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SCREENING OF COTTON CULTIVARS FOR DROUGHT TOLERANCE UNDER FIELD CONDITIONS

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ABSTRACT

To develop cotton germplasm with improved yield under drought conditions is one of the major goals for cotton breeders. The main purpose of this study was to evaluate 96 cotton genotypes for drought tolerance by measuring yield performance under deficit (water-limited) and full irrigation conditions. The field experiment was conducted under full (FI-100) and deficit (DI-50) irrigation conditions during the two growing seasons of 2011 and 2012 at the Agricultural Research Station of Adnan Menderes University, Aydin, Turkey. The mean data on performance of 96 different cotton genotypes showed the existance of considerable genotypic variations for yield, yield components, and drought tolerance indices. Correlation and regression analysis indicated that cotton genotypes characterizied with high GMP and low DSI could be selected as a potentially droght-tolerant genotypes. It is concluded from the present studies that, based on biplot analysis, 20 genotypes were found highly susceptile to water stress, 26 genotypes were highly susceptible to water stress but produced high yield in full irrigation, and 23 genotypes were not only water stress tolerant but also give maximum seed cotton yield. However, GC 555, Nieves, DAK-66/3, MS-30/1, Nazilli M-503, Zeta 2, Eva, NIAB 999, and Delta Diomand were found highly water stress tolerant because of maximum GMP and minimum DSI values. These genotypes could be exploited as genetic resources in breeding programs aiming to improve drought tolerance in cotton.

Key words: Cotton, *Gossypium hirsutum* L. water stress, selection criterias

INTRODUCTION

Amongst the abiotic stresses, water stress has been considered as a threat for low crop productivity in many regions of the world (Turner, 1997; Sinclair, 2005). While demands on water resources for agricultural purposes is increasing, declining water availability, and increasing human demands are limiting its availability for agriculture. Approximately one third of the cultivated area of the world suffers from chronically inadequate supplies of water (Massacci et al., 2008). Further it is reported that future climatic changes are expected to increase risks of drought (Rizza et al., 2004).

Cotton is an excellent candidate for irrigation. With proper management, irrigation has been shown to increase lint yield by more than 350 kg ha^{-1} in Georgia (Bednarz et al., 2002). Numerous studies have reported how cotton reproductive growth, yield and fibre quality are affected by moisture deficits. Cotton yield is dependent upon the production and retention of bolls, and both can be decreased by water stress (Guinn and Mauney, 1984). Under water stress, decrease in seed cotton yield is primarily due to the reduction in number of bolls and boll weight (Pettigrew, 2004; Wang et al., 2004; Mert, 2005; Basal et al., 2009). Water stress affects lint quality in numerous ways, especially during the fibre elongation period, which results in a decrease in fibre length and causes fibre immaturity (Ritchie et al., 2004; Mert, 2005).

Previous studies reported that there is genetic variability for drought response in cotton subjected to water deficient since cotttableon originates from areas that are often exposed to water-deficit stress (Quisenberry et al., 1981, Lacape et al., 1998; Pettigrew and Meredith, 1994). Therefore, selection for drought tolerance is a major interest of plant breeders in cotton, as well as other agricultural crop commodities. A number of different morphological (leaf, stem and root growth parameters) and physiological traits (more than 30 traits) have been suggested as important selection criteria relative to drought tolerance in cotton (Loka et al., 2011). However, none of the above physiological traits has so far been consistently correlated positively with drought tolerance (Loka et al., 2011). The difficulty in identification of a physiological parameter as a reliable indicator of yield in drought conditions has suggested that yield performance over a range of environments should be used as the main indicator for drought tolerance (Voltas et al., 2005).

Most of the screening studies were conducted under controlled conditions by using pot experiments. Unfortunately, pot experiments can have several serious disadvantages that make the results difficult to extrapolate to the field (Passioura, 2006). When the growing conditions are below the optimum, small variations in growing conditions will amplify differences in plant growth. Hence, pot experiments under stress conditions will increase error variance due to the pot size, the physical constraint of roots in a small container, potting mixture (media), commercial plant nutrients, shoock stress treatment (http://www.plantstress.com/methods/PotExp.htm). Therefore, the experiments were conducted under field conditions to quantify cotton genotypes performance for drought tolerance.

Since drought is the most significant environmental stress in global agriculture, developing germplasm with improved yield under drought conditions is a major plant breeding goal (Cattivelli et al., 2008). In order to improve such new cultivars, two basic requirements must be available. Firstly, there must be variability for water stress tolerance in the crop as a whole, and secondly, this variation must be genetically controlled. To develop cotton varieties for drought tolerance, the first step in breeding programme is to determine suitable parents. Thus, the main purpose of this study is to screen the cotton genotypes for drought tolerance by measuring yield performance under deficit (water-limited) and full irrigation conditions, and to select drought tolerant cotton genotypes that would be used as genetic resources by cotton breeders in hybridiziaton breeding programme for improving cotton productivity under drought conditions in future investigations.

