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S_1 RECURRENT SELECTION FOR DROUGHT TOLERANCE IN MAIZE

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ABSTRACT

A total of 144 S_1 maize progenies were obtained from DTP-1 in 2001 season and evaluated in 2002 season under water-stress and non-stress conditions. The best performed 10 % of lines (15) were selected under water-stress (WS) and non-stress (NS) environments. Lines selected under NS were also selected for performance across water environments. WS and NS lines were separately intercrossed in early 2003 season in isolation to develop Pop-1 and Pop-2, respectively, and were compared with the original DTP-1 (Pop-0) under NS and WS environments in late 2003 season. The objectives of this study were to increase the adaptation of CIMMYT DTP drought tolerant population to drought encountered during flowering, determine selection strategy for achieving maximum progress and identify secondary traits strongly associated with grain yield (GY). Results indicated wide genetic variation among S_1 progenies. WS reduced means and ranges of the S_1 progenies for grain yield and its components. Broad sense heritability (h^2_b) of grain yield tended to decrease with drought stress. Results indicated that kernels m^{-2}, ears $plant^{-1}$, % barrenness and ASI traits are valuable for increasing the efficiency of selection for grain yield under water-stress. One cycle of S_1 recurrent selection under NS caused a significant improvement in GY of Pop-1 over Pop-0 under WS of 30.8 % (1.34 ard/fad) and under NS conditions by 16.0 % (2.57 ard/fad). Predicted gain from selection among S_1 progenies in GY suggested that selection should be carried out under conditions of the target environment. However, actual progress under stress (30.8%) was achieved when genotypes were selected under NS environment or on the basis of average performance of NS and WS environments for use under water-stress as target environment.

Key words: ***Maize, Zea mays, population improvement, drought tolerance, recurrent selection, genetic progress, selection environment, secondary traits.***

INTRODUCTION

There is current interest in expanding maize acreage in the newly reclaimed desert lands. Sandy soils of the desert lands are characterized by a low water holding capacity that would expose maize plants to drought stress and reduce grain yield. In addition, future deficits in irrigation water supply for heavy soils of the Nile valley and delta requires that maize breeders should pay more attention to enhance drought tolerance.

Maize populations with improved tolerance to drought would be suitable sources for extracting inbred lines for the production of hybrids and synthetics of high yielding ability in droughty environments.

S_1 recurrent selection is widely used, highly efficient procedure for intra-population improvement in maize. Selection based on S_1 progeny performance is more effective in utilizing additive genetic variance than other intra-population improvement methods and presents an opportunity for selection against major deleterious recessive genes during inbreeding (Genter 1973 and Tanner and Smith 1987).

Plant breeders and physiologists have investigated different selection strategies for achieving maximum genetic gain under drought. Selection may be practiced under well-watered environments, where heritability and predicted genetic gain are generally higher than under water-stress conditions (Johnson and Geadelman 1989, Blum 1988 and Allen *et al* 1978). However, the actual progress from selection for high yield under well-watered conditions is greatly reduced under crop water deficits (Arboleda-Rivera and Compton 1974 and Byrne *et al* 1995). An alternative strategy is to select only under stressed environments. This strategy was employed successfully by Arboleda-Rivera and Compton (1974), who reported increased yield in stressed and un-stressed environments. One drawback to this strategy is that some traits that contribute to survival under drought may lower productivity under favorable conditions (Blum 1988 and Ludlow and Muchow 1990). Another potential limitation is that heritability of grain yield, and thus the effectiveness of selection, is often reduced under moisture stress (Blum 1988). A third alternative, is simultaneous selection under stress and non-stress conditions, *i.e.* selecting those genotypes that perform well under both environments. However, in the presence of a large genotype X stress-level interaction, progress from selection based on combined data may be limited (Byrne *et al* 1995). Thus the question of which selection strategy produces the best results remains unresolved.

In this report, we present the results of one cycle of S_1 recurrent selection in one of the CIMMYT's drought tolerant maize populations (DTP-1) to improve its response to drought that occurs just before and during flowering stage, and is most detrimental to grain yield potential. The specific objective were i) to assess variation among S_1 maize progenies in tolerance to drought imposed during flowering compared to well-water conditions, ii) to compare performance of developed populations by selection under drought and well-water conditions, iii) to test the efficiency of three selection strategies in maize for the improvement of drought tolerance, and iv) to identify the maize secondary traits strongly associated with grain yield under drought stress and non-stress conditions.

MATERIALS AND METHODS

This study was carried out during the period from 2001 to 2003 at Sids Agric., Res., Station, Field Crops Research Institute (FCRI) of the Agricultural Research Center (ARC), Egypt.

Materials

We used the exotic white grain drought tolerant maize population (DTP-1) introduced from CIMMYT. DTP-1 was developed by mixing seed of diallel crosses among 13 diverse genotypes of maize that possess different drought tolerance traits followed by 7 cycles of selection for drought tolerance (Edmeades *et al* 1996).

Developing the S_1's seed

In 2001, DTP-1 was sown under well-watered conditions in an isolated field at Sids. One thousand vigorous, disease-free plants were selected before silking and self-pollinated. At harvest, 144 selfed ears were selected based on grain yield quantity and ear characteristics. The 144 selected S_1 ears were separately shelled and preserved for evaluation in the next season.

Progeny evaluation and selection

In 2002 season, the 144 S_1 lines were sown for trial in two isolated fields one was well-watered (NS) and the other was water-stressed. A 12 X 12-lattice design with three replications was used for each trial (Cochran and Cox 1957). Plots were single rows 5 m long, 80 cm wide (4 m^2). The well-watered trial was irrigated at 13 day intervals along the whole season. In the water-stressed trial, irrigation was given at 1st and 2nd irrigations, withheld for the 3rd, 4th and 5th irrigations and then given at the 6th and subsequent irrigations. The water-stress period (52 days) extended from shortly before tassel emergence to the end of flowering. After harvest, the best 10 % of the S_1's (15) were selected in each trial and across trials. Selection was based on grain yield per unit area. The same lines were selected under NS conditions and across water regimes, thus two groups of lines, were selected. It is worthy to note that both groups had 5 S_1's in common.

Intercrossing fields

During the 2003 early season, the selected S_1 lines were grown for intercrossing in two isolated fields. A mixture of equal number of seeds of each selected line was planted on March 15, 2003. Plants were sib-pollinated and harvested ears from each field were shelled and mixed together. F_1 seed of lines selected under NS, and under WS was designated as Pop-1 and Pop-2, respectively, whereas DTP-1 was designated as Pop-0.

