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GENETIC IMPROVEMENT OF MAIZE FOR LOW-SOIL NITROGEN TOLERANCE VIA S_1 RECURRENT SELECTION

A.M.M. Al-Naggar[1], R. Shabana[1], A.A. Mahmoud[2] and S.A.M. Shaboon[2]

[1] Agronomy Department, Faculty of Agriculture, Cairo University, Giza, Egypt.
[2] Field Crops Research Inst., Agriculture Research Center, Giza, Egypt.

ABSTRACT

One cycle of S_1 recurrent selection for low-soil N tolerance was practiced in the Egyptian maize composite Giza-2 in five seasons during the period from 2004 to 2007. A total of 121 S_1 maize progenies were obtained in 2004 and evaluated in 2005 season under high-N (HN) and low-N (LN) environments. The best 18 S_1 progenies in grain yield were selected separately under HN and LN and grown to produce the S_2's. The selected HN and LN S_2 lines were intercrossed in two isolated blocks in early 2006 season to produce two new populations i.e Giza 2-HN and Giza 2-LN.Such populations were grown in late 2006 season in two isolated blocks and left for random mating to reach equilibrium. In 2007 season the equilibrated populations along with the original one (Giza-2) were evaluated under high- and low-N conditions. The objectives of this study were to determine the effectiveness of selection and evaluate some alternative screening criteria for selecting nitrogen-use efficient maize genotypes. Results indicated wide genetic variation among S_1 progenies for most studied traits under both selection environments. Broad sense heritability (h^2_b) for 8 out of 9 studied traits was higher under LN than under HN conditions; with the highest h^2_b (81.99%) for economic nitrogen use efficiency (NUE_e) under LN. Results on S_1's predicted that anthesis-silking interval (ASI) and leaf senescence traits could be recommended as valuable criteria in increasing the efficiency of selection for low-N tolerance. Predicted gain from selection among S_1 progenies in grain yield (GY) suggested that selection should be carried out under conditions of the target environment. Consistent with the expectation, actual gain from selection under both LN and HN conditions caused considerable significant actual improvements for GY of 21.88% and 23.22%, respectively under LN conditions. Actual gain in grain yield was associated with significant desirable changes in most unselected studied traits. Grain dry matter (GDM), total above ground dry matter (TDM) and total N content (TN) were the best predictors of genotypic performance of economic NUE, biological NUE and nitrogen uptake efficiency (NUPE), respectively. GDM proved to be a good predictor for measuring all N use efficiency traits.

Key words: *Maize, Recurrent selection, Nitrogen use efficiency; NUE, Nitrogen uptake efficiency; NUPE, Nitrogen translocation efficiency; NTRE, Nitrogen utilization efficiency; NUTE, Dry matter, Low-N tolerance, Alternative criteria.*

INTRODUCTION

The increased use of N fertilizers in modern agricultural systems was accompanied by a steady growth in average maize yield. On the contrary, negative impacts of N-components on the atmosphere, the ground water and other components of the ecosystems have also been reported (Socolow 1999). Because of these negative effects, the European Community developed specific directives to prevent nitrate contamination of water from agricultural sources, such as by restricting the use of N fertilizers, enlarging the water protected areas as well as increasing the acreage of organic farming (Organic Centre Wales 2001). In many developing countries (such as Egypt) farmers cannot increase yield, as the availability of N fertilizers in crop production is often limited (FAO 2000). Crop cultivars with improved low-N tolerance have much to contribute to production systems where input of N fertilizers is restricted due to environmental and/or economical reasons.

Population improvement for low N tolerance has been accomplished in some maize populations by recurrent selection using full-sib and S_1 family selection methods (Edmeades *et al* 1999). Recurrent selection is a population improvement procedure that increases the frequency of desirable alleles through repeated cycles of selection and systematic recombination. This breeding method has been widely used for improving quantitative traits in cross-pollinated crops. Several genes usually control the expression of tolerance to low-soil N in maize with a preponderance of additive gene action (Hallauer and Miranda 1988, Lafitte and Edmeades, 1995 a and b, Below 1997 and Beck *et al* 1998). Lafitte and Banziger (1997) reported an average response in maize grain yield of 4.5% cycle^{-1} under low-N after five cycles of full-sib recurrent selection. A similar response was reported by Salah *et al* (1997) after three cycles of full-sib recurrent selection. Omoigui *et al* (2006) also reported that after three cycles of full-sib recurrent selection for low-N tolerance resulted in grain yield increase per cycle of 2.3% under low-N and 1.9 % under high-N. They added that selection also increased stay green ability by 17.7% and kernel weight by 4.7% cycle^{-1} under low-N. Ajala *et al* (2007) evaluated different cycles of full-sib and S_1 recurrent selection and reported that a minimum yield gain of 100 Kg ha^{-1} cycle^{-1} under low-N is feasible. They discussed the advantages of S_1 over full-sib selection and mentioned that selected S_1 lines for recombination can further be selfed to generate homozygous inbreds for hybrid production and also, progress from selection can be hastened through the use of S_2 versions of selected progenies for recombination, thus increasing parental control and selection gain.