MATERIALS AND METHODS

The experiments were conducted during the two growing seasons of 2011 and 2012 at the Agricultural Research Station of Adnan Menderes University, Aydin, Turkey. The longitude and latitude of the experiment site are 37° 51' N and 27° 51' E, respectively. Climate in this region is semiarid with total annual precipitation of 657 mm. The soil type of the experimental area was loam and sandy loam in texture. For the cotton experiment area, water content at field capacity varied from 20.3 to 27.6 %, and wilting point varied from 7.2 to 9.7 % on dry weight basis. The dry soil bulk densities ranged from 1.42 to 1.50 g cm^{-3} throughout the 1.2 m deep profile. The experiment was arranged in the augmented block design with four replications. Ninety eight (96) cotton genotypes and five check varieties (Carmen, Sahin 2000, BA 119, GSN 12, and Claudia) were used as plant material. Total 101 cotton genotypes were planted on 19 May 2011 and on 03 May 2012 respectively. Cotton plants were planted at 0.70 m (row width) 0.20 m (between plants). Each cotton genotype was planted one row with 12 m long and only 10 m length was harvested. A compound fertilizer (15 %, 15 % and 15 % composite) was applied at a rate of 60 kg ha^{-1} pure N, P and K before planting. The required remaining portion of nitrogen was followed by 82 kg ha^{-1} as ammoniumnitrate 33 % before first irrigation.

The experiment included two irrigation regimes, namely full (meeting 100 % of crop water needs) and deficit irrigation (meeting 50 % of crop water needs). The irrigation treatments were based on replenishment of soil water depletion. The control treatment, full irrigation, (FI-100) was designated to receive 100 % replenishment of soil water depletion. Depletion was defined as the difference between the depth of water held in the root zone at field capacity and the depth of water actually held in the root zone at the time of irrigation. Irrigation was applied when 50 % of available soil moisture was consumed in the 1.20 m root zone in the FI-100 treatment during the irrigation periods. The measured soil moisture level at the control (FI-100) treatment was used to initiate irrigation of cotton during the growing season. In treatments, deficit irrigation (DI-50) was applied at the rates of 50 % of control treatments (FI-100) on the same day. A drip irrigation system was designated for the experiment. The average amount of applied water was about 313 mm for DI-50 (deficit irrigation) and 626 mm FI-100 (full irrigation). Soil water level was monitored by using the gravimetric method in the plots of the second replication of the various treatments. Cotton yield was determined by hand harvesting in each plot on 29 September 2011 and on 14 September 2012.

Seed cotton yield (kg ha), lint percentage (%), boll number (per plant), and boll weight were tested for differences in genotypes. Also the drought susceptibility index (DSI) and geometric mean productivity (GMP) were calculated as follows: Drought intensity index (DI) for each cultivar was calculated as

$$DI = 1 - \frac{\hat{Y}s}{\hat{Y}p}$$

where $\hat{Y}s$ and $\hat{Y}p$ are the means of all genotypes under full irrigated and deficit irrigated conditions, respectively.

The formula proposed by Fisher and Maurer (1978) was used to calculate drought susceptibility index (DSI) for each cultivar.

$$DSI = 1 - \frac{\frac{Ys}{Yp}}{DI}$$

Where Yp and Ys are mean yields of a given cultivar under full irrigated and deficit irrigated conditions, respectively and DI is drought intensity index.

Geometric mean productivity (GMP) was calculated by using the formula proposed by Fernandez (1992):

$$GMP = \sqrt{Yp \times Ys}$$

Statistical analysis was performed using JMP 5.0.1 statistical software (SAS Institute Inc., 2002) and the means were grouped with Fisher's Least Significant Difference (LSD) test at alpha level of 0.05. Linear associations among traits of intrest were determined by estimating correlation coefficient. Also, multiple regression analysis was carried out to dermined the variables affecting the seed cotton yield under water stress conditions.

RESULTS AND DISCUSSION

Cotton genotypes had different response to the two moisture conditionsin in terms of investigated parameters (Table 1). Seed cotton yield of 96 cotton genotypes measured in full irrigation differed from each other, and ranged from 2,441 kg $h^{-1}$of CABU/CS2-1-83 (No. 7) to 6,517h^{-1} of NP EGE 2009 (No. 65). Under water stressed condition, seed cotton yield markedly reduced and these ranged from 1,791 kg h^{-1} of CABU / CS2-1-83 (No. 7) to 3,993 kg h^{-1} of NP EGE 2,009 (No. 65) followed by DAK-66/3 (No. 53), Nazilli M-39 (No 58), and Zeta 2 (No. 77). Under deficit irrigation among the control varieties GSN 12 was in the first rank with 3,192 kg h^{-1} yield. While the difference in seed cotton yield between NP EGE 2009 and GSN 12 was not significant, NP EGE 2009 produced more lint yield than GSN 12 under water stress condition (data do not shown). Substantial variation in geometric mean productivity (GMP) ranging from 2,082 kg h^{-1}(CABU / CS2-1-83, No. 7) to 5,091 kg h^{-1}(NP EGE 2009 (No. 65) was found among the cotton, respectively. On average, seed cotton yield of 96 cultivars was 2,977 kg h^{-1} in stress conditions as compared to 4076 kg h^{-1} in non-stressed conditios. Average seed cotton yield decreased 27 % in water stressed conditions. Percentage reduction of yield was different among cotton genotypes. The largest reduction in seed cotton yield due to drghout stress was in Tamcot 22 (51%) (No. 51) followed by Taskent 1 (49%) (No. 68). In contrast, Zeta 2 (No. 77) maintained its yield in both stress (3677 kg h^{-1}) and non-stress (3,697kg h^{-1}), and therefore it had the lowest yield reduction (1%) and low DSI value (0.13).