Experimental population evaluation

In the late 2003 season, Pop-0, Pop-1 and Pop-2 were evaluated in separate trials under NS and WS conditions using the same irrigation schemes of 2002. A RCB design with 4 replications was used for each trial. The experimental plots consisted of 4 rows 6 m long, 70 cm wide (16.8 m^2).

In all experiments sowing was made in hills spaced 25 cm along the row and plants were thinned to one plant per hill. Except for irrigation, other agricultural practices were followed as recommended.

The soil of the experimental site at Sids was clayey. Depth of the water table of the experimental field at the end of the stress period was 94.2 and 115.8 cm for the well-watered trials and 127.5 and 134.2 cm for the water-stressed trials in 2002 and 2003 seasons, respectively.

Traits recorded

Anthesis-silking interval (ASI) in days, plant height (PH), leaf rolling (LR) score using a scale of 1 to 5 in with 1 unrolled and 5 is tightly rolled, barren stalks (BS) %, leaf temperature (LT) in c, stay green score (SG) using a scale from 1 to 5 in which 1 completely dry leaves and stems and 5 completely green leaves and stems, ears per plant^{-1} (EPP), kernels m^{-2} (KP m^2), 100-kernel weight (KW) and grain yield per faddan (GY) in ardabs (adjusted at 15.5% grain moisture).

As the relative efficiency of lattice design was similar to that of the randomized complete blocks data were analyzed as RCB, according to Cochran and Cox (1957) as shown in Table (1).

Table 1. Analysis of variance and expected mean squares (E.M.S) of RCB design under separate and across environments.

S.O.V	D.F	M.S	E.M.S
		Separate environment	
Replications	r-1	-	-
Genotypes	g-1	M2	$\delta^2_e + r\,\delta^2_g$
Error	(r-1) (g-1)	M1	δ^2_e
		Across environments (irrigation regimes)	
Irrigations (I)	i-1	-	-
Reps/I	i(r-1)	-	-
Genotypes (G)	g-1	M3	$\delta^2_e + r\,\delta^2_{ge} + ri\,\delta^2_g$
G × I	(g-1) (i-1)	M2	$\delta^2_e + r\delta^2_{ge}$
Error	2 (r-1) (g-1)	M1	δ^2_e

Genotypic (δ^2_g), phenotypic (δ^2_p) and interaction (δ^2_{ge}) variances were computed by equating the appropriate mean squares with their expectations from Table (1). Phenotypic variance was computed for individual trials as $\delta^2_p = \delta^2_g + \delta^2_e / r$ and for combined trials as $\delta^2_p = \delta^2_g + \delta^2_{ge} / r + \delta^2_e / ri$

where, i = number of irrigation regimes = 2 and r = number of replications. Heritability (%) in the broad sense (h^2_b) was computed for a separate trial as $h^2_b \% = 100 \ \delta^2_g / (\delta^2_g + \delta^2_e / r)$ and for combined analysis across water regimes as $h^2_b \% = 100 \ \delta^2_g / (\delta^2_g + \delta^2_{ge} / r + \delta^2_e / ri)$

The genotypic (r_g) correlations between grain yield and each studied trait were calculated as $r_g = cov_{gxy} / (\delta^2_{gx} \cdot \delta^2_{gy})^{1/2}$ where: cov_{gxy} = the genotypic covariance of the two traits, x and y, respectively and δ_{gx} and δ_{gy} = the genotypic variance of the same two traits, x and y, respectively.

Expected genetic advance from direct selection for all studied traits under stress and non-stress environments was calculated according to Singh and Chaudhary (1999) as $GA = 100 \ i \ h^2 \delta_p / x$ where: i = selection differential (i = 1.76, for 10 % selection intensity), x = general mean of the appropriate moisture regime and $_p$ = square root of phenotypic variance.

Indirect correlated response (CR) in moisture regime j (or in yield) from selection in moisture regime (or in a secondary trait) k was estimated according to Falconer (1989) as $CR_j = 100 \ i \ H^{1/2}_j \ H^{1/2}_k \ r_{gjk} \ _p / x_j$, where: $H^{1/2}_j$ and $H^{1/2}_k$ = square roots of heritabilities of moisture regimes (or traits) j and k, respectively, r_{gjk} = genetic correlations among moisture regimes (or traits) j and k, CR_j = correlated response in moisture regime j (or in yield) and x_j = general mean of moisture regime j (or of yield).

Analysis of variance of a randomized complete block design (RCBD) for each of the two experiments (two irrigation regimes) separately and combined over the two experiments (over the two irrigation regimes) was carried out in 2003 season for the evaluation of Pop-0, Pop-1 and Pop-2 populations and the LSD was calculated to test the significance of differences between means (Cochran and Cox 1957).

RESULTS AND DISCUSSION

S_1 progeny evaluation

Results of the combined analysis of variance (not presented) showed highly significant differences among the two irrigation regimes for all studied traits, except for leaf rolling traits and highly significant differences existed among genotypes for all studied traits, except for leaf rolling and leaf temperature.

Mean squares due to genotypes (S_1 progenies) X irrigations interaction were either significant or highly significant for all studied traits, indicating the possibility of selection within the DTP-1 population for improved performance under a specific moisture environment, as proposed by Fischer *et al* (1989). A characteristic of this trial was the large increase in the coefficient of variation of the water-stressed as compared to non-stressed environment for all studied traits, except barrenness, ear height, leaf temperature and stay green trait which exhibited opposite direction. The small, single-row plots (chosen in part because of the restriction in seed number which would exist in a conventional testing program) may have contributed to this high variation (Fischer *et al* 1989).

Separate analysis of variance (not presented) revealed that highly significant differences ($P \leq 0.01$) existed among genotypes (S_1 progenies) for all studied traits under both well-watered and water-stress conditions.

Performance of S_1 progenies

The mean grain yields of the 144 S_1 progenies were 5.78 and 2.54 ard/fad (ranging from 0.0 to 16.0 and from 0.0 to 5.0 ard/fad) under well-watered and water-stress environments, respectively (Table 2). Significant reduction of 56.1 % in grain yield/fad of the 144 S_1 progenies due to water-stress was accompanied by reduction in EPP (43.6 %), kernels/m^2 (55.1 %), 100-kernel weight (61.7 %), plant height (15.1 %) and stay green (28.7%) and by increases in BS (210.2 %), ASI (31.9 %), leaf rolling (7.7 %) and leaf temperature (7.8 %) (Table 2).