We initiated a program of S_1 recurrent selection for improving maize tolerance to low-soil nitrogen in 2004. The local composite Giza-2 was used as the original population for practicing this program; with an ultimate goal of developing new maize population(s) of an increased tolerance to low-soil nitrogen. The specific objectives were to (i) determine the effectiveness of one cycle of S_1 recurrent selection for grain yield under high- and low-N environments by comparing the actual gain with expected one based on estimates of variances and heritability of S_1 progenies and (ii) identify alternative screening criteria for selecting nitrogen use efficient maize genotypes.

MATERIALS AND METHODS

This study was carried out in five seasons during the period from 2004 to 2007 at Sids Agric., Res., Station, Field Crops Research Institute (FCRI) of the Agricultural Research Center (ARC), Egypt.

Plant material

We used the white local composite of maize Giza-2 in this study as the base population. This population was initially formed in 1965 from a mixture of diallel crosses among ten populations; seven exotics (Tep #5, Tep #6, Lira III, Mexican June, Syn. Laposta, Kitale Syn. II and Blanco Comune) and three locals (American Early, Composite C and Local 14) and was subjected to 11cycles of S_1 recurrent selection (Personal communication with National Maize Research Program).

Developing the S_1's seed

In 2004 season, Giza-2 was sown in an isolated field at Sids and recommended agricultural practices were used including nitrogen fertilizer of 135 Kg N fed^{-1}. One thousand of vigorous and disease-free plants were self pollinated. After harvest, 121 selfed (S_1) ears were chosen randomly. The 121 S_1 ears were separately shelled and seeds were preserved for evaluation and producing S_2 seed in the next season.

S_1 Progeny evaluation

In 2005 season, one part of each of 121 S_1 seeds was used for evaluation of S_1 progenies in yield trials under high- (135 Kg N fed^{-1}) and low-N (no addition of N) conditions and the other part was used to develop the S_2's seed. A split-plot design in lattice arrangement (11 X 11) with two replicates was used for S_1 progeny evaluation trial. Each experimental plot consisted of one ridge of 5 meters long and 80 cm wide with a total area of 4.0 m^2. Sowing was done in hills of 25 cm apart along the ridge. Thinning was done before 1st irrigation (i.e after 20 days from sowing) and one plant was left in each hill to reach a plant density of 21,000 plants/ feddan. Main plots were allotted to nitrogen levels, while sub-plots were assigned to S_1 progenies. Two nitrogen levels were used, *i.e.* high-N level by adding the recommended N fertilization (135 Kg N fed^{-1}) in two equal doses in the form of Urea (46.5% N) before 1st and 2nd irrigations and low-N level through non-applying of any nitrogen fertilizer. The previous crop was wheat and available soil nitrogen in the experimental site (Sids Agric. Res. Sta.) was analyzed before sowing and found to be 30.44 Kg N fed^{-1}. Available soil nitrogen was therefore 7.88 g per plant under high-N and 1.45 g $plant^{-1}$ under low-N conditions.

Selection and developing the S_2's seed

In the same season (2005) the other part of each S_1 seed was sown in an isolated block at Sids and their plants were self-pollinated to develop the S_2 seed of each of the 121 progenies. Based on results of the S_1 evaluation experiments, the best 18 S_1's (15%) in grain yield plant^{-1} were determined under each selection environment (making two groups of selected S_1's; i.e 18 S_1's under HN and 18 S_1's selected under LN), their S_2 versions were selected and their S_2 seeds were kept for making intercrossing (among each group of S_2 lines) in the next season.