Generally, the cultivars having DSI less than 1.0 presents the water stress tolerance as compared to other cultivars showing DSI values higher than 1.0. The DSI for seed cotton yield was the lowest for Zeta 2 (0.13; No. 77), followed by Nazilli 87 (0.23; No. 57), DAK 66/3 (0.26; No. 53), and NIAB 999 (0.26; No. 82). The highest DSI (1.89) was found in Taskent 1 (No. 68) followed by Tamcot 22 (No. 83), Taskent Uzbek (No. 70), and Coker 208 (No. 9). In this study, CABU/CS2-1-83 (No. 7) had DSI value (0.73) less than 1.0, but the cultivar had the lowest yield (1,791 kg h^{-1}) under stress condition. On the other hand, NP EGE 2009 (No. 65) had DSI value (1.43) greater than 1.0, however the cultivar had the highest yield under stressed condition. These results show that drought tolerance is a complex trait that can involve many different growth-related traits and genes, corresponding to different ways. Also, water stress tolerance can not be attributed to a genotype, because of its superiority for a single trait, therefore different parameters would be used to determine tolerant genotypes for water stress as suggested by Al-Hamdani and Barger (2003).

Water stress generally increased lint percentage of most genotypes. Mean lint percentage of 96 cotton genotypes was 36.3 % for control (full irrigation) and 36.9 % for deficit irrigation (water stress) application. The SG 125 (No. 29) was found with highest lint percentage under both control and stress conditions. Delcerro MS-30 (No. 75) had the lowest lint percentage under both irrigation regimes. Boll number per plant declined significantly under drought condition. Data on boll number per plant revealed that cotton genotypes had different response to the two moisture conditions. The highest (14.9 boll $plant^{-1}$) and the lowest boll number (6.9 boll $plant^{-1}$) were found in Nazilli M-503 (No. 60) and Nazilli 87 (No. 57) under normal condition, respectively. Under stress conditions the highest boll number (12.1 boll $plant^{-1}$) was of MS-30/1 (No. 54), while DPL 883 (No. 15) maintained the lowest boll number (5.7 boll $plant^{-1}$). Average bolls per plant reduced to 8 bolls per plant in stress conditions against 10.9 bolls per plant in non-stressed conditions. With bolls per plant, boll weight is one of the important yield components in cotton. Based on boll weight data in Table 1, 96 cotton genotypes again appeared to respond differently to non-stressed and stressed conditions. The boll weight in control (full irrigation) ranged from 2.6 g of Nazilli 87 (No. 57) to 6.4 g of AZ 31 (No. 78). Boll weight under water stress markedly reduced and varied from ranged from 2.9 g of Tamcot 22 (No. 83) to 6.5 g of NIAB 999 (No. 82) (Table 2).

Correlation coefficients for seed cotton yields, lint percentages, boll numbers, and boll weights from the FI and DI environments were positive and significant (Table 3). A positive association was found between yield under full irrigation and GMP for seed cotton yield, boll number and boll weight. Yield in DI condition was positively correlated with boll number and boll weight, but was negatively correlated with drought susceptibility index. Also it was positively correlated with geometric mean for both boll number and boll weight.

Regression equation from multiple regression analysis of seed cotton yield under water stress was determined as:

$$Yield = 0.955 \times GM - 0.607 \times DSI.$$

The results from multiple regression analysis indicated that geometric mean productivity (GMP) and drought susceptibility index (DSI) explained 65 and 35 % of the variation observed in the seed cotton yield under water stress, respectively. The positive effects of geometric mean productivity (GMP) and negative effect of drought susceptibility index (DSI) on seed cotton yield indicated that higher value of GMP and lower value of DSI would increase seed cotton yield under stressed condition. Therefore, drought tolerant cotton genotypes could be selected based on these parameters. Previous studies suggested that the most effective approach in breeding for drought resistance in common bean (Ramirez-Vallejo and Kelly, 1998), in soybean (Teran and Singh, 2002), and in cotton (Ullah et al., 2006) would be based first on selection for high GMP followed by selection among the high yielding individuals for low to moderate levels of the DSI.

Table 1. Mean seed cotton yield and lint percentage for 96 cotton genotypes and check varieties evaluated in full irrigation and deficit irrigation environments.

