001$) influence of moisture deficit on staple length as well a marked contrast among varieties (Table III). The reduction of staple length ranged from 0.1 - 0.9 mm in different varieties studied. An intermediate level of moisture stress (2 cycles of drought) did not cause any significant reduction as there had been observed an increase in staple length at this moisture deficit regime (Table II).

The NIAB-Karishma appeared to be more prone to the highest moisture deficit for fiber quality. The responses of other varieties, was found to be insignificantly consistent at the maximum drought intensity (Table II). However the varieties exhibited variable responses after receiving two cycles of drought, where half of the varieties; BH-118, MNH-552, MNH-554 and NIAB-Karishma showed increased fiber strength and differed significantly from other varieties. Statistical analysis revealed significant ($P < 0.001$) differences between varying degrees of moisture deficit regimes as well as significant ($P < 0.001$) differences between varieties (Table III).

Water deficits had remarkable ($P < 0.001$) decreasing effect on ginning out turn. Varietal differences were also found to be significant ($P < 0.001$) (Table III). Drought cycles significantly influenced the ginning out turn in FH-900, MNH-552 and MNH-554 at their growth after receiving two cycles of drought. However, MNH-552 showed the maximum ginning out turn in response to the highest moisture stress. Ginning out turn was also significantly reduced in all other varieties at the highest water deficit regime but FH-901 did not show any variability for this attribute at the maximum moisture stress (Table II).

The study revealed a significant ($p < 0.001$) amount of intra specific variability as well as a significant ($p < 0.001$) adverse effect of moisture stress on this character (Table III). Fiber fineness decreased significantly in response to the severe moisture deficit in CIM-446, FH-901 and MNH-93. However the highest fineness of the trait was observed for FH-901 at four cycles of drought. Fiber fineness of the varieties was not much influenced by two cycles of drought and only two varieties (MNH-93 & MNH-554) showed significantly variable responses at an intermediate level of moisture stress (Table II).

DISCUSSION

The effect of water stress during the vegetative growth and reproductive stages were compared for eight cotton (*Gossypium hirsutum* L.) varieties. In present study, the varieties exhibited considerable diversity for growth and productivity traits in relation to varying moisture deficit periods. The varieties could not show an increase in plant height except MNH 93 after receiving two water deficit cycles. Although, in other varieties an increase in plant

Table II. Mean values ± S.E. for various yield attributes of eight cotton varieties (*Gossypium hirsutum* L.) after 2 and 4 drought cycles (n = 3)

Characters		Varieties								
		BH-118	CIM-446	FH-900	FH-901	MNH-93	MNH-552	MNH-554	NIAB-KARISHMA	LSD at 5%
Number of bolls/plant	T_0	8.0±0.58	7.0±0.58	7.0±1.15	8.0±0.58	6.0±0.56	4.0±0.57	5.0±0.54	4.0±0.50	1.59
	T_1	4.0±0.58	3.0±0.50	4.5±0.52	3.5±0.29	4.0±0.58	3.0±0.48	5.5±0.29	4.5±0.87	
	T_2	2.5±0.29	3.5±0.29	1.5±0.20	1.5±0.24	2.0±0.00	4.0±0.58	1.5±0.29	3.5±0.25	
Boll diameter (cm)	T_0	2.75±0.09	2.90±0.06	2.25±0.03	2.45±0.14	2.40±0.06	2.20±0.06	2.65±0.09	2.80±0.06	0.37
	T_1	2.05±0.09	2.00±0.06	1.58±0.04	1.90±0.12	2.15±0.09	2.25±0.06	1.95±0.09	2.55±0.14	
	T_2	1.80±0.06	1.75±0.20	2.00±0.23	1.95±0.03	1.50±0.17	1.55±0.09	1.60±0.12	1.80±0.06	
Staple length (mm)	T_0	27.4±0.06	26.8±0.03	28.4±0.03	26.6±0.06	27.1±0.06	27.5±0.07	27.2±0.09	26.5±0.07	0.025
	T_1	27.5±0.22	27.1±0.09	28.5±0.06	26.6±0.09	26.9±0.14	27.6±0.14	27.5±0.06	26.3±0.07	
	T_2	26.5±0.09	26.7±0.03	28.3±0.12	26.4±0.06	26.6±0.14	27.6±0.06	27.2±0.07	26.0±0.06	
Fiber strength (tppsi)	T_0	95.8±0.38	96.9±0.38	93.6±0.18	91.7±0.09	93.5±0.20	98.3±0.41	96.7±0.32	96.9±0.31	0.58
	T_1	95.1±0.09	97.2±0.06	93.5±0.23	91.5±0.09	93.4±0.14	97.3±0.18	96.1±0.12	94.4±0.09	
	T_2	95.5±0.12	97.1±0.06	93.4±0.12	91.4±0.09	93.1±0.14	98.0±0.06	97.2±0.12	93.7±0.12	
Ginning out turn (%)	T_0	38.7±0.03	36.0±0.06	37.3±0.09	38.2±0.06	36.1±0.03	40.2±0.06	40.3±0.06	35.2±0.07	0.19
	T_1	38.7±0.12	35.9±0.07	37.2±0.09	38.1±0.06	35.9±0.03	40.0±0.06	40.4±0.03	35.1±0.06	
	T_2	38.4±0.09	35.9±0.09	37.3±0.09	37.9±0.06	35.7±0.03	40.2±0.09	40.1±0.03	34.9±0.06	
Fiber fineness (micronaire)	T_0	4.4±0.03	4.6±0.06	4.5±0.09	5.0±0.09	4.5±0.06	4.1±0.06	4.3±0.06	4.9±0.06	0.19
	T_1	2.47±0.20	1.99±0.18	2.44±0.03	2.25±0.03	1.30±0.04	2.66±0.03	2.54±0.08	1.93±0.13	
	T_2	1.70±0.13	1.53±0.02	2.34±0.11	1.82±0.21	2.09±0.06	2.30±0.05	1.58±0.03	1.82±0.11	