Reductions in means of the 144 S_1 progenies due to water deficits was also accompanied by reductions (narrowness) in their ranges for the traits grain yield, ears/plant, kernels/m^2 and plant height. Moreover, increases in means of the 144 S_1's due to drought stress were accompanied by increases (broadness) in their ranges for the traits, ASI and stay green. Means and ranges of the remaining traits showed opposite responses due to water-stress effect. Mean grain yields of the best 15 S_1 progenies (selected on the basis of their grain yields) were 12.47 and 4.35 ard/fad (with ranges from 0.0 to 16.0 and 1.2 to 5.0 ard/fad) under well-watered and water-stress conditions, respectively. Mean grain yield of the best 15 S_1's was significantly higher than that of the 144 S_1's by 6.69 ard/fad (115.7 %) and 1.81 ard/fad (71.3%) under well-watered and water-stress environments, respectively (Table 2).

Table 2. Means (± standard errors; SE) and ranges for studied traits of 144 S_1's and selected 15 S_1's (based on grain yield) derived from DTP-1 population evaluated under water-stress (S) and non-stress conditions (N) in 2002 season.

Trait	Treatment	Mean		Difference (µ-x)		Range			
		144 S_1's (µ± SE)	Best 15 S_1's (x)	Absolute	% of 144 S_1	144 S_1's		Best 15 S_1's	
						Lowest	Highest	Lowest	Highest
Grain yield (ard/fad) (GY)	N	5.78 ± 0.67	12.47	6.69**	115.7	0.0	16.0	10.9	16.0
	S	2.54 ± 0.20	4.35	1.81**	71.3	0.0	5.0	3.7	5.0
	DE %	-56.1**	-65.1**	-	-	-	-	-	-
Ears/plant (EPP)	N	0.78 ± 0.10	1.00	0.22	28.2	0.13	1.42	0.79	1.18
	S	0.44 ± 0.10	0.81	0.37*	84.1	0.25	0.98	0.71	0.98
	DE %	-43.6**	-19.0**	-	-	-	-	-	-
Kernels/m^2 (KPm^2)	N	1271 ± 343	1863	592**	48.6	0.0	2713	1432	2713
	S	571 ± 271	1213	642**	112.4	0.0	2029	804	2029
	DE %	- 55.1	- 34.9	-	-	-	-	-	-
100-Kernel weight (KW)	N	23.59±1.2	26.22	2.63	11.1	19.7	30.3	22.5	28.8
	S	14.56 ± 1.7	22.25	7.69**	52.8	12.4	28.2	15.7	22.3
	DE %	- 61.7**	- 15.1	-	-	-	-	-	-
Barren stalks % (BS)	N	15.67 ± 7.0	5.52	-10.15	-64.9	0.0	88.57	1.59	21.5
	S	48.88 ± 9.3	23.76	-25.12*	-41.4	12.9	98.1	14.1	40.8
	DE %	210.2**	330.4**	-	-	-	-	-	-
ASI (days)	N	2.13±1.5	0.84	-1.29	-60.6	- 3.0	5.0	0.0	2.30
	S	2.81±1.8	1.43	-1.38	- 49.1	- 5.0	10	-1.3	3.7
	DE %	31.9**	70.2	-	-	-	-	-	-
Plant height (cm) (PH)	N	130.7±6.6	137.4	6.7	5.1	98.0	163	115.7	159.3
	S	110.9±6.0	112.8	1.9	1.7	84.0	140	99.3	127
	DE %	- 15.1	- 17.9	-	-	-	-	-	-
Leaf rolling (score) (LR)	N	2.59 ± 0.33	2.15	-0.44	-17.0	1.30	4.0	1.30	3.2
	S	2.79 ± 0.39	2.43	-0.36	-12.9	1.70	4.30	1.70	3.0
	DE %	7.7	13.0	-	-	-	-	-	-
Leaf temperature (c) (LT)	N	37.39 ± 0.37	37.12	-0.27	-0.7	35.9	38.7	35.9	38.3
	S	40.32 ± 0.32	40.23	-0.09	-0.2	38.9	41.6	38.9	41.5
	DE %	7.8	8.4	-	-	-	-	-	-
Stay green (score) (SG)	N	2.65 ± 0.24	3.03	+0.38	+14.3	2.0	3.7	2.3	3.7
	S	1.69 ± 0.31	1.58	-0.11	-0.7	1.0	3.0	1.0	3.3
	DE %	-28.7	-48.8	-	-	-	-	-	-

*and** indicate significant difference at 0.05 and 0.01 levels of probability, respectively.,
DE (Drought effect) = 100 (S-N)/N

The superiority of the 15 S_1's over the 144 S_1's in grain yield was higher under well-watered than under water-stress conditions. Superiority in grain yield of the 15 S_1's over the 144 S_1's was associated with superiority in ears/plant (28.2 and 84.1 %), kernels/m^2 (48.6 and 112.4 %) and 100-kernel weight (11.1 and 52.8 %), *i.e.* in all yield components under well-watered and water-stressed environments, respectively. On the other hand, the best 15 S_1's in grain yield exhibited lower means than the 144 S_1's for barrenness (64.9 and 41.4 %), ASI (60.6 and 49.1 %) and leaf rolling (17.0 and 12.9 %) under non-stress and water-stress conditions, respectively (Table 2).

Significant reduction of 65.1 % in grain yield/fad of the best 15 S_1's due to water-stress was accompanied by reduction in ears plant^{-1} (19.0 %), kernelsm^{-2} (34.9%) and 100-kernel weight (15.1 %), *i.e.* in all yield components. Drought also caused reduction in means of the selected 15 S_1's for plant height (17.9 %) and stay green (48.8 %) and increase in their means for ASI (70.2 %), leaf rolling (13.0 %) and leaf temperature (8.4 %) (Table 2).

Reductions in means of the best 15 S_1's progenies due to drought stress were accompanied by narrowness in their ranges for grain yield and ears plant^{-1}, kernels m^{-2}, plant height and leaf temperature and by broadness in their ranges for, 100-kernel weight, and stay green traits. On the other hand, increases in the means of 15 S_1's because of drought was accompanied by broadness in their ranges for barrenness and ASI and by narrowness in the range leaf temperature trait.