Num.	Genotype	Country of Origin	Seed cotton yield ($kg\ ha^{-1}$)				Lint Percentage (%)		
			*FI	DI	GMP	DSI	FI	DI	GMP
1	Sealand 542	USA	4162	2724	3373	1.33	33.2	34.9	34.0
2	DPL 90	USA	3250	2584	2884	0.58	38.2	39.4	38.8
3	Acala 1517	USA	3271	2574	2888	0.61	34.9	35.9	35.4
4	Acala 5	USA	3403	2520	2921	0.89	36.5	35.5	36.0
5	Auburn M	USA	3224	2209	2668	1.12	32.6	32.4	32.5
6	Blightmaster	USA	4228	2764	3425	1.32	36.9	36.7	36.8
7	CABU / CS2-1-83	USA	2441	1791	2082	0.73	37.0	36.3	36.7
8	Carolina Queen	USA	4341	3034	3629	1.16	38.5	38.3	38.4
9	Coker 208	USA	4223	2582	3315	1.52	37.4	37.5	37.4
10	Deltaopal	USA	4146	3287	3679	0.77	38.0	38.7	38.3
11	DP-388	USA	3583	2640	3069	0.81	38.9	38.6	38.8
12	DPL 6	USA	3556	3012	3253	0.45	36.2	35.9	36.0
13	DPL 5415	USA	3753	2804	3236	0.87	37.9	37.8	37.9
14	DPL 882	USA	3449	2864	3125	0.53	36.6	36.0	36.3
15	DPL 883	USA	3925	2939	3390	0.86	35.0	35.1	35.1
16	DPL 20	USA	3653	2774	3174	0.84	38.9	37.6	38.2
17	DPL 886	USA	4744	2967	3763	1.42	37.4	36.3	36.8
18	DPL C-37 Prima	USA	3818	2588	3146	1.12	36.4	34.6	35.5
19	DPL SR-383	USA	3524	2447	2936	1.19	35.9	33.2	34.5
20	GC 262	USA	4241	2865	3489	1.04	37.6	37.3	37.4
21	GC 555	USA	4634	3492	4016	0.79	36.6	36.4	36.5
22	GSA-78	USA	4100	2769	3373	1.19	36.7	35.0	35.8
23	Lankart 57	USA	4232	3131	3635	1.03	38.7	36.6	37.6
24	McNair 220	USA	4075	2981	3481	0.99	37.0	39.0	38.0
25	Paymaster 404	USA	4012	2818	3362	1.07	36.5	37.1	36.8
26	Rex 1	USA	4178	3034	3561	1.03	34.2	36.5	35.3
27	S.J.V. VisaliaElmer	USA	3603	2709	3126	0.87	36.0	38.0	37.0
28	SG 1001	USA	4373	2773	3481	1.36	37.9	38.5	38.2
29	SG 125	USA	4856	3011	3822	1.36	40.3	42.5	41.4
30	Stoneville 213	USA	3792	2867	3299	0.94	35.6	39.0	37.2
31	Stoneville 453	USA	4042	3209	3604	0.75	33.6	35.0	34.3
32	Stoneville 8751	USA	4254	2731	3407	1.25	37.0	38.3	37.7
33	Tamcot CABCS	USA	3621	2781	3176	0.92	36.1	36.8	36.4
34	TKY 9309	USA	4705	2983	3745	1.26	35.8	36.4	36.1
35	TKY 9409	USA	3681	2390	2965	1.33	38.5	40.6	39.6
36	TKY 9304	USA	2846	2395	2615	0.61	37.1	35.6	36.3
37	Togo	S. Africa	3663	3049	3346	0.63	34.6	35.1	34.9
38	Samon	Albanian	3549	2661	3075	0.89	34.2	34.4	34.3
39	N-727 CC	Australia	4422	2792	3512	1.38	38.9	40.0	39.4
40	Nieves	Australia	4022	3442	3725	0.56	35.8	38.2	37.0
41	Semu SS/G	Australia	3953	2447	3109	1.33	32.9	34.1	33.5
42	Sicala 3/2	Australia	3791	3332	3559	0.53	33.5	34.6	34.1
43	Sicala 33	Australia	4064	3043	3518	1.03	35.4	36.5	35.9
44	Sahel 1	Iran	3480	2693	3063	0.94	37.0	38.0	37.5
45	Veramine	Iran	4290	3190	3701	1.02	33.7	34.9	34.3
46	Corona	Spain	3128	2681	2901	0.53	37.5	38.6	38.1
47	Lachata	Spain	3916	3252	3572	0.71	36.0	36.9	36.5

Table 1. Continious

Num.	Genotype	Country of Origin	Seed cotton yield (kg ha^{-1})				Lint Percentage (%)		
			*FI	DI	GMP	DSI	FI	DI	GMP
48	Nata	Spain	4020	2778	3342	1.26	35.4	37.2	36.3
49	Vulcano	Spain	3425	3041	3233	0.43	34.8	37.8	36.3
50	Erşan 92	Turkey	3649	3313	3492	0.44	37.4	37.8	37.6
51	Sayar 314	Turkey	4016	3469	3745	0.61	36.7	37.8	37.3
52	Ayhan 107	Turkey	3345	2876	3113	0.62	37.0	36.4	36.7
53	DAK-66/3	Turkey	3986	3825	3923	0.26	37.4	37.9	37.6
54	MS-30/1	Turkey	4061	3688	3885	0.47	35.3	35.8	35.5
55	Nazilli 143	Turkey	4988	3592	4234	1.05	37.6	36.6	37.1
56	Nazilli 84-S	Turkey	3911	2901	3371	0.94	39.8	40.7	40.2
57	Nazilli 87	Turkey	3546	3456	3519	0.23	35.2	33.9	34.5
58	Nazilli M-39	Turkey	5332	3700	4440	1.07	34.1	36.1	35.1
59	Nazilli M-503(93-7)	Turkey	4420	3496	3937	0.9	34.0	33.1	33.6
60	Nazilli M-503	Turkey	4817	3351	4016	1.23	32.7	32.2	32.4
61	NGF-63	Turkey	4157	3231	3670	0.83	37.9	37.7	37.7
62	Barut 2005	Turkey	4911	3683	4256	0.98	37.2	37.6	37.4
63	Menderes 2005	Turkey	4048	2805	3367	1.19	36.8	36.3	36.6
64	NAPA 122	Turkey	3975	3129	3533	0.89	37.9	38.9	38.4
65	NP Ege 2009	Turkey	6517	3993	5091	1.43	36.3	38.5	37.3
66	NP Özbek 100	Turkey	4921	3599	4210	0.96	37.3	37.5	37.4
67	SamarkantUzbek	Uzbekistan	4044	2709	3305	1.39	34.7	34.4	34.5
68	Taşkent 1	Uzbekistan	4135	2117	2933	1.89	36.0	36.4	36.2
69	Taşkent-6	Uzbekistan	3795	2881	3310	0.8	35.5	36.2	35.8
70	Taşkent Uzbek	Uzbekistan	4493	2594	3398	1.72	31.3	33.5	32.3
71	152 F	Uzbekistan	3483	2727	3088	0.83	34.0	34.4	34.2
72	Aleppo-1	Syria	4594	2927	3659	1.4	30.7	32.8	31.7
73	S-9	Syria	4158	2847	3433	1.12	34.1	35.3	34.7
74	Delcerro	USA	2675	2611	2641	0.33	34.8	35.1	34.9
75	Delcerro MS-30	USA	3061	2692	2867	0.41	30.7	31.8	31.3
76	Sindos 80	Greece	3580	2825	3175	0.74	36.4	35.8	36.1
77	Zeta 2	Greece	3697	3677	3686	0.13	35.9	36.0	35.9
78	AZ 31	Israil	5112	3387	4152	1.02	35.4	34.7	35.0
79	Eva	Greece	4441	3467	3918	0.64	35.7	36.5	36.0
80	GW Teks	USA	4508	3106	3734	1.1	38.0	37.3	37.7
81	NIAB 111	Pakistan	4037	3156	3564	0.72	37.6	37.9	37.7
82	NIAB 999	Pakistan	3947	3468	3696	0.26	37.4	37.7	37.5
83	Tamcot 22	USA	4670	2292	3256	1.73	35.6	35.8	35.7
84	Tamcot Sphinx	USA	4214	2986	3540	0.88	34.8	35.0	34.9
85	SJ- U 86	USA	5549	3135	4159	1.47	35.9	37.7	36.8
86	Candia	Australia	4427	3039	3660	0.76	40.2	41.5	40.8
87	Celia	Australia	3931	2616	3198	1.18	36.4	38.9	37.6
88	Elsa	Australia	5062	3436	4163	1.05	38.9	40.6	39.7
89	Delta Diomand	Spain	4913	3349	4048	0.87	37.3	38.3	37.8
90	Gloria	Australia	4775	3154	3872	1.09	39.7	38.9	39.3
91	Julia	Australia	4230	3093	3610	0.91	38.9	39.8	39.3
92	Flora	Australia	4277	2824	3467	1.14	37.0	36.9	36.9
93	PG 2018	Turkey	4757	3347	3983	0.94	38.6	40.9	39.7
94	BA 308	Turkey	4349	3009	3610	1.04	36.6	37.3	36.9
95	BA 525	Turkey	4583	3131	3780	1.04	39.0	40.4	39.6
96	Lider	Turkey	3583	2637	3067	0.89	39.3	41.6	40.4
	Mean		**4076**	**2977**	**3474**	**0.95**	**36.3**	**36.9**	**36.6**
	Check Varieties								
	Carmen		3699	2932	3288	0.79	38.0	38.0	38.0
	Şahin 2000		4536	2840	3582	1.44	34.6	33.0	33.8
	BA 119		4102	3045	3516	0.83	38.9	41.3	40.1
	GSN 12		4261	3192	3685	0.84	37.7	39.7	38.7
	Claudia		3765	2732	3205	0.96	40.4	40.5	40.4
	Mean		**4073**	**2948**	**3455**	**0.97**	**37.9**	**38.5**	**38.2**
	LSD$_{(0.05)}$		1230	902	972	1.12	2.4	2.8	1.4