Intercrossing fields

In the 2006 early season, the selected S_2 lines of each of the two groups were grown for intercrossing in two isolated blocks. A mixture of equal number of seeds of each selected S_2 line was made for each group (HN and LN). Each mixture of seed was planted in an isolated block at the 1st of March, 2006. Plants were artificially sib-pollinated in each isolated block and harvested ears from each intercrossing block were shelled and their seeds were blended together making two mixtures of F_1 seeds (one between lines selected under HN and other one between lines selected under LN) which thereafter will be referred to as Giza 2-HN and Giza 2-LN, respectively.

Random-mating of the new populations

In the 10th of August, 2006, F_1 seeds of the two mixtures (Giza 2-HN and Giza 2-LN) were planted separately in isolated blocks. Plants of each mixture were sib-pollinated randomly in each block in order to achieve a considerable level of genetic equilibrium. Each block was harvested separately, and seeds from each block were blended thoroughly. Therefore, seeds of two new (improved) equilibrated populations were obtained, i.e. Giza 2-HN and Giza 2-LN.

Population evaluation

In the 2007 season seeds of the two new populations (Giza 2-HN and Giza 2-LN) and of the original population (Giza-2) were sown in the 1st of May in a yield trial under high- and low-N. A split-plot design with 4 replicates was used. The main plots were allotted to soil-N levels and the sub-plots were assigned to the populations. The experimental sub-plot consisted of 4 rows of 6 m long and 80 cm wide (i.e sub-plot size = 19.2 m^2). Hills spaced 25 cm along the row and plants were thinned to one plant per hill. All other recommended agricultural practices were followed for all evaluation experiments. The soil of the experimental site was clayey.

Traits recorded

Data were collected on days to 50 % silking (DTS), anthesis-silking interval (ASI), leaf senescence (LS) measured 15 days before physiological maturity using a scale from 1 to 10 where, 1 = 10% dead leaf area and 10 = 100% dead leaf area according to Banziger *et al* (2001), plant height (PH) in cm, ears per plant (EPP), kernels per plant (KPP), 100-kernel weight (100KW) in g, grain yield per plant (GYPP) in g (adjusted at 15.5% grain moisture), economic nitrogen use efficiency (NUE_e) in g/ g (NUE_e = GDM/ N_s), where GDM = grain dry matter and N_s = soil nitrogen plant^{-1}.

For the population evaluation experimental trial at physiological maturity stage, three random plants were removed from each plot and bulked as one sample per plot and separated into leaf blades, stalks (including leaf and ear sheathes), tassels and ears. Samples were dried at 70 °C in a forced air to a constant weight and each part was weighed separately. Grain dry matter (GDM)n g , total above ground dry matter plant^{-1} (TDM) in g and Harvest index (HI) in % were estimated. Biological nitrogen use efficiency (NUE_b in g/ g was determined as follows: $NUE_{b\ (m)} = TDM_m/N_s$. Nitrogen concentration in each part of the plant was determined at the laboratory using Kjeldahl method according to A.O.A.C (1980). Nitrogen content in mg was estimated for grains (GN), leaves (LN), stalks (SN) and tassels (TASN) and their total plant nitrogen content (TN) was calculated as follows: TN = GN + LN + SN + TASN. Nitrogen uptake efficiency (NUPE) in % as NUPE = (TN/N_s) X 100, nitrogen translocation efficiency (NTRE) in % as NTRE = (GN/TN) X 100, plant nitrogen utilization efficiency ($NUTE_p$) in % as $NUTE_p$ = (GDM/TN) X 100, and grain nitrogen utilization efficiency ($NUTE_g$) in % as $NUTE_g$ = (GDM/GN) X 100, were also estimated according to Moll *et al* (1987).

Data on ASI and LS traits were normalized using the transformation formula √(trait + 10) and those on traits measured as percentages were normalized using arcsines transformation. Analysis of variance of the split plot design was computed after carrying out Bartlet test according to Snedecor and Cochran (1989). Moreover, each main plot in each trial was analyzed as a lattice design for S_1 progeny and RCBD for population to determine genetic parameters separately under each environment, considering replicates as fixed effects, entries as random effects and incomplete blocks as random effects within replicates. Because the relative efficiency of the randomized complete block design (RCBD) was higher than that of the lattice design, expected mean squares under a separate environment were estimated from ANOVA table of RCBD (Table 1) according to Halluaer and Miranda (1988). Estimates of LSD were calculated to test the significant differences between means according to Snedecor and Cochran (1989).