To= Control, T_1= 2 drought cycles, T_2= 4 drought cycles

Table III. Summary of analysis of variance for various growth and yield attributes of eight cotton varieties (*Gossypium hirsutum* L.) after 2 and 4 drought cycles (n = 3)

Characters	Varieties					
	MS_t	Significance	$MS_{var.}$	Significance	MS_i	Significance
Plant height (cm)	265.191	***	57.575	***	31.315	**
Number of leaves	107.295	***	6.793	**	7.807	***
Leaf area (cm^2)	23294.541	***	7703.061	***	1823.478	***
Specific Leaf Area	4.18	**	4.50	**	3.15	*
Plant dry weight (g)	14.627	***	1.396	**	1.002	**
Leaf dry weight (g)	1.144	***	0.702	***	0.328	***
Number of bolls/Plant	73.013	***	1.561	NS	5.704	***
Boll diameter (cm)	3.9	**	0.148	*	0.156	**
Staple length (mm)	0.183	***	4.055	***	0.075	***
Fiber strength (tppsi)	2.063	***	41.287	***	0.96	***
Ginning out turn (%)	0.194	***	34.576	***	0.032	*
Fiber fineness (micronaire)	0.28	***	0.5435	***	0.052	***

NS= non significant, *, **, ***= significant at 0.05, 0.01 and 0.001 probability levels
MSt= Mean square treatments, MSvar.= Mean square varieties, MSi= Mean square interaction (T x Var.)

height was observed by the completion of the four water deficit cycles, but only MNH-93 had significantly greater plant height. This indicated that commencement of early periods of drought had more drastic effects on plant height.

Parolin (2001) described the critical role of water for meristematic activities. Therefore, water availability appeared to be more crucial during cell division and elongation. These findings are comparable to Chaves *et al.* (2003), who also described the significance of water availability during vegetative growth.

The present study indicated that the juvenile growth stages were more susceptible to water deficit. However, time course changes for certain characters might allow the plants to acclimatize prevailing stress. These observations are in lines with Bohnert (1998), who reported more injurious effects of initial moisture stress, however, extended drought periods allowed plants to cope better. Similar trends were also observed when varieties were compared for other growth traits such as number of leaves, leaf area and specific leaf area (SLA). There was a consistent decline for these growth traits in all varieties when subjected to initials periods of drought. The early periods of drought caused more profound effect on these growth traits in MNH-93, however, the variety showed sustainable growth after receiving four cycles of drought. Though, FH-901 had reduced number of leaves and leaf area but an increase in SLA. Similar responses were also recorded for MNH-93. The maintenance of growth under water deficit environment can be attributed to the modification of leaf traits. Water economy seems to be attained by enhanced water retention through a decrease in an overall leaf area and at the same time an increase in SLA under deficit conditions. Therefore these traits can be used as a predictor for the selection of moisture deficit tolerance in plants.

Total dry biomass signifies total assimilates of the plants (Chaves *et al.,* 2002) and is a good predictor for the appraisal of tolerance to stress. The results of the study revealed that all cotton varieties had lower dry biomass under water stress conditions.

However, MNH-93 showed consistently greater total dry biomass of the plants under varying drought regimes. Thus, the resistance of this variety can be attributed successful carbon assimilation under such conditions. These assumptions are in close conformity to Habib and Ashraf (2005) and Chaves (1991), who widely reviewed sustainable rate of carbon assimilations in a number of drought resistant species under water stress. In general, there was a consistent relationship between leaf area number of leaves and dry biomass production for MNH-93 and FH-901. These morphological expressions of the varieties signified better growth and were readily identifiable.

