Drought Susceptibility Index as an Indicator of Genotypic Drought Tolerance in Upland Cotton

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ABSTRACT

The drought susceptibility index developed by Fisher and Maurer was used to calculate the drought tolerance of 25 upland cotton genotypes and one interspecific hybrid (G. hirsutum x G. barbadense) in three field experiments under dryland conditions. One was conducted in 1995 on a sandy loam soil and the other two in 1996 on a clay soil with two dates of sowing. Potential yield was evaluated under irrigation in 1996. The statistical model was a randomized complete block design with four replications. An analysis of variance indicated a significant genotypic susceptibility index and a significant interaction with location. This interaction revealed the stability of some genotypes but differential performance of other genotypes across locations. In general, there was a noticeable trend with the earliest genotypes performing better when the growing season was shorter. The biplot of the susceptibility and maximum yield (seed cotton) under irrigation showed a differential performance of the genotypes. Some genotypes have a low susceptibility index (possessing actual drought resistance) but different yield potential. The drought susceptibility index was linearly related (positive correlation) to yield potential. This relation supports the method of selecting "in situ" in a breeding program for drought resistance in cotton. Exceptions to this trend were the Spanish cultivars Victoria and Maria del Mar and the Australian cultivar Sicala 33.

Introduction

Until now, few improvement programs have addressed drought resistance in most crops, particularly in cotton. The majority of the breeding programs are undertaken in optimum conditions, due in part to the fact that greater progress in productivity is easier to achieve by selecting under optimum conditions (Rosielle and Hamblin, 1981) and due also to the fact that tolerance to drought is a complex characteristic with no clarity as to which adaptive mechanisms are related to greater yield under water stress conditions (Fereres, 1987). There is evidence that variability in cultivar behaviour of different crops under water stress conditions exists. Highlighting this variability can be achieved in several ways, the simplest being the placement of several cultivars under both optimum and water deficit conditions (Fisher and Maurer, 1978).

Blum (1979) points out that two philosophies exist relating to breeding for high yields under drought conditions: selection for high potential yield, accepting the hypothesis that if the yield of a genotype is increased in optimum conditions it will also be increased in non-optimum conditions (Medersi and Jeffers, 1973) or selection for high yield under stress conditions. In this case the selection of the type best adapted to the drought conditions where the genotype is going to be developed would be attempted.

Fisher and Maurer (1978) proposed the Drought Susceptibility Index (DSI) to express the decrease in yield of a cultivar under drought conditions with respect to the mean reduction of all the cultivars under consideration. Fisher and Wood (1979) found a high positive correlation between DSI and the potential yield in wheat. These results suggest the concept that for wheat the direct selection under optimum conditions would increase drought susceptibility. Fisher *et al.* (1984) reached the same conclusion for corn. In sunflower, this correlation was not found (Gimenez 1985; Fereres *et al.*, 1986). This aspect suggests that in sunflower it is possible to select drought tolerant genotypes under optimum conditions but this does not always apply (Alza Aramburu, 1995).

In cotton a modification of this index was used by Cook (1989) to study the behaviour of several upland cultivars. He found significant differences among the genotypes studied. Lopez (1998) has used the same index and found variability among genotypes and a positive correlation between the index and potential yield. Knowledge of the behaviour of cotton cultivars under drought conditions is very important in Spain where the growing season for cotton (the main cotton producing area is located in the Guadalquivir Valley, SW Spain) is characterized by a long dry period with high temperatures. Rains are rare during the fruiting period (July-August). Furthermore the availability of irrigation water may diminish soon because of the increasing demand for water from urban areas and the periodic droughts from which southern Spain suffers.

The objective of this study was to determine the differences in the behaviour of 26 genotypes under drought and irrigation conditions using the DSI as a measure of drought tolerance.

Material and Methods

Twenty five upland cotton genotypes of different geographical origin and an interspecific hybrid (*G. hirsutum* x *G. barbadense*) HA 182 from Israel were studied in three field experiments under dryland conditions. One was in Alcalá del Rio (Seville) in 1995 on a sandy loam soil (Typic Xerofluvent) and the other two in 1996 in Carmona (Seville) on a clay soil (Typic Chromoxerert). Potential yield was evaluated under irrigation in Alcalá del Rio (Seville) in 1996. The experimental design was a completely randomized block with 4 replications. The plots were two rows of 10-m long spaced 0.75 m apart.

In 1995, the field experiment was planted under dryland conditions on May 6 and under irrigation using plastic mulch on March 20. In 1996, the first dryland experiment was planted on April 19 and the second on May 30. The irrigated experiment was planted on 20 March using plastic mulch. The genotypes, indicated by the given codes, are shown in Table 1.