Table 1. Analysis of variance and expected mean squares (E.M.S) of RCBD under a separate environment.

S.O.V	df	MS	EMS
Replications	r-1	-	-
Genotypes	g-1	M_2	$\delta^2_e + r\,\delta^2_g$
Error	(r-1) (g-1)	M_1	δ^2_e

Genotypic (δ^2_g) variance was computed by equating the appropriate mean squares with their expectations from Table (1) $\delta^2_g = M_2 - M_1 / r$, where, r = number of replications. Heritability (%) in the broad sense (h^2_b) for a separate environment was estimated as $h^2_b\ \% = 100\ \delta^2_g / (\delta^2_g + \delta^2_e / r)$. The genotypic ($r_g$) correlations between grain yield and each studied trait were calculated as $r_g = cov_{gxy} / (\delta^2_{gx} . \delta^2_{gy})^{1/2}$ where, cov_{gxy} = the phenotypic and genotypic covariance of the two traits, X and Y, respectively. δ^2_{gx} and δ^2_{gy} = the genotypic variance of the two traits, x and y, respectively.

Expected genetic advance (GA) from direct selection for all studied traits under each environment (high- or low-N) was calculated according to Singh and Narayanan (2000) as $GA = 100\ k\ h^2\ \delta_p / x$ where, k = selection differential (k = 1.56 for 15 % selection intensity), x = general mean of the appropriate nitrogen level and δ_p = square root of the denominator of the appropriate heritability under the nitrogen level. Indirect correlated response (CR) in nitrogen level (or in yield) j from selection in nitrogen level (or in a secondary trait) k was estimated according to Falconer (1989) as $CR_j = 100\ i\ H^{½}_j\ H^{½}_k\ r_{gjk}\ \delta_p / x_j$, where, $H^{½}_j$ and $H^{½}_k$ = square roots of heritabilities of N levels (or traits) j and k, respectively, r_{gjk} = genetic correlations among N levels (or traits) and k, CR_j = correlated response in nitrogen level (or in yield) j and x_j = general mean of nitrogen level (or of yield) j.

RESULTS AND DISCUSSION

I. S_1 progeny evaluation experiment

Results of the combined analysis of variance (not presented) for S_1 progenies (derived from Giza-2 population) showed that significant and highly significant differences existed among the two levels of nitrogen and among the genotypes (121 S_1's) for all studied traits. Mean squares due to S_1 progenies X N levels interaction were also significant or highly significant for all studied traits, indicating the possibility of selection within Giza-2 population for improved performance under a specific soil-nitrogen environment, as proposed by Fischer *et al* (1989) and Al-Naggar *et al* (2006).

Performance of S_1 progenies

Means of grain yield plant^{-1} of the 121 S_1 progenies were 111.4g (ranging from 49.8 to 163.0 g plant^{-1}) under high-N and 50.8 g (from 5.0 to 131.0 g plant^{-1}) under low-N. (Table 2). A significant average reduction of 73.1% in grain yield plant^{-1} of the 121 S_1 progenies due to low-N stress was accompanied by a reduction in kernels plant^{-1} (50.3%), ears plant^{-1} (29.4%), plant height (13.6%) and 100-kernel weight (11.3%) (Table 2). As a yield component, maximum reduction due to low-N stress was shown by kernels plant^{-1}. On the other hand, low-N stress caused a significant increase in the mean of S_1 progenies for ASI and NUE_e. Ranges in 5 traits (grain yield plant^{-1}, ears plant^{-1}, 100 kernels weight, kernels plant^{-1} and stay green) were broader under low-N than under high-N.

Mean grain yields of the best 18 S_1 progenies (selected on the basis of their grain yields) were 146.0 g plant^{-1} (ranging from 135.0 to 163.0 g plant^{-1}) under high-N and 93.8 g plant^{-1} (from 77.7 to 131.8 g plant^{-1}) under low-N conditions. The superiority of the 18 S_1's over the 121 S_1's in grain yield was higher under low-N (84.7%) than under high-N (32.0%) conditions. Superiority in mean grain yield plant^{-1} of the 18 S_1's over the121 S_1's was associated with superiority in ears plant^{-1} (10.1 and 27.3%), kernels plant^{-1} (24.3 and 84.0%) and NUE_e (27.6 and 84.8%) under high- and low-N, respectively. On the other hand, the best 18 S_1's in grain yield were characterized by lower means than the 121 S_1's for ASI (92.1and 57.0%) and days to silking (0.4 and 4.0%) under high- and low-N conditions, respectively (Table 2). The harmful effect of low-N stress was smaller for the selected 18 S_1's than that of the 121 S_1's for ears plant^{-1}, kernels plant^{-1}, ASI and plant height traits.