Variance components and heritability

In general, the changes in magnitude of δ^2_p, δ^2_g and δ^2_e from well-watering to drought stressed environment were in the same direction and of similar magnitude for all traits (Table 3). The magnitude of δ^2_g and δ^2_p was considerably smaller under drought stressed than non-stressed environment for grain yield, kernels m^{-2} and plant height. On the other hand, the magnitude of δ^2_g and δ^2_p was larger under drought stressed than well-watered environment for barrenness, ears plant^{-1}, 100-kernel weight, ASI and stay green trait. This indicates that selection for grain yield, kernels m^{-2} and plant height is predicted to be more efficient under well-watered than water-stressed environments, while using the drought stressed environment is expected to result in more efficient selection for the remaining traits as compared to using the well-watered environment. It is worthnoting that δ^2_g under both stressed and non-stressed environments constitutes the major part of δ^2_p except LR trait under water-stress. These results indicate the existence of wide genetic diversity among the 144 S_1 progenies, and that can be

Table 3. Genetic (δ^2_g), phenotypic (δ^2_p), environmental (δ^2_e) and genetic x environment (δ^2_{ge}) variances and heritability in the broad sense (h^2_b) for studied traits of the 144 S_1's (derived from DTP-1) evaluated under water-stress (S), non-stress (N) and combined (C) across N and S environments at Sids in 2002 season.

Parameter	Grain yield			Ears plant^{-1}			Kernels m^{-2}			100-kernel weight			Barren stalks %		
	N	S	C	N	S	C	N	S	C	N	S	C	N	S	C
δ^2_p	7.71	0.623	4.17	0.055	0.065	0.06	268936	156480	175325	14.41	55.4	34.89	198.2	410.3	304.2
δ^2_g	7.26	0.584	1.18	0.044	0.055	0.03	215065	127566	115888	12.90	52.56	7.33	149.5	323.9	133.1
δ^2_e	0.45	0.240	0.24	0.011	0.010	0.01	53871	28914	4910	1.51	2.84	2.17	48.7	86.4	76.6
δ^2_{ge}	-	-	2.75	-	-	0.02	-	-	54527	-	-	25.39	-	-	103.5
h^2_b%	94.16	93.74	28.3	80.00	84.61	50.0	79.97	81.52	66.10	89.52	94.87	21.01	75.43	78.93	43.76
	ASI			Plant height			Leaf rolling			Leaf temperature			Stay green		
δ^2_p	6.39	7.6	5.39	184.20	111.9	115.0	0.26	0.276	0.19	0.37	0.38	0.199	0.16	0.231	0.142
δ^2_g	3.48	3.899	2.02	140.72	75.69	48.77	0.16	0.128	0.03	0.24	0.277	0.051	0.10	0.151	0.035
δ^2_e	2.91	3.701	2.685	43.48	36.21	26.68	0.10	0.148	0.088	0.13	0.103	0.081	0.06	0.080	0.052
δ^2_{ge}	-	-	0.685	-	-	39.55	-	-	0.072	-	-	0.067	-	-	0.055
h^2_b%	54.42	51.3	37.48	76.40	67.63	42.41	60.33	46.32	15.79	65.73	73.05	25.63	64.78	65.37	24.65

attributed to the fact that the DTP-1 population from which these S_1's were derived is a composite of 13 different sources of widely divergent origins.

The magnitude of the genetic x environmental (δ^2_{ge}) variance was considerably larger than δ^2_g for grain yield, 100-kernel weight, leaf rolling, leaf temperature and stay green. This indicates that these traits are largely affected by environmental conditions. This is the reason why broad-sense heritability calculated from the combined data over the stressed and non-stressed environments for these traits was greatly reduced when compared to the corresponding h^2_b estimates under separate environments (either stressed or non-stressed). Similar results were obtained by Walter *et al* (1991) and Bolanos and Edmeades (1996).

Broad-sense heritability estimates were generally high for all studied traits under separate environments (stressed and unstressed), except ASI under both environments, leaf rolling under stress conditions which were of medium magnitude.

When data were combined over the two environments, the highest estimates of h^2_b (66.10 %) was exhibited by kernel m^{-2}, while the lowest h^2_b estimate (15.79 %) was obtained from leaf rolling (Table 3). The magnitude of h^2_b for combined data was low (28.29 %) for grain yield/fad. This is likely because δ^2_{ge} of grain yield each constitutes a large portion of the corresponding δ^2_p and the magnitude of δ^2_{ge} is larger than the corresponding δ^2_g. This observation is also shown by 100-kernel weight.

The heritability for grain yield, ASI, plant height and leaf rolling showed a general tendency to decrease with imposing drought stress. On the contrary, for all studied yield components, leaf rolling and stay green traits h^2_b was larger under drought stress than non-stress conditions. Empig *et al* (1972) suggested that the expected values of δ^2_g would be equal to additive genetic variance (δ^2_A) if dominance and /or epistasis were lacking in the population or when gene frequency for the segregating loci is equal to 0.5. In this respect, heritability estimates obtained from the combined data across the two environments (stressed and unstressed) will be more reliable than that obtained from data of single environment. In addition, high heritability estimates for the studied traits indicate that selection based on the mean performance of S_1 families would be a successful tool in improving this population (DTP-1). Similar conclusion was supported by Sadek *et al* (1988) and Walter *et al* (1991).

Correlations between traits and grain yield

Data in Table (4) indicated a strong genetic correlation between grain yield/fad under drought and number of kernels m^{-2} (0.95), ears plant^{-1} (0.91), barren stalks (-0.89) and to a lesser degree with 100-kernel weight (0.62). Under full irrigation, grain yield/fad had a strong genetic association with kernels m^{-2} (0.89), ears plant-^{1} (0.81), barren stalks (-0.77) and ASI (-0.66) and to a lesser degree with 100-kernel weight (0.52), and stay green (0.57) LR (-0.59) and leaf temperature (-0.34).

Table 4. Genetic correlations (r_g) between each of studied traits and grain yield of the 144 S_1's under stress and non-stress conditions in 2002 season (N = 432).

Environment	EPP	KP m^2	100-KW	BS %	ASI	PH	LR	LT
Water-stress	0.91	0.95	0.62	-0.89	-0.39	-0.04	-0.34	-0.12
Non-stress	0.81	0.89	0.52	-0.77	-0.66	0.11	-0.59	-0.34

High correlations between grain yield and its components are normally found because of lack of independence among them (Blum 1988). Nonetheless, correlation analysis showed that ears/plant and kernels/m^2 were more important determinates of grain yield than weight per kernel. Results of Tables (4) confirm that water stress before and during flowering affected mainly the kernels m^{-2} and to a lesser extent the size of the kernel. Similar conclusion was also reported by Hall *et al* (1981). As stress increased, the dependence of grain yield on kernels/m^2 and ears/plant increased. The value of the genetic correlation points to a strong genetic relationship between grain yield/fad and ears/plant (0.91) under water stress. Bolanos and Edmeades (1996) reported also a strong genetic relationship between grain yield and ears/plant (0.90 ± 0.14) under severe stress. These values are somewhat larger than those reported by Guei and Wassom (1992).