The formula developed by Fisher and Maurer (1978) was used to calculate the Drought Susceptibility Index (DSI) of each entry in which:

$DSI= [1 -(Y_d /Y_p)] /D$

where Y_d = seed cotton yield in the non-irrigated treatment,
Y_p = seed cotton yield in the irrigated treatment (potential yield),
and D = Drought Intensity = 1-[(mean Y_d of all genotypes in the non-irrigated treatment) /(mean Y_p of all genotypes in the irrigated treatment)].

Analysis of variance (ANOVA) was performed for each test and over locations and dates for DSI and for seed cotton yield. Correlation coefficients between earliness of the genotypes in the different fields and their production were calculated. Earliness was calculated as the ratio between the number of open bolls to total bolls per plant using the PMAP Program (Landivar, 1992).

Results and Discussion

Table 2 summarizes the results of the analysis of variance for DSI of the 26 genotypes in the three-dryland experiments during the years 1995 and 1996. The years and location have been considered jointly as Location (E). Tables 3, 4 and 5 summarize the analysis of variance for the different individual. Tables 3, 4 and 5 show that the differences between genotypes are highly significant in all the experiments. Table 2 shows that not only the differences between genotypes but also the genotype x location interactions are highly significant. The significant differences between genotypes in each of the experiments manifests the high variability with respect to DSI, and the interaction genotype-location shows the differential behaviour of the genotypes over locations or environments.

Figure 1 is the biplot between DSI and the maximum production under irrigation in 1996 for the three fields under consideration. Values of less than 1 for DSI indicate genotypes with tolerance to water stress, while those with values over 1 show susceptibility. There are four quadrants in Figure 1. Quadrant I contains those genotypes susceptible to drought and with high production under irrigated conditions. Quadrant II corresponds to susceptible genotypes and with low maximum production. Quadrant III is characterized by having genotypes that are highly resistant to drought while giving low production under irrigated conditions. Quadrant IV corresponds to genotypes that are drought resistant and have a high production capacity in irrigated conditions. Of the genotypes included in these quadrants, some show stable behaviour in all environments, while others do not.

This instability has been demonstrated in the corresponding ANOVA by the interaction G*E (Table 2). In Table 6 we can observe the coefficients of the correlation between the earliness of the genotypes in the different fields and their production. A significant and negative correlation (-0.47) exists between earliness and production in the 1995 experiment, indicating a tendency of better behaviour of later genotypes. In the 1996 experiments, earliness is not significant in the first sowing date and is highly significant, and positive, in the later sowing date.

We can observe that, depending on the location and the sowing date, earliness, and therefore some genotypes have had differential behaviour according to the environment. Examples of cultivars with a high interaction are NC8 (25), Zaire (24) and SV-PI4 (23). These cultivars do not have high maximum production under irrigation and are long season genotypes, showing bad behaviour in a short season environment. Other varieties that show interaction are Paymaster 792 (11) and Tashkent 9 (20) whose behaviour was contrary to those mentioned above, given that they are very early varieties. Those varieties with stable behaviour are Precoce 1 (22), Tashkent 7 (19), Maria del Mar (3), KC 311 (1), DP 90 (5) and Stoneville 324 (9). In Table 7 the coefficients of the correlation between the DSI of the different cultivars in each of the fields with the potential production in irrigated conditions can be observed.

As can be observed, a high correlation exists between potential production and stress susceptibility. This relation supports the method of selection in situ, as in the cases cited above for wheat and corn in a programme for improvement to drought resistance. Exceptions to this tendency are the cultivars in quadrant IV such as the Spanish varieties Maria del

Mar (3) and Victoria (4), the Australian Sicala 33 (6) variety and the American variety Acala 1517-E2 (17).

References

Alza Aramburu, J.O. (1995): Resistencia a sequía e interacción genotipo-ambiente en girasol bajo condiciones ambientales con distinta disponibilidad de agua. Estudios genéticos y de estabilidad. Tesis Doctoral. E.T.S.I.A.M. Universidad de Córdoba. 238 pp.

Blum, A. (1979): Genetic improvement of drought resistance in crops plants: a case for sorghum. In: Stress Physiology in Crops Plants (H. Mussell and R.C. Staples, eds.). Wiley-Interscience, New York. Pp. 430-445.

Cook, C.G. (1989): Relationship of root and shoot traits and canopy temperature of upland cotton to drought resistance, lint yield, and fiber quality. Ph.D. Thesis. Texas A&M University, 127 pp.

Fereres, E., C. Giménez, and J.M. Fernandez. (1986): Genetic variability in sunflower cultivars under drought. I: Yield relationship. Aust. J. Agric. Res. 37:573-582.