*FI: Full irrigation, DI: Deficit irrigation, GMP: Geometric mean productivity, DSI: drought susceptibility index.

Table 2. Mean boll number and boll weight for 96 cottongenotypes and check varieties evaluated in full irrigation and deficit irrigation environments.

Num.	Genotype	Country of Origin	Boll number (Boll plant^{-1})			Boll weight (g)		
			*FI	DI	GMP	FI	DI	GMP
1	Sealand 542	USA	9.8	7.8	8.7	6.0	5.1	5.5
2	DPL 90	USA	10.5	7.5	8.9	4.1	5.0	4.6
3	Acala 1517	USA	11.4	7.9	9.5	4.3	4.4	4.4
4	Acala 5	USA	9.6	5.9	7.6	5.8	6.0	5.9
5	Auburn M	USA	11.5	8.0	9.6	4.1	4.5	4.3
6	Blightmaster	USA	10.2	6.9	8.4	5.2	4.5	4.8
7	CABU / CS2-1-83	USA	12.4	6.2	8.9	3.1	4.3	3.6
8	Carolina Queen	USA	12.5	6.2	9.0	4.9	6.0	5.4
9	Coker 208	USA	9.4	7.6	8.4	6.1	4.7	5.3
10	Deltaopal	USA	11.4	9.1	10.2	4.7	4.6	4.6
11	DP-388	USA	11.3	6.9	8.9	4.0	4.9	4.5
12	DPL 6	USA	10.8	6.0	8.2	5.0	5.6	5.3
13	DPL 5415	USA	11.0	7.8	9.3	4.9	4.8	4.8
14	DPL 882	USA	9.8	5.9	7.7	5.0	6.2	5.6
15	DPL 883	USA	9.6	5.7	7.5	5.5	5.9	5.7
16	DPL 20	USA	8.3	6.5	7.3	4.8	5.5	5.1
17	DPL 886	USA	13.2	8.6	10.7	4.6	5.0	4.8
18	DPL C-37 Prima	USA	9.7	6.5	7.9	4.7	5.5	5.1
19	DPL SR-383	USA	10.8	7.0	8.7	4.7	4.9	4.8
20	GC 262	USA	10.8	7.1	8.8	5.4	5.5	5.5
21	GC 555	USA	11.8	7.5	9.5	5.6	5.8	5.7
22	GSA-78	USA	10.0	6.8	8.3	6.0	5.7	5.9
23	Lankart 57	USA	11.4	6.9	9.0	5.7	5.5	5.6
24	McNair 220	USA	11.2	7.9	9.4	4.9	5.0	5.0
25	Paymaster 404	USA	11.5	6.6	8.8	4.1	5.3	4.6
26	Rex 1	USA	8.2	7.2	7.7	5.9	5.9	5.9
27	S.J.V. VisaliaElmer	USA	11.9	7.7	9.6	4.2	5.0	4.6
28	SG 1001	USA	10.2	7.5	8.7	5.0	5.0	5.0
29	SG 125	USA	13.7	8.4	10.7	4.0	5.7	4.8
30	Stoneville 213	USA	10.5	6.7	8.4	4.6	4.8	4.7
31	Stoneville 453	USA	13.8	10.1	11.8	4.0	4.8	4.4
32	Stoneville 8751	USA	8.7	7.0	7.8	6.2	4.8	5.4
33	Tamcot CABCS	USA	10.0	7.6	8.7	4.7	5.0	4.8
34	TKY 9309	USA	11.7	6.6	8.8	4.8	5.3	5.0
35	TKY 9409	USA	9.8	5.8	7.5	4.6	5.2	4.9
36	TKY 9304	USA	8.2	6.8	7.4	4.0	4.2	4.1
37	Togo	S. Africa	10.9	8.1	9.4	4.0	4.3	4.1
38	Samon	Albanian	9.4	7.3	8.3	4.7	5.4	5.0
39	N-727 CC	Australia	12.9	8.9	10.7	3.2	4.2	3.7
40	Nieves	Australia	13.8	7.9	10.4	4.5	6.1	5.3
41	Semu SS/G	Australia	10.6	9.2	9.8	5.7	3.9	4.6
42	Sicala 3/2	Australia	13.4	9.8	11.4	3.2	4.6	3.9
43	Sicala 33	Australia	13.1	8.1	10.3	3.7	4.7	4.2
44	Sahel 1	Iran	8.4	7.9	8.1	4.1	4.8	4.5
45	Veramine	Iran	11.7	7.4	9.3	4.2	4.9	4.5
46	Corona	Spain	12.9	6.8	9.4	3.0	4.5	3.7
47	Lachata	Spain	10.4	8.9	9.6	4.4	5.1	4.7
48	Nata	Spain	13.4	9.6	11.4	3.7	4.5	4.1
49	Vulcano	Spain	10.0	7.1	8.4	4.2	5.2	4.7
50	Erşan 92	Turkey	10.2	10.2	10.3	4.5	4.7	4.6
51	Sayar 314	Turkey	9.9	10.1	10.1	4.9	4.8	4.9
52	Ayhan 107	Turkey	8.1	10.7	9.5	5.4	3.2	4.2
53	DAK-66/3	Turkey	11.0	10.4	10.8	4.1	5.1	4.6
54	MS-30/1	Turkey	14.3	12.1	13.2	4.4	3.4	3.9
55	Nazilli 143	Turkey	10.3	9.1	9.7	5.6	4.6	5.1