Correlations between traits and grain yield

Data in Table (3) indicated a strong positive genetic correlation under low-N between grain yield plant^{-1} and each of NUE_e ($r_g = 0.87$), kernels plant^{-1} ($r_g = 0.84$) and ears plant^{-1} ($r_g = 0.63$). Results also indicated a negative significant correlation under low-N between grain yield and leaf senescence trait ($r_g = -0.37$). Similar results were also reported by Lemcoff and Loomis (1986), Lafitte and Edmeades (1994c), Banziger and Lafitte (1997) and Monneveux *et al* (2005). The same trend was also observed in this study under high-N; but with higher r_g estimates under high- than under low-N. Nonetheless, correlation analysis showed that ears plant^{-1} and kernels plant^{-1} were more important determinates of grain yield than kernel weight. Results of Table (3) confirm that low-N stress was affected mainly by the number of kernels plant^{-1} and to a less extent by ears plant^{-1}. A similar conclusion was also reported by Lemcoff and Loomis (1986), Lafitte and Edmeades (1994a) and Monneveux *et al* (2005) under low-N conditions.

Table 2. Means and ranges for all studied traits of 121 S_1's and selected 18 S_1's (based on grain yield) derived from Giza2 population and evaluated under high- and low-N conditions at Sids in 2005 season.

Trait	Treatment	Mean		Difference		Range				LNE	
		121 S_1's	Best 18 S_1's	Absolute	% of 121 S_1's	121 S_1's		Best 18 S_1's			
						Lowest	Highest	Lowest	Highest	121 S_1's	Best 18 S_1's
GYPP (g)	High-N	111.4	146.0	35.6	32.0	49.8	163.0	135.0	163.0	-	-
	Low- N	50.8	93.8	43.0	84.7	5.04	131.8	77.7	131.8	-73.1**	-76.2**
EPP	High-N	1.1	1.20	0.1	10.1	0.60	1.6	1.0	1.6	-	-
	Low- N	0.8	1.0	0.21	27.3	0.14	1.4	0.7	1.2	-29.4**	-18.3**
KPP	High-N	310.6	386.0	75.4	24.3	153.1	439.4	342.0	435.0	-	-
	Low- N	154.3	284.0	129.7	84.0	16.0	438.5	208.0	438.5	-50.3**	-26.5**
100KW (g)	High-N	37.0	38.1	1.1	2.9	31.2	45.0	33.4	42.1	-	-
	Low- N	32.8	33.4	0.6	1.7	24.5	41.5	27.9	40.5	-11.3**	-12.4**
DTS (d)	High-N	57.0	56.8	-0.2	-0.4	53.5	60.0	54.5	58.5	-	-
	Low- N	61.2	58.7	-2.5	-4.0	54.0	71.5	56.0	61.5	7.2*	3.4*
ASI (d)	High-N	0.3	0.03	-0.27	-92.1	-2.0	2.0	-2.0	2.0	-	-
	Low- N	2.4	1.0	-1.37	-57.0	-5.0	8.5	0.0	2.5	624.2**	3861.5**
PH (cm)	High-N	213.0	216.0	3.0	1.4	157.0	266.5	202.0	241.0	-	-
	Low- N	184.0	195.6	11.6	6.3	132.0	228.0	167.0	228.0	-13.6**	-9.4*
LS (1-10)	High-N	8.0	8.0	0.0	0.0	2.0	10.0	2.0	5.5	-	-
	Low- N	8.0	7.8	-0.2	-2.6	5.0	9.5	6.0	9.5	0.5	-2.1
NUEe	High-N	15.5	19.8	4.3	27.6	6.7	22.5	18.5	22.1	-	-
	Low- N	37.9	70.0	32.1	84.8	3.8	98.4	55.9	93.8	144.5**	254.0**

*and** indicate significance at 0.05 and 0.01 levels of probability, respectively. LNE (low-N effect) = 100(low N - high N)/ high N.

Table 3. Genetic correlation coefficients (r_g) between grain yield and all studied traits, genetic variances (δ^2_g) and heritability in the broad sense (h^2_b) of 121 S_1' s (derived from Giza-2) evaluated under high- and low-N conditions at Sids in 2005 season.