Fereres, E. (1987): Responses to water deficits in relation to breeding for drought resistance. In: Drought tolerance in winter cereals. J.P. Srivastava, (Ed). John Wiley Interscience Publication, New York. Pp. 263-275.

Fischer, K.S. and R. Maurer. (1978): Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. 29:897-912.

Fisher, K.S. and J.T. Wood. (1979): Drought resistance in spring wheat cultivars. III. Yield associations with morpho-physiological traits. Aust. J. Agric. Res. 30:1001-1020.

Fishher, K.S, G.O. Edmeades and E.C. Johnson. (1984): Mejoramiento y selección de maiz tropical para incrementar su resistencia a la sequía. Centro Internacional de Mejoramiento de Maiz y Trigo. El Batán, Mexico. 20 pp.

Giménez, C. (1985): Resistencia a sequía de cultivares de girasol bajo condiciones de campo. Tesis Doctoral. ETSIA. Universidad de Córdoba, 190 pp.

Landivar, J.A. (1992): PMAP, a plant analysis program for cotton (Preliminary version 3,0). TAES Computer Software Documentation Series, MP 1740. Texas A&M University, College Station, Texas. 32 pp.

López, M. (1998): Estudio de la variabilidad genotípica de cultivares de algodón en respuesta a condiciones de sequía. Tesis Doctoral. Facultad de Biología. Universidad de Córdoba, 242 pp.

Mederski, H.K. and D.J. Jeffers. (1973): Yield response of soybean varieties grown at two soil moisture stress levels. Agron. J. 65:410-412.

Rossielle, A. and J. Hamblin. (1981): Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci. 21:943-946.

Table 1. List of cotton genotypes studied in 1995 and 1996, with reference to their origin.

Genotypes	Code	Origin
Crema 111 (KC 311)	1	Commercial, USA
McNair 220	2	Commercial, USA
María del Mar	3	Commercial, Spain
Victoria	4	Commercial, Spain
DP 90	5	Commercial, USA
Sicala 33	6	Commercial, Australia
Sicala 34	7	Commercial, Australia
Nazilli 84	8	Commercial, Turkey
Aria (Stoneville 324)	9	Commercial, USA
Accesion 1124	10	Giessen Bot. Garden
Paymaster 792	11	Commercial, USA
Tamcot SP-21	12	Commercial, USA
Aleppo 1	13	Cotton Bureau, Syria
Accesion 71046	14	Commercial, Greece
Hazera 182	15	Commercial, Israel
Acala 1517-77-BR	16	Commercial, USA
Acala 1517-E2	17	Commercial, USA
Tamcot CD3H	18	Commercial, USA
Tashkent 7	19	N.I. Vavilov Inst., Russia
Tashkent 9	20	N.I. Vavilov Inst., Russia
CNPA 3H	21	CNPA/EMBRAPA, Brasil
Precoce 1	22	CNPA/EMBRAPA, Brasil
Genotypes (cont.)	Code	Origin
SV-PI4	23	CNPA/EMBRAPA, Brasil
Zaire 407/1157	24	Glembloux Bot. Garden (Zaire, Africa)
Cv. NC8	25	Glembloux Bot. Garden (Zaire, Africa)
MARCHUB	26	Commercial, USA

Table 2. Analysis of variance for drought Susceptibility Index (DSI) for 1995 and 1996 for twenty six genotypes.

Source	df	Mean square value
Location (E)	2	0.00332436ns
E*R (error a)	9	0.00233120
Genotypes (G)	25	0.03914728 **
G*E (error b)	50	0.01641536***
Total	225	

,* Significant at the 0.01 and 0.001 probability levels, respectively. ns, not significant at the 0.05 level.

Table 3. Analysis of variance for drought Susceptibility Index (DSI) in 1995 for twenty six genotypes.

Source	df	Mean square value
Genotypes (G)	25	0.04793446***
Replications	3	0.00346795
Error	75	0.00304862

*** Significant at the 0.001 probability level

Table 4. Analysis of variance for drought Susceptibility Index (DSI) for 1996-1 (first date of sowing) for twenty six genotypes.

Source	df	Mean square value
Genotypes	25	0.00858938***
Replications	3	0.00148974
Error	75	0.00115708

*** Significant at the 0.001 probability level.

Table 5. Analysis of variance for drought Susceptibility Index (DSI) for 1996-2 (second date of sowing) for twenty six genotypes.