Table 2. Continious

Num.	Genotype	Country of Origin	Boll number (Boll plant^{-1})			Boll weight (g)		
			*FI	DI	GMP	FI	DI	GMP
56	Nazilli 84-S	Turkey	11.3	9.3	10.3	4.1	3.9	4.0
57	Nazilli 87	Turkey	6.9	8.2	15.3	2.6	6.0	4.0
58	Nazilli M-39	Turkey	11.6	9.2	10.3	5.4	4.9	5.2
59	Nazilli M-503(93-7)	Turkey	12.3	9.9	14.3	3.3	3.9	3.6
60	Nazilli M-503	Turkey	14.9	10.5	12.5	4.1	3.9	4.0
61	NGF-63	Turkey	12.3	9.9	11.1	3.8	4.0	3.9
62	Barut 2005	Turkey	11.9	10.0	11.0	5.2	4.1	4.6
63	Menderes 2005	Turkey	8.3	8.0	8.3	4.9	4.1	4.5
64	NAPA 122	Turkey	10.1	10.3	10.3	4.9	3.8	4.3
65	NP Ege 2009	Turkey	12.3	10.4	11.4	6.3	4.6	5.4
66	NP Özbek 100	Turkey	13.3	8.7	10.7	4.3	5.3	4.8
67	SamarkantUzbek	Uzbekistan	11.3	9.2	10.2	4.6	3.6	4.1
68	Taşkent 1	Uzbekistan	9.9	7.7	8.7	4.6	4.0	4.3
69	Taşkent-6	Uzbekistan	12.4	9.5	10.9	3.7	3.3	3.5
70	Taşkent Uzbek	Uzbekistan	10.1	7.9	8.9	5.2	4.2	4.7
71	152 F	Uzbekistan	8.2	8.0	8.2	5.3	4.4	4.9
72	Aleppo-1	Syria	8.2	7.7	8.0	5.9	4.6	5.3
73	S-9	Syria	7.4	8.1	7.8	5.4	4.3	4.8
74	Delcerro	USA	11.4	6.1	8.4	3.9	5.0	4.3
75	Delcerro MS-30	USA	10.8	7.7	9.2	4.8	4.0	4.4
76	Sindos 80	Greece	11.1	9.7	10.4	4.4	3.7	4.0
77	Zeta 2	Greece	9.7	8.1	8.9	5.6	4.4	5.0
78	AZ 31	Israil	8.7	7.1	7.9	6.4	5.5	5.9
79	Eva	Greece	11.6	7.3	9.2	5.4	5.1	5.2
80	GW Teks	USA	11.5	6.3	8.5	5.0	4.9	4.9
81	NIAB 111	Pakistan	11.3	8.6	9.9	4.8	4.5	4.6
82	NIAB 999	Pakistan	8.7	6.0	7.2	6.2	6.5	6.3
83	Tamcot 22	USA	12.8	8.8	10.6	5.4	2.9	4.0
84	Tamcot Sphinx	USA	9.8	6.0	7.6	5.4	5.0	5.2
85	SJ- U 86	USA	11.5	7.6	9.4	6.2	3.9	5.0
86	Candia	Australia	10.4	6.9	8.4	4.7	4.7	4.6
87	Celia	Australia	11.6	6.9	8.9	5.5	4.6	5.1
88	Elsa	Australia	12.5	7.8	9.9	5.2	4.7	5.0
89	Delta Diomand	Spain	12.2	9.4	10.7	5.2	4.0	4.6
90	Gloria	Australia	12.1	7.2	9.3	5.6	4.7	5.2
91	Julia	Australia	12.1	7.3	9.4	4.4	4.4	4.4
92	Flora	Australia	10.0	6.7	8.2	5.4	4.7	5.0
93	PG 2018	Turkey	9.7	7.7	8.7	5.3	4.2	4.7
94	BA 308	Turkey	7.8	6.4	7.1	6.1	4.9	5.5
95	BA 525	Turkey	9.6	9.4	23.9	3.9	4.5	4.1
96	Lider	Turkey	10.4	10.7	10.6	4.8	3.2	4.0
	Mean		**11.0**	**8.0**	**9.6**	**4.8**	**4.7**	**4.7**
	Check Varieties							
	Carmen		10.5	8.6	9.4	4.5	5.0	4.7
	Şahin 2000		12.5	10.3	11.5	4.5	3.4	3.9
	BA 119		10.6	8.3	9.3	4.6	4.8	4.6
	GSN 12		11.9	8.6	10.0	4.6	4.7	4.6
	Claudia		12.1	8.3	10.0	4.4	4.0	4.2
	Mean		**11.2**	**8.8**	**10.0**	**4.5**	**4.4**	**4.4**
	$LSD_{0.05}$		4.6	4.2	3.2	2.4	3.9	2.7