Trait	r_g		δ^2_g		h^2_b%	
	High-N	Low-N	High-N	Low-N	High-N	Low-N
GYPP	-	-	214.4	301.20	39.62	54.89
EPP	0.75†	0.63†	0.0181	0.0169	53.55	59.58
KPP	0.99†	0.84†	2680.9	6491.0	50.97	47.64
100KW	0.42†	0.35†	1.78	2.516	22.38	51.06
DTS	-0.06	-0.02	0.967	2.213	54.36	61.87
ASI	-0.34†	-0.01	0.003	0.0046	19.23	32.39
PH	0.37†	0.36†	195.10	185.67	67.88	72.66
LS	-0.34†	-0.37†	0.002	0.0439	05.95	77.97
NUEe	0.74†	0.87†	3.495	103.26	63.45	81.99

† Estimate exceeds its standard error twice

Genetic variance and heritability

The magnitude of genetic variance (δ^2_g) among S_1 progenies was considerably higher under low-N than that under high-N for 7 out of 9 studied traits (grain yield plant^{-1}, kernel plant^{-1}, 100-kernel weight, days to silking, ASI, leaf senescence, and NUE_e). Broad-sense heritability (h^2_b) estimates were generally of medium magnitude for most studied traits. The highest h^2_b estimate under low-N was exhibited by NUE_e (81.99%) followed by LS (77.97%) and plant height (72.66%) (Table 3).

Estimates of h^2_b showed a general tendency to increase with imposing low-N stress for all studied traits except for KPP. This indicates that selection for these traits is predicted to be more efficient under low- than under high-N environments. This conclusion is in agreement with that reported by Lafitte and Edmeades (1994a).

Predicted genetic advance from selection

The predicted genetic advance for eight traits showing high heritabilities and strong genetic correlations with grain yield plant^{-1} were calculated for direct and indirect selection using 15% selection intensity (Table 4).

Table 4. Genetic advance from direct selection (*i.e.* selection environment same as target environment) and correlated genetic response (CR) for indirect selection (*i.e.* selection and target environments differ in nitrogen levels or selection in a secondary trait for the improvement of grain yield plant^{-1}).

Selection environment	GYPP	EPP	KPP	100-KW	ASI	LS	NUE$_e$
			Direct selection response (R)				
1- High-N (HN)	28.66	19.92	27.84	7.29	0.08	1.51	28.66
2- Low-N (LN)	79.40	40.39	79.23	11.06	10.11	0.22	79.40
			Indirect selection response (CR)				
			a. Selection environment vs target environment				
1- HN for use under LN	2.31	4.65	4.39	2.80	0.37	0.03	2.31
RE %	(8.10)	(23.3)	(15.8)	(38.4)	(462.5)	(2.00)	(8.10)
2-LN for use under HN	5.72	145.5	11.0	1.57	0.75	0.02	0.56
RE %	(7.20)	(360.2)	(13.9)	(14.2)	(7.40)	(9.10)	(0.71)
			b. Secondary traits vs grain yield plant^{-1}				
1-High-N (HN)	-	11.37	26.86	-0.45	-0.22	0.23	28.66
RE %	-	(57.10)	(96.50)	(-6.20)	(-275.0)	(15.2)	(100.0)
2- Low-N (LN)	-	3.19	3.04	3.76	-0.28	0.29	2.31
RE %	-	(7.90)	(3.80)	(34.0)	(-2.80)	(131.8)	(2.90)
3- HN for use under LN	-	10.52	7.68	-2.12	-8.51	1.59	5.72
RE %	-	(52.8)	(27.6)	(29.10)	(-10637)	(105.3)	(20.0)
4-LN for use under HN	-	3.59	3.09	-0.90	-1.50	0.47	2.14
RE %	-	(8.90)	(3.90)	(-8.10)	(-14.8)	(213.6)	(2.70)

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

Direct selection

Predicted genetic advance from direct selection reached its maximum value under low-N selection environment for six traits (grain yield plant^{-1}, ears plant^{-1}, kernels plant^{-1}, 100-kernel weight, NUE$_e$ and ASI) and under high-N selection environment for one trait (leaf senescence) mainly due to high heritability for these traits observed under the respective environment (Table 4).