The genetic correlation between grain yield/fad and ASI was -0.39 and -0.66 under stress and non-stress, respectively, indicating that a short ASI was linked to high grain yield either under water stress or non-stress conditions.

Predicted genetic advance from selection

The expected genetic advance for grain yield and five traits showing high heritabilities and strong genetic correlations with grain yield under water-stressed and non-stressed environments were calculated for direct and indirect selection using a 10 % selection intensity (Table 5).

Table 5. Genetic advance from direct selection (*i.e.* selection environment same as target environment) and correlated genetic response (CR) from indirect selection (*i.e.* selection and target environments differ in irrigation regimes or selection in a secondary trait for the improvement of grain yield/fad).

Selection environment	Grain yield/fad (ard)	Barren stalks	Ears/ plant	Kernels/ m^2	100-Kernel weight	ASI
Direct selection response (R)						
1- Non-stressed (N)	79.61	119.27	42.33	57.43	25.35	113.67
2- Stressed (S)	51.27	57.57	86.28	99.39	85.36	88.58
3- Combined (C) across N & S	24.44	41.63	35.34	52.89	11.45	62.0
Indirect selection response (CR)						
a. Selection environment vs target environment						
1- N for use under S	46.07	73.20	27.00	41.17	14.35	73.94
RE %	(89.86)	(127.15)	(31.29)	(41.42)	(16.81)	(83.47)
2- S for use under N	29.80	33.76	48.28	69.89	45.60	61.13
RE %	(37.43)	(28.30)	(114.06)	(121.69)	(179.88)	(53.78)
3- Combined for use under N	73.74	46.34	39.54	54.86	28.58	92.07
RE %	(92.63)	(38.85)	(93.41)	(95.52)	(112.74)	(80.99)
4- Combined for use under S	32.34	51.35	41.85	53.04	23.31	95.79
RE %	(63.08)	(89.19)	(48.50)	(53.36)	(27.31)	(108.14)
5- N for use under combined	42.81	77.03	29.72	49.23	9.65	83.01
RE %	(175.16)	(185.03)	(84.09)	(93.08)	(84.28)	(133.89)
6- S for use under combined	20.47	39.99	60.62	80.82	38.08	71.39
RE %	(83.76)	(96.06)	(171.53)	(152.81)	(332.58)	(115.14)
b. Secondary traits vs grain yield/fad						
1- Non-stressed (N)	-	-54.87	58.71	65.30	40.37	-39.95
RE %	-	(-68.92)	(73.75)	(82.02)	(50.71)	(-50.18)
2- Stressed (S)	-	-63.68	67.41	69.08	48.63	-22.50
RE %	-	(-124.2)	(131.48)	(134.74)	(94.85)	(-43.88)
3- Combined (C)	-	-24.77	26.48	33.77	13.84	-22.25
RE %	-	(-101.35)	(108.35)	(138.17)	(56.63)	(-91.04)
4- N for use under S	-	-37.17	41.51	45.93	-19.98	13.51
RE %	-	(-72.49)	(80.96)	(89.58)	(-38.97)	(26.35)
5- S for use under N	-	-19.90	26.05	29.36	-12.52	8.98
RE %	-	(-24.99)	(32.72)	(36.88)	(-15.73)	(11.28)
6- Combined for use under N	-	-30.76	33.45	36.85	-24.32	7.74
RE %	-	(-38.64)	(42.02)	(46.29)	(-30.55)	(9.72)
7- N for use under combined	-	-39.89	-44.96	55.90	27.19	-36.36
RE %	-	(-163.22)	(-183.96)	(228.72)	(111.25)	(-148.77)
8- Combined for use under S	-	-28.79	30.66	31.50	-7.61	-14.03
RE %	-	(-56.15)	(59.80)	(61.44)	(-14.84)	(-27.36)
9- S for use under combined	-	-25.75	29.02	36.08	16.58	-24.48
RE %	-	(-105.36)	(118.74)	(147.63)	(67.84)	(-100.16)

***Values in parentheses are the relative efficiencies (RE) = 100 (CR/R).**

Direct selection

Expected genetic advance from direct selection (selection based on grain yield per unit area) in each moisture regime reached its maximum value under well-watered selection environment for increasing grain yield/fad (79.61%) and decreasing barrenness (119.27 %) and ASI (113.67%), and under water-stressed environment for increasing EPP (86.28%), kernels m^{-2} (99.39%) and 100-kernel weight (85.36 %) due to higher heritability and/or phenotypic variance estimates for these traits observed under the respective environments (Tables 3 and 5).

Indirect selection

1. Selection environment *vs* target environment

The expected genetic advance from direct selection in each environment was generally greater than the predicted from indirect selection at another environment, as indicated by the relative efficiency values < 100 % for most single environments (Table 5). It is therefore concluded that in this study the predicted gain form direct selection especially for grain yield under a specific soil moisture environment would improve the trait under consideration in a better way than the indirect selection. The direct selection under water-stressed environment would ensure the preservation of alleles for drought tolerance (Langer *et al* 1979) and the direct selection under full irrigation regime would take advantage of the high heritability (Allen *et al* 1978 and Blum 1988).

Some exceptions are shown in the results of the present study in favor of the indirect selection. The indirect selection under well-watered for the use under water-stress environment was more efficient than direct selection under water-stress for barrenness (RE = 127.15 %). This may be attributed to the very low generation mean of barren stalks under well-watered (selection) environment. Moreover, the indirect selection under well-water for the use under a combination of stressed and unstressed environments was more efficient than direct selection under the same combination of environments for grain yield/fad (RE = 175.16 %), BS (RE = 185.03) and ASI (RE = 133.89 %). This may also be attributed to the low generation mean and/or the low heritability estimate of such traits under the combination of stress and unstress conditions, which raised the value of correlated response. This conclusion is in agreement with that obtained by Allen *et al* (1978) and Shabana *et al* (1980).

The indirect selection under water-stress for the use under optimum environment was more efficient than direct selection for optimum environment for ears/plant (RE = 114.06 %), kernels/m^2 (RE = 121.69 %) and 100-kernel weight (RE = 179.88 %) and than direct selection for a combination of stressed and unstressed environments for EPP (RE = 171.35 %), kernels m^{-2} (RE = 152.81 %), 100-kernel weight (RE = 332.58 %), days to silking (RE = 112.63 %), ASI (RE = 115.14 %). The reason for that could be ascribed to its higher heritability estimate under the stressed environment than heritability under optimum environment and under a combination of the two environments, resulted in higher correlated response than the predicted gain from selection under optimal or combined conditions. These results are in a harmony with those obtained by Stuber and Moll (1977) and Troyer and Rosenbrook (1983).