**FI: Full irrigation, DI: Deficit irrigation, GMP: Geometric mean productivity.

Table 3. Correlation coefficients among full irrigation, deficit irrigation, geometric mean productivity, and drought susceptibility index for seed cotton yield, lint percentage, boll number, and boll weight for 96 cotton genotypes.

		Seed cotton yield ($kg\ ha^{-1}$)			Lint percentage (%)			Boll number ($boll\ plant^{-1}$)			Boll weight (g)		
		DI	**GMP**	**DSI**	**FI**	**DI**	**GMP**	**FI**	**DI**	**GMP**	**FI**	**DI**	**GMP**
Seed cotton yield	FI	0.42**	0.88**	0.68**	0.09	0.10	0.01	0.14	0.12	0.20*	0.40**	0.05	0.30**
	DI		0.81**	-0.37**	0.11	0.15	0.14	0.11	0.22*	0.19*	0.16	0.42**	0.36**
	GMP			0.25**	0.12	0.15	0.14	0.15	0.20*	0.23*	0.35**	0.26**	0.39**
	DSI				0.02	-0.01	0.01	0.05	-0.04	0.05	0.29**	-0.27**	0.02
Lint percentage	FI					0.87**	0.96**	0.11	-0.01	0.09	-0.14	0.06	-0.05
	DI						0.97**	0.07	0.01	0.06	-0.09	0.09	0.01
	GMP							0.09	0.01	0.08	-0.11	0.08	-0.02
Boll number	FI								0.20*	0.91**	-0.41**	-0.04	-0.31**
	DI									0.58**	-0.25**	-0.59**	-0.52**
	GMP										-0.48**	-0.28**	-0.49**
Boll weight	FI											0.27**	0.81**
	DI												0.78**

* Indicates significant at P = 0.05

** Indicates significant at P = 0.01

The result of a biplot analysis is shown in Figure 1 which is divided into four quadrants. In biplot, quadrant I demonstrate 23 genotypes which are not only water stress tolerant but also give maximum seed cotton yield (No: 10, 21, 31, 40, 42, 47, 50, 51, 53, 54, 57, 59, 61, 64, 77, 79, 81, 82, 84, 86, 89, 91, and 93). Quadrant II, includes 27 genotypes which are fairly tolerant to water stress but produced lower production (No: 2, 3, 4, 7, 11, 12, 13, 14, 15, 16, 27, 30, 33, 36, 37, 38, 44, 46, 49, 52, 56, 69, 71, 74, 75, 76, and 96). Quadrant III, represents 26 genotypes which are highly susceptible to water stress but produced high yield in full irrigation (No: 8, 17, 20, 23, 24, 26, 28, 29, 34, 39, 43, 45, 55, 58,60, 62, 65, 66, 72, 78, 80, 85, 88, 90, 94, and 95). Quadrant IV corresponds to susceptible 20 genotypes with lower yields (No: 1, 5, 6, 9, 18, 19, 22, 25, 32, 35, 41, 48, 63, 67, 68, 70, 73, 83, 87, and 92).