The results of present study for yield and yield components clearly indicated that MNH-93, MNH-552, MNH-554, CIM-446, FH-900 and NIAB-Krishma appeared to be drought tolerant with respect to their yield. The MNH-552 and MNH-554 excelled for their ginning out turn under water deficit conditions. The study indicated a trade off between vegetative growth and yield parameters for these varieties. Hence those varieties, which invested more for yield did not produce better growth and vice versa.

These results can be related to early findings of Joseph *et al.* (1997), who found differential responses of crops for different traits. However, MNH-93 maintained both growth and yield thus did not ascertain any trade off. However, a consistent degree of tolerance for both growth and yield may resolve overall success of the plant as argued by Ponnuswamy and Karivaratharaju (1996).

Based on the results presented here it was affirmed that the varieties used in this study differed in their responses to water stress with respect to various growth, yield and yield components. Differential abilities of the varieties to cope with water stress were also evident from this study. Therefore, it was possible to discriminate among these varieties on the basis of these parameters and there was a clear-cut distinction between varieties for tolerance and susceptibility to water stress. On the basis of morphological character expressions in response to water deficit, it can be concluded that MNH-93 appeared to be more drought tolerant for both growth and yield parameters. MNH-93, MNH-552, MNH-554, CIM-446, FH-900 and NIAB-Krishma also exhibited some potential for yield and yield components under varying drought intensities. The study affirmed that certain attributes can certainly signify drought tolerance in these cotton varieties and provide morphological basis of selection criterion.

Furthermore, these morphological characters can lead to the selection of certain molecular markers, which can be used to identify genetic variability for water deficit tolerance.

REFERENCES

Belhassen, E. and P. Monneveux, 1996. The Diversity of drought adaptation in a wide. *Pl. Growth Regulation*, 20: 85–92

Bohnert, H.J. and E. Sheveleva, 1998. Plant stress adaptation – making metabolism move. *Current Opinion Pl. Biol*., 1: 267–74

Bray, E.A., 1997. Plant responses to water deficit. *Trends Pl. Sci*., 2: 48–54

Chaves, M.M., 1991. Effects of water deficits on carbon assimilation. *J. Exp. Bot.,* 42: 1–46

Chaves, M.M., J.S. Pereira, J. Maroco, M.L. Rodrigues, C.P.P Ricardo, M.L. Osorio, I. Carvalho, T. Faria and C. Pinheiro, 2002. How plants cope with water stress in the field: Photosynthesis and growth. *Ann. Bot*., 89: 907–16

Chaves, M.M., P.P. Maroco and J.S. Pereira, 2003. Understanding plant responses to drought-from genes to the whole plant. *Funct. Pl. Biol.,* 30: 239–64

Elms, M.K., C.J. Green and P.N. Johnson, 2001. Variability of cotton yield and quality. *Comm. Soil Sci. Pl. Analysis,* 32: 351–68

Fischer, G., M. Shah, H. Velthuizen and F.O. Nachtergaele, 2001. *Global Agroecological Assessment for Agriculture in the 21st Century*. Laxenburg, Austria: IIASA and FAO

Giorgi, F., 2005. Climatic change predictions. *Climatic Change*, 73: 239–65

Habib, R.A. and M. Ashraf, 2005. Photosynthesis under drought stress. *In*: Pessarakli, M. (ed.), *Hand Book of Photosynthesis*, Pp: 783–804. Marcel and Dekker, New York

Hoekstra, F.A., E.A. Golovina and J. Buitink, 2001. Mechanisms of plant desiccation tolerance*. Trends Pl. Sci.*, 6: 431–8

Joseph, E.M., M.A Angokai and H. Qusmanou, 1997. Effect of water stress on abscission of reproductive organs in cotton during rainy season in Northern Cameroon. *Proc. Beltwide Cotton Conference New Orleans, USA*, 2: 1442–3

Khatri, A., I.A. Khan, M.A. Siddique, G.S. Nizamani and S. Raza, 2004. Performance of oilseed *Brassica* in different water regime, *Pakistan J. Bot.,* 36: 351–7

Parolin, P., 2001. Morphological and physiological adjustments to waterlogging and drought in seedlings of Amazonian flood plain trees. *Oecologia*, 128: 326–35

Passioura, J.B., 1996. Drought and drought tolerance. *Pl. Growth Regulation*, 20: 79–83

Ponnuswamy, A.S. and T.V. Karivaratharaju, 1996. Effect of soil moisture stress on seed cotton yield and quality of cotton cv. MCU. *Madras J. Agric.,* 83: 225–7

Salisbury, F.B. and C.W. Ross, 1992. *Plant Physiology (4th ed.),* P: 682. Wadsworth Publishing, California

Snedecor, G.W. and W.G. Cochran, 1980. *Statistical Methods (7th ed.),* P: 508. Iowa State University Press, Ames, Iowa

(Received 09 May 2006; Accepted 01 September 2006)