Moreover the indirect selection under a combination of stressed and unstressed conditions for the use under optimum environment was more efficient than direct selection under the optimum environment for 100-KW (RE = 112.74 %), and than direct selection under water stress for ASI (RE = 108.14 %). The predicted results of the present study are in favor of the first selection strategy in most cases and especially for grain yield/fad and agreed with the second and third strategy for cases and traits. Calhoun *et al*. (1994) indicated that evaluation under both optimum and drought conditions appears to be an effective method to take advantage of the increased selection response under full irrigation while preserving alleles for high yield under drought.

2. Selection for yield associated traits

An ideal secondary trait should be genetically associated with grain yield under drought, carries no yield penalty under favorable conditions, be heritable, cheap and rapid to measure and stable over the measurement period (Edmeades *et al* 1998).

Direct selection for grain yield was more efficient than the predicted genetic advance from indirect selection for all secondary traits in most cases at improving grain yield. Exceptions for the previous conclusion in this study indicated that indirect selection, *i.e.* responses of grain yield to selection for secondary traits was more efficient than direct selection for grain yield itself for KPm^2, EPP and BS under water-stress, a combination of stressed and unstressed environments, under well-water or water-stress for the use under a combination of the two environments, for 100-KW and ASI and under well-water for the use under a combination of both environments, where RE value was more than 100 % (Table 5).

Responses to selection for single secondary traits were highest under well-watered conditions for use under a combination of stressed and unstressed conditions, followed by responses under water-stressed environments, and then under water-stress for use under a combination of stressed and unstressed conditions. The reason for that could be attributed to the low heritability under a combination of stressed and unstressed environments due to the very large estimates of the genetic X environment interaction variance.

When responses of grain yield to selection for single secondary traits were compared under any selection environment, responses of grain yield to selection for high number of kernels/m^2 was predicted to be the largest, followed by the responses of grain yield to selection for high number of ears/plant and low percentage of barren stalks and short ASI. Response of grain yield to selection for low ASI was predicted to be of high efficiency when selection is practiced under optimum environment for use under a combination of stressed and unstressed conditions.

It is therefore concluded that selection for secondary traits such as kernels/m^2, ears/plant, barrenness and ASI are valuable adjunct in increasing the grain yield under water-stress and non-stress conditions. These traits should be used in water deficit breeding programs. They are related to genetic water-stress tolerance, with kernels/m^2 ears/plant, barrenness probably being the more important secondary traits. Other secondary traits which were not considered in this study may deserve further attention regarding their value in a water deficit breeding program.

Selection for improved performance under drought based on grain yield alone has often been considered inefficient, but the use of secondary traits of adaptive value whose genetic variability increased under drought can increase selection efficiency (Bolanos and Edmeades 1996). Physiologists and ideotype breeders have advocated the judicious incorporation of secondary traits within breeding programs (Blum 1988 and Ludlow and Muchow 1990). Results of the present study suggest that to maximize the genetic gain from selection, for improved grain yield, future research should focus on the incorporation of secondary traits such as barren stalks, ears/plant, kernels/m^2 and ASI traits in the selection programs along with the grain yield trait.

Populations evaluation

Analysis of variance

Results of the combined analysis of variance (not presented) showed that significant or highly significant differences existed among the two irrigation regimes and among the three populations (Pop-0, Pop-1 and Pop-2) for all studied traits. Mean squares due to populations X irrigation regimes interaction were significant and highly significant for all studied characters, except kernels/m^2, 100-kernel weight and leaf rolling.

In the experimental population trial, using a larger plot size than in the S_1 progeny evaluation trial generally lowered the coefficient of variation (C.V) for all studied traits under well-water, water-stress and a combination of the two irrigation regimes and lowered the difference in C.V. values between well-watered and water-stressed environments. From this observation it was concluded that there is a genetic variation for yield and other traits under limiting as well as adequate moisture in the DTP-1 population, that this variation can be identified using the selection procedure described, and that improved performance under drought is not at the expense of performance under conditions of adequate moisture. This finding is consisted with the observations of Fischer *et al* (1989) that unidentified drought-adaptive alleles exist at relatively high frequency in common breeding populations.

Separate analysis of variance (not presented) revealed significant or highly significant differences among populations either under well-watered or water-stress environment for all studied traits, except for BS, 100-KW, ASI, and PH under full irrigation and EPP and PH under limiting moisture.

Performance of populations

Means of the two improved experimental populations (Pop-1 and Pop-2) derived from intercrossing of the corresponding two selected S_1 progenies groups under the well-watered (1st group) and water-stressed (2nd groups) environments as well as the original (Pop-0) population (DTP-1) evaluated under the same irrigation regimes at Sids in 2003 season are presented in Table (6). The mean grain yields of Pop-0, Pop-1 and Pop-2 were 16.07, 18.64 and 15.42 ard/fad under well-watered and 4.35, 5.69 and 4.58 ard/fad under water-stressed environment, respectively (Table 6).

Pop-1 showed the best grain yield per fad and was significantly superior to both Pop-0 and Pop-2 either under well-watered or water-stressed environments. Moreover, Pop-1 exhibited the largest means of

Table 6. Means of all studied traits for the 3 populations evaluated under water-stress (S) and non stress (N) conditions at Sids in 2003 season.

Trait	Pop-0			Pop-1			Pop-2			LSD (0.05)	
	N	S	DE (%)	N	S	DE (%)	N	S	DE (%)	N	S
Grain yield /fad(ard)	16.07	4.35	-72.93	18.64	5.69	-69.47	15.42	4.58	-70.29	1.22	0.58
Barren stalks %	2.0	21.25	962	2.24	7.25	223.7	2.78	12.0	331.6	ns	1.38
Ears/plant	0.98	0.52	-46.91	1.26	0.71	-43.15	1.06	0.66	-37.74	0.108	0.03
Kernels/m^2	3104	1200	-61.34	3104	1317	-57.57	2609	1068	-59.06	422	85.97
100-kernel weight (g)	28.67	27.24	-5.00	30.83	29.60	-3.99	33.13	29.00	-12.47	ns	1.10
ASI (days)	0.50	3.50	600	0.25	0.25	-0.00	0.25	1.25	400	ns	0.498
Plant height (cm)	160.25	126.75	-29.90	153.0	130.0	-15.03	158.0	126.25	-20.09	ns	ns
Leaf rolling (score)	3.50	2.00	-42.85	4.00	3.25	-18.75	4.75	3.50	-26.32	0.645	0.64
Stay green (score)	2.00	1.37	-31.50	3.00	2.00	-33.33	3.25	2.76	-15.39	0.498	0.594