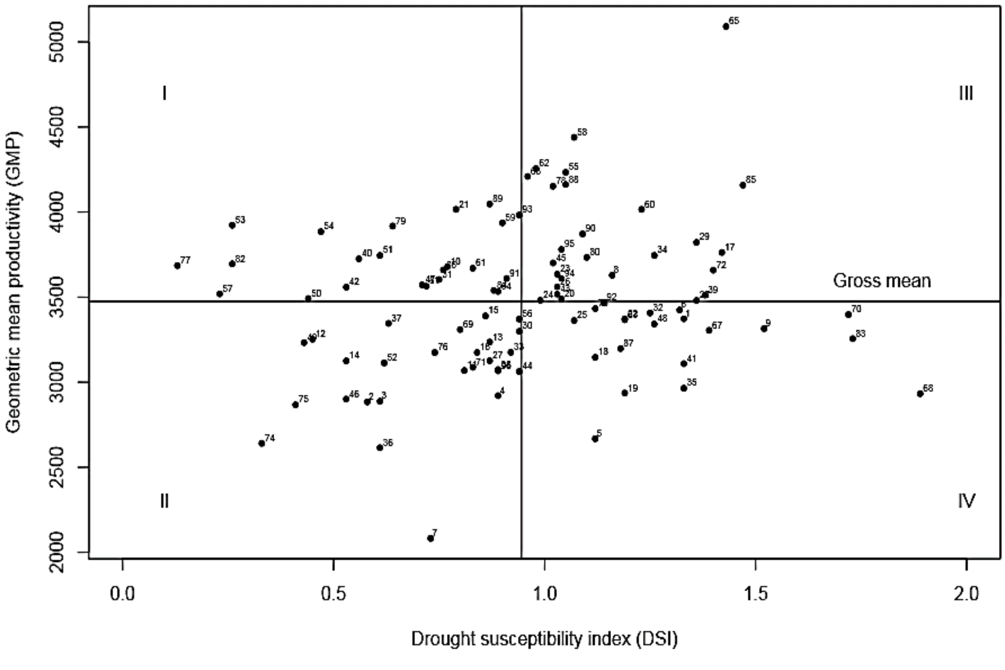

Figure 1. Biplot between geometric mean productivity (GMP) and drought susceptibility index (DSI) values for cotton genotypes.

Drought is the most significant environmental stress in global agriculture. Therefore, the major plant breeding goal is to develop germplasm with improved yield potential under drought conditions (Cattivelli et al., 2008). Existance of useful genetic variation for specific traits releted to drought tolerance in parental germplasm is crucial for successful improvement of crop cultivars (Teran and Singh, 2002). Thus, during recent years the cotton breeders throughout the world have started to develop cotton materials bringing genetic modification in the elite cultivars as parents of new populations, and also utilizing new germplasm in their breeding programme (Iqbal et al., 1997, Basal et al., 2005; Iqbal et al., 2005; Ullah et al., 2006). The difficulty in identification of a physiological parameter as a reliable indicator of yield in drought conditions has suggested that yield performance over a range of environments should be used as the main indicator for drought tolerance in rice (Voltas et al., 2005), barley (Rizza et al., 2004), maize (Tollenaar and Lee, 2002), sugar beets (Ober et al., 2004), and cotton (Ullah et al., 2006). In this study, overall cotton genotypes mean performance for yield and yield components in stress conditions was low as compared to non-stress conditions, nevertheless some genotypes exhibited less mean difference in both irrigation regimes, thus showing genotypic variation for drought tolerance.

Significant and positive correlations between seed cotton yield under DI and boll number and boll weight under DI shows that these two yield components could be good indicators to determine water stress tolerant cotton genotypes. Positive correlation between seed cotton yield in DI and FI shows that high yielding in the DI was also high yielding in FI environment. These results agree with those reported by Ramirez Vallejo and Kelly (1998) and Teran and Singh (2002) in common bean, Abdi et al. (2013) in sunflower, Khokhar et al. (2012) in barley. However, there have been contradictory reports in the literature, Gholipouri et al. (2009) and Anwar et al. (2011) reported that, the yield under irrigated conditions has a very weak association with stress conditions, therefore, indirect selection for stresses environment based on the performance of irrigated conditions would not be effective in wheat. Rosielle and Hamblin (1981) predicted that high yielding genotypes in drought stress were likely to be low yielding in well-watered environments. Negative association between seed cotton yield in DI and DSI would be expected because a higher yield in DI should result in lower percentage reduction and DSI values. Significant negative association of DSI with cotton yield in DI suggested DSI as a useful predictor of drought tolerance in cotton. These findings also support those of Rashid et al. (1999), Moinuddin et al. (2005), and Ullah et al. (2006) who reported that DSI might provide a more effective mean to assess drought tolerance in crops. However, positive association between GMP and DSI suggested that cotton genotypes having high GMP for yield also may result in high reduction in yield (DSI value higher than (1) under DI environment. On the other hand, GMP was positively and significantly correlated with seed cotton yield in DI. Regression analysis also showed that GMP had positive and DSI had negative effect on seed cotton yield under water stressed condition. This result indicates that cotton genotypes with high GMP and low DSI would be selected as drought tolerant genotypes. Our results corroborate those of Ullah et al. (2006), who reported that selection for combination of DSI and GMP indices might be more useful in improving drought tolerance in cotton instead of using a single yield basis criterion since each index is a potential indicator of different biological responses to drought.

CONCLUSION

The present study was aimed to examine drought tolerance of a set of Upland cotton genotypes under FI and DI regimes. Seed cotton yield and its components of 96 cotton genotypes were markedly affected DI regime. Water stress caused a significant variation in yield and ranged from 1,791 kg h^{-1} to 3,993 kg h^{-1}. The results demonstrated that genetic variability for water stress tolerance existed in the material examined. Significant and positive correlation between seed cotton yields in DI and FI shows that indirect selection based on the performance of irrigated conditions would be used for genetic improvement in cotton under stressful environment. Based on correlation and regression analysis, GMP and DSI could be used as reliable screening criteria for drought resistance. It is concluded from the present study that based on biplot analysis, 23 cotton genotypes were identified suitable for stress conditions, and GC 555, Nieves, DAK-66/3, MS-30/1, Nazilli M-503, Zeta 2, Eva, NIAB 999, and Delta Diomand were found highly water stress tolerant due to the high GMP and low DSI values. These genotypes could be used as genetic resources for improving seed cotton yield productivity under drought conditions.

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