Indirect selection

Selection environment *vs* target environment

Predicted genetic advance from indirect selection, which incorporates both the heritability and the genetic correlation between two different environments (high-N and low-N) for the same trait, could be used to identify the best selection environment based on its relative efficiency (RE) in that environment (Table 4). 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 4). It is therefore concluded that in this study the predicted gain from direct selection under a specific soil nitrogen environment would improve the trait under consideration in a better way than the indirect selection. This conclusion is in agreement with Allen *et al* (1978), Blum (1988), Smith *et al* (1990) and Braun *et al* (1992).

Some exceptions are shown in the results of the present study (Table 4) in favor of the indirect selection. The indirect selection under high-N for the use under low-N environment was more efficient than direct selection under high-N for ASI trait (RE = 462.5%). This may be attributed to the very low S_1 generation mean of ASI under high-N selection environment (Table 2). Moreover, the indirect selection under low-N for the use under high-N was more efficient than direct selection under low-N for ears plant^{-1} (RE = 360.2%). This may be attributed to the low S_1 generation mean of ears plant^{-1} and stay green under low-N selection environment which raised the value of correlated response. This condition is in agreement with that reported by Allen *et al* (1978), Ceccarelli *et al* (1992) and Itoh and Yamada (1990).

In general, the predicted results of the present study indicated that genotypes may be evaluated under the conditions in which they will ultimately be produced, namely a certain soil-N environment. The results also assured that genotypes may be evaluated under high-N to be used under low-N environment for ASI trait and may be evaluated under low-N to be used under high-N conditions for ears plant^{-1} trait. The direct selection under low-N environment would ensure the preservation of alleles for low-N tolerance and would take the advantage of high heritability shown in this study for most traits under low-N conditions. A similar conclusion was reported by Langer *et al* (1979), Atlin and Frey (1990), Zavala Gracia *et al* (1992), Banziger *et al* (1997), Prestrel *et al* (2003) and Ajala *et al* (2007).

A secondary trait *vs* grain yield

Direct selection for grain yield was generally more efficient than indirect selection for all secondary traits to improve grain yield. This conclusion is based on comparisons between predicted responses of improving grain yield indirectly *via* a single secondary trait and directly *via* grain yield itself by calculating the value of relative efficiency. These comparisons showed that direct selection for grain yield was significantly superior to indirect selection *via* any single secondary trait (Table 4). 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 short anthesis-silking interval (ASI) and low leaf senescence score under high-N for the use under low-N environments and for low leaf senescence under low-N for the use under high-N. Predicted correlated response of grain yield to selection for low ASI under high-N and low leaf senescence and high NUE_e under low-N environment was more efficient than selection for grain yield itself (Table 4).

It is therefore concluded that secondary traits such as ASI, leaf senescence and ears plant^{-1}are valuable criteria in increasing the efficiency of selection for grain yield under high- and low-N environments. These traits should be recommended to breeding programs for improving low-N tolerance. Selection for improved performance under low-N based on grain yield alone has often been considered inefficient, but the use of secondary traits of adaptive value whose genetic variability increased under low-N can increase selection efficiency (Bolanos and Edmeades 1996). Physiologists and 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 improving grain yield, future research should focus on the incorporation of secondary traits such as ASI and leaf senescence traits in the selection programs along with the grain yield trait.

II. Population evaluation experiment

Analysis of variance

Combined analysis of variance (not presented) showed that significant and highly significant differences existed among the two N environments for all studied traits, except for stay green and among the three populations (Giza-2, Giza 2-HN and Giza 2-LN) for all studied traits, except for 100-kernel weight and total nitrogen content plant^{-1}. Mean squares due to populations X N levels interactions were significant and highly significant for all studied traits, except for 100-kernel weight and plant height. Separate analysis of variance (not presented) revealed significant or highly significant differences among populations either under low-N or high-N environment for all studied traits, except for grain yield plant^{-1}, ears plant^{-1}, ASI, total dry matter (TDM) and nitrogen translocation efficiency (NTRE) under high-N only.

Performance of populations

Mean grain yield of Giza-2, Giza 2-HN and Giza 2-LN was 96.9, 119.4, 118.1 g plant^{-1} under low-N and 139.3, 141.3 and 143.9 g plant^{-1} under high-N conditions, respectively (Table 5).

Under low-N, Giza 2-HN and Giza 2-LN showed significant superiority in grain yield plant^{-1} over Giza-2; with no significant differences among Giza 2-HN and Giza 2-LN. Although there was no significant differences in grain yield plant^{-1} among the three populations under high-N, there was a trend of

Table 5. Means of studied traits for three populations (2 improved and one original) evaluated under high- and low-N environments at Sids in 2007 season.