* Pop 0 = original population, Pop 1 = improved population under well-watered, Pop 2 = improved population under water stress. ns = non significant. DE (Drought Effect) = 100 (S-N)/N.

ears/plant (1.26 and 0.71) and kernels/m^2 (3104 and 1317) under full irrigation and drought stress conditions, respectively. Pop-1 also exhibited the lowest means (favorable) for ASI (0.25 and 0.25) under well-watered and water-stressed, respectively and barren stalks (7.25 %) under water-stress conditions. Pop-1 showed the lowest reduction (favorable) due to drought stress for grain yield per fad (69.47 %) kernels/m^2 (57.57 %), 100-kernel weight (3.99 %) and plant height (15.03 %) and the smallest increase (favorable) in barren stalks (223.7 %). Pop-2 came in the 2nd rank for grain yield/fad after Pop-1 under water-stress conditions. Pop-2 expressed the lowest reduction due to water-stress for ears/plant (37.74 %), ear height (11.21 %) and stay green (15.39 %).

Change due to selection

1. Change in grain yield/fad.

One cycle of S_1 recurrent selection for grain yield using the well-watered environment or a combination of stressed and non-stressed conditions as selection environment caused a significant improvement in grain yield of the Pop-1 over its original population (Pop-0) under soil moisture deficits around flowering by 30.8 % (1.34 ard fad^{-1}) and under well-watered conditions by 16.0 % (2.57 ard fad^{-1}) (Table 7).

The improved Pop-2, developed by using the soil moisture deficits as a selection environment, however, did not show significant improvements either under the drought stress or under the non-stress environments, though a tendency of grain yield improvement of 5.29 % (0.23 ard fad^{-1}) under water stressed environments was observed over its original population (Pop-0). Selection under stress is often considered less efficient because of the commonly observed decline in heritability (Blum 1988) and several reports of selections made in maize appear to confirm this (Arboleda-Rivera and Compton 1974 and Johnson and Geadelmann 1989). Our results also confirm that gains when selecting for improved yield under adequate soil moisture conditions that coincide with flowering of maize are clearly obtainable under both environments (stressed and unstressed) and even are more pronounced under water-stressed conditions. The magnitude of the observed gains in grain yield of Pop-1 under well-watered conditions was surprising, given that maintenance rather than improvement of unstressed yield is a breeding objective (Fischer *et al* 1989).

Table 7. Change in studied traits due to one cycle of S_1 recurrent selection in the 2 improved populations in absolute units and relative (%) values as compared to the original population under stress and non-stress conditions at Sids in 2003 season.

Trait	non stress				stress			
	Pop-1		Pop-2		Pop-1		Pop-2	
	Absolute	Relative %	Absolute	Relative %	Absolute	Relative %	Absolute	Relative %
Grain yield (ard/fad)	2.57	16.0	-0.65	-4.04	1.34**	30.8	0.23	5.29
Barren stalks %	0.24	12.0	0.78	39.0	-14.0**	-65.9	-0.25	-43.5
Ears/plant	0.28**	28.6	0.08	8.2	0.19**	36.54	-0.05	26.9
Kernels/m^2	0.0	0.0	-495*	-15.9	-117*	9.75	-132	-11.0
100-kernel weight (g)	2.16	7.5	4.46	15.6	2.36	8.66	-1.76	6.46
ASI (days)	-0.25	-50.0	-0.25	-50.0	-3.25	-92.9	2.25	-50.0
Plant height (cm)	-7.25	-4.5	-1.75	-1.1	3.25	2.56	-0.50	-0.39
Leaf rolling (score)	-0.5	14.3	1.25**	35.7	1.25**	62.5	1.5	75.0
Stay green (score)	1.00**	50.0	1.25**	62.5	0.63*	46.0	1.39	101.5

Pop.0 = original population, pop 1 = improved population under well-watered, pop 2 = improved population under water stress.,
Absolute change = Pop-1 or Pop-2 – Pop-0, Relative change = 100 (Pop-1 or Pop-2 – Pop-0)/Pop-0.
*and** indicate significance at 0.05 and 0.01 levels of probability, respectively.

2. Change in the unselected traits:

Selection improvement in grain yield of Pop-1 over Pop-0 under the moisture deficit target environment was associated with a significant decrease in percentage of barren stalks of 14% (65.9 %) and ASI of 3.25 days (92.9%) and a significant increase in ears/plant of 0.19 (36.54%), kernels/m^2 of 117 (9.75%), 100-kernel weight of 2.36 g (8.66 %), and stay green score of 0.63 (46.0 %) (Table 7).

Under the well-watered target environment, selection improvement in grain yield for Pop-1 over Pop-0 was attributed to significant improvements in other traits, expressed in significant increases in ears/plant of 0.28 (28.6 %) and stay green score of 1.0 (50.0 %) (Table 7).

Significant changes in the unselected traits of Pop-2 over Pop-0 include a decrease in barren stalks of 9.25 % (43.5 %), ASI of 1.75 days (50.0 %) and an increase in ears/plant of 0.14 (26.92 %) and stay green score of 1.39 (101.5 %) under drought stress and a decrease in kernels/m^2 of 495 (15.9 %) and an increase in leaf rolling score of 1.25 (35.7 %) and stay green score of 1.25 (62.5 %) under well-watered conditions.

Actual *vs* predicted progress

The largest predicted gain by direct selection under full irrigated (non-stress) environment (79.61 %), followed by direct selection under water-stressed environment (51.27 %) and the lowest was from direct selection under a combination of stressed and unstressed environments (24.44%) (Table 5). The corresponding actual gain from selection in this study is presented in Table (8). In general, estimates of actual progress in grain yield/fad as a result of practicing one cycle of S_1 recurrent selection were much lower than those of the predicted progress. This could be due to the overestimation of the heritabilities based on the total genetic variance (in the broad sense). It is believed that a considerable amount of non-heritable genetic variance (dominance and epistasis) is included in such total genetic variance. The highest actual progress in grain yield/fad was 2.57 ard/fad (16%) when the selection environment was well-watered followed by 1.59 ard/fad (19.15%) when the selection environment was a combination of stressed and unstressed environments, while the lowest actual progress was 0.23 ard/fad (5.29%) when the selection environment was water-stressed.

Table 8. Actual progress in grain yield/fad *via* one cycle of S_1 recurrent selection.