Source	df	Mean square value
Genotypes	25	0.01545415***
Replications	3	0.00203590
Error	75	0.00129990

*** Significant at the 0.001 probability level.

Table 6. Pearson correlation coefficients between the earliness of the twenty six genotypes in the different fields and their production.

n = 26	earliness 95	earliness 96	Yield 95
earliness 95	1		
earliness 96	0.51**	1	
Yield 95	-0.47**	-0.19	1
Yield 96-1	0.41**	0.02	0.20
Yield 96-2			

** Significant at the 0.01 probability level.

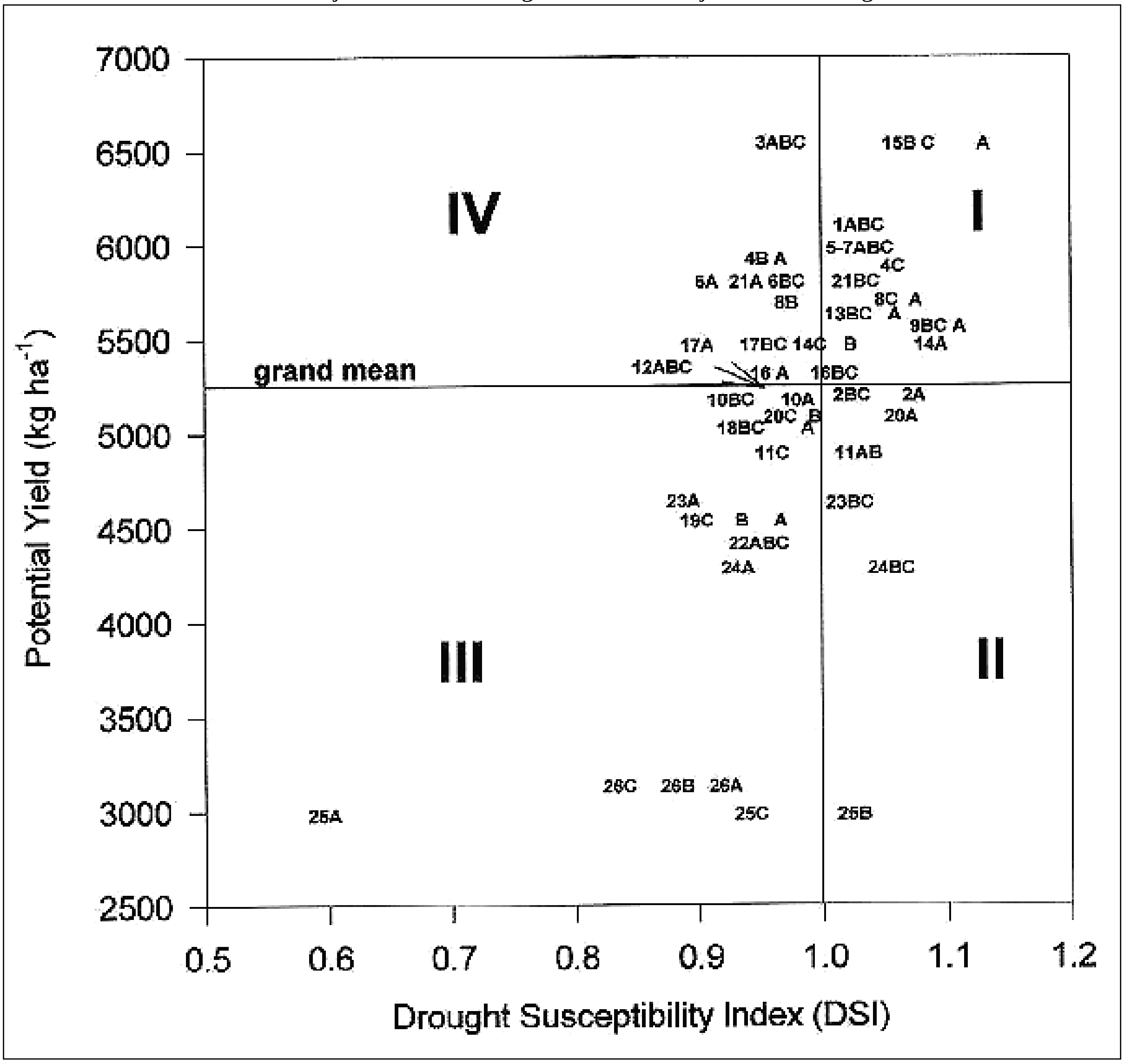
Table 7. Pearson correlation coefficients between the DSI for twenty six genotypes in the different fields with the potential production in irrigated conditions.

n = 26	DSI 95	DSI 96-1	DS 96-2
Potential Yield	0.64***	0.38**	0.65***

, * Significant at the 0.01 and 0.001 probability levels, respectively.

Figure 1. Biplot between maximum production under irrigation and DSI for three fields and twenty six genotypes.

A = Las Torres 1995: B = Tomejil 1996 first sowing date. C = Tomejil second sowing date.



number = code of the genotype (see Table 1).