Selection environment	Progress	
	Absolute (ard/fad)	% of generation mean
	Direct selection	
Non-stress (N)	2.57	16.00
Stress (S)	0.23	5.29
Combined (C)	1.95	19.15
	Indirect selection (selection environment vs target environment)	
N *vs* S	1.34	30.80
S *vs* N	-0.65	-4.04
N *vs* C	1.95	19.15
C *vs* N	2.57	16.00
S *vs* C	-0.21	-2.06
C *vs* S	1.34	30.80

Actual progress in this study supports the superiority of the optimum environment or using a combination of stress and non-stress conditions as selection environments for maximizing the genetic progress in grain yield (30.8%) under the stressed target environment. These results of actual selection gain confirm the validity of both 2nd and 3rd strategies of selection (genotypes should be selected under well-watered conditions for use under drought stressed environment or selected genotypes should perform well under both stress and non-stress environments) and not the 1st strategy which was supported by the predicted progress.

The actual progress obtained in the present study due to practicing one cycle of S_1 recurrent selection and expressed in the newly-improved population (Pop-1) using full irrigation as a selection environment was considerably high (16.0% when evaluated under well-watered and 30.8% when evaluated under stressed environment). This progress assure the efficiency of the selection procedure used in this study for developing a new population (Pop-1) which was superior to its original population (Pop-0) in grain yield under water deficits as well as under optimum environments. Chapman and Edmeades (1999) also found that under drought, changes per cycle of S_1 recurrent selection was 12.6% for grain yield. Edmeades *et al* (1999) also found that in water-stressed environments, gains from selection per cycle for grain yield were 12.6% in Laposta Sequia and 3.8% in Tuxpeno Sequia populations. Moreover, El-Morshidy *et al* (2002) obtained an actual gain of 5.23% from one cycle of S_1 recurrent selection in Giza-2 for grain yield. The higher gains in grain yield from selection per cycle achieved in the present study as compared to those reported by other investigators might be attributed to the advantages of the 3rd selection strategy used in this study (high heritability under optimum environment and increasing the frequency of alleles of desirable traits of drought tolerance), the richness of the original population (DTP-1) in genetic variability for drought tolerance traits and to using the S_1 progeny, instead of half-sib or full-sib selection used in other studies, which utilizes the additive genetic variance in a better way than other intra-population improvement methods.

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الانتخاب الدوري لأنسال الجيل الذاتي الأول لتحمل الجفاف في الذرة الشامية

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١. قسم المحاصيل , كلية الزراعة, جامعة القاهرة, الجيزة, ج. م. ع.

٢. قسم بحوث الذرة الشامية, مركز البحوث الزراعية الجيزة, ج. م. ع.

تم إجراء التجارب الحقلية لهذه الدراسة في محطة بحوث سدس التابعة لمركز البحوث الزراعية ، حيث تم تكوين ١٤٤ نسل من أنسال الجيل الذاتي الأول المستمدة من عشيرة تحمل الجفاف(DTP-1) المستوردة من السيميت وذلك في موسم ٢٠٠١ . ثم قيمت الأنسال في موسم ٢٠٠٢ تحت كل من ظروف الجفاف (في مرحلة التزهير) وظروف الري الكامل. وبناء على ذلك تم انتخاب أفضل ١٠ % من هذه الأنسال (على أساس المحصول) تحت ظروف الجفاف أو ظروف الري الكامل كل على حده وتحت ظروف توليفة البيئتين معا. ولما كانت أفضل السلالات المنتخبة تحت ظروف الري الكامل هي نفسها المنتخبة تحت ظروف توليفة البيئتين معا فقد كان لدينا في الحقيقة مجموعتين فقط من السلالات الأولى منتخبة تحت ظروف الجفاف والثانية منتخبة تحت ظروف الري الكامل أو تحت ظروف توليفة البيئتين معا. وفي الموسم المبكر لعام ٢٠٠٣ تم زراعة هاتين المجموعتين من الأنسال في حقول منفصلة ، وتم عمل كل التهجينات الممكنة بينها ، وتم الحصول على عشيرتين تجريبيتين جديدتين (Pop-1 و Pop-2) ثم قيمت هاتين العشيرتين الجديدتين مع عشيرة الأساس (Pop-0) في موسم ٢٠٠٣ تحت ظروف كلا البيئتين. وكانت أهداف هذه الدراسة : (١) استنباط وتقييم عشائر ذرة أكثر تحملا للجفاف من عشيرة الأساس ، و (٢) اختبار أي من استراتيجيات الانتخاب الثلاث الأكثر كفاءة في تعظيم التحسين المتحصل عليه بالانتخاب ، و (٣) تحديد الصفات الثانوية الأقوى ارتباطا بالمحصول لاستخدامها في برامج التربية المستقبلية. أظهرت النتائج وجود تباعد وراثي بين ال ١٤٤ سلالة وأن الإجهاد المائي تسبب في نقص المتوسطات وتضييق المدى للسلالات بالنسبة للمحصول ومكوناته.وأظهرت قيمة كفاءة التوريث العامة للمحصول اتجاها عاما للانخفاض عند التعرض للجفاف. كما أشارت النتائج أن الانتخاب لصفات عدد الحبوب / م^{٢} وعدد الكيزان / نبات والتذكير والفترة بين نثر اللقاح وخروج الحريرة يمكن أن تكون ذات قيمة عالية لتحسين محصول الفدان تحت ظروف الإجهاد المائي. وقد أدى استخدام دورة واحدة من الانتخاب الدوري لأنسال الجيل الذاتي الأول تحت الظروف المثلى للري (كبيئة انتخابية) إلى تحسين معنوي في محصول حبوب الفدان للعشيرة الجديدة (Pop-1) مقارنة بعشيرة الأساس (Pop-0) قدره ٣٠,٨ % (١,٣٤ أردب / فدان) تحت ظروف الجفاف و ١٦ % (٢,٥٧ أردب / فدان) تحت ظروف الري الكامل وهذا التحسين الكبير يؤكد على كفاءة

الطريقة المستخدمة للانتخاب في هذه الدراسة. وقد دعمت نتائج التحسين المتوقع بالانتخاب لصفة محصول الفدان الاستراتيجية الأولى للانتخاب (وهي أن التراكيب الوراثية يجب انتخابها تحت نفس ظروف الري في بيئة الهدف أي تحت ظروف الجفاف)بينما دعمت نتائج التحسين الحقيقى النظرية الثانية أو الثالثة للانتخاب (حيث تم الحصول على أعلى نسبة تحسين حقيقي وهي ٣٠,٨% عندما تم انتخاب التراكيب الوراثية تحت ظروف الري أو تحت توليفة من البيئات المجهدة وغير المجهدة مائيا وذلك للأستخدام تحت ظروف الجفاف).