Population	GYPP (g)	EPP	KPP	100KW (g)	DTS (d)	ASI (d)
			High-N			
Giza 2	139.3	0.99	413.6	33.73	60.25	1.25
Giza 2-HN	141.3	0.99	416.5	34.01	58.75	1.00
Giza 2-LN	143.9	1.01	440.3	32.68	58.75	1.25
LSD $_{0.05}$	ns	ns	26.66	1.49	1.82	Ns
			Low N			
Giza 2	96.9	0.70	335.8	28.87	65.75	2.69
	(-30.4)	(-29.3)	(-18.8)	(-14.4)	(9.13)	(82.9)
Giza 2-HN	119.4	0.85	406.4	29.59	60.75	1.55
	(-15.5)	(-14.1)	(-2.42)	(-13.0)	(3.40)	(55.0)
Giza 2-LN	118.1	0.78	358.7	32.90	61.00	1.80
	(-17.9)	(-22.8)	(-18.5)	(0.67)	(3.83)	(36.0)
LSD $_{0.05}$	15.75	0.05	53.58	3.89	2.06	0.60
	LS (1-10)	GDM (g)	TDM (g)	HI (%)	GN (g)	TN (g)
			High-N			
Giza 2	1.87	119.8	221.7	54.04	0.87	11.74
Giza 2-HN	2.50	128.6	225.2	57.10	1.07	12.66
Giza 2-LN	1.87	127.8	228.7	55.88	1.02	11.78
LSD $_{0.05}$	0.20	6.51	ns	2.04	0.18	0.83
			Low N			
Giza 2	2.65	90.62	157.9	57.39	2.00	11.30
	(41.7)	(-24.4)	(-30.9)	(5.84)	(216.1)	(-3.89)
Giza 2-HN	2.27	106.4	184.4	57.70	2.92	12.19
	(-0.92)	(-17.3)	(-18.1)	(-1.05)	(172.9)	(-3.71)
Giza 2-LN	2.65	104.2	190.6	54.67	2.77	11.83
	(41.7)	(-18.5)	(-14.0)	(-2.21)	(171.6)	(0.42)
LSD $_{0.05}$	0.19	14.41	14.51	ns	0.38	0.77
	NUEe (g/g)	NUE$_b$ (g/g)	NUPE (g/g)	NTRE (g/g)	NUTE$_p$ (g/g)	NUTE$_g$ (g/g)
			High-N			
Giza 2	14.59	30.00	1.057	7.41	95.23	325.3
Giza 2-HN	16.05	30.47	1.077	8.45	100.4	370.6
Giza 2-LN	16.21	30.95	1.082	8.66	97.85	336.7
LSD $_{0.05}$	1.25	ns	0.01	Ns	3.48	23.85
			Low N			
Giza 2	67.62	117.8	1.36	25.91	90.11	182.9
	(363.5)	(281)	(26.85)	(249.7)	(-7.35)	(-43.77)
Giza 2-HN	79.40	137.6	1.38	23.95	90.92	191.5
	(394.7)	(352)	(28.13)	(167.0)	(-9.44)	(-48.33)
Giza 2-LN	77.80	142.3	1.39	23.42	101.4	206.0
	(379.9)	(374)	(26.28)	(183.0)	(5.77)	(-38.82)
LSD $_{0.05}$	10.15	10.83	ns	5.27	5.51	8.89

Estimates followed means between parenthesis indicate stress effect% = 100(LN-HN)/ HN.

superiority for the new populations (Giza 2-LN and Giza 2-HN) over Giza-2. The significant superiority over Giza-2 under low-N included all studied traits, except harvest index (HI) and nitrogen uptake efficiency (NUPE) for new populations, 100-KW and plant nitrogen utilization efficiency ($NUTE_p$), for Giza 2-HN and grain dry matter (GDM) and total nitrogen content (TN) for Giza 2-LN. Both populations (Giza 2-LN and Giza 2-HN) exhibited significant tolerance to low-N, over Giza-2 expressed as a relative value of stress effect (Table 5) for all studied traits, except for HI, grain nitrogen (GN), TN, and NUPE traits.

Alternative screening criteria for NUE traits

Genetic correlation coefficients (r_g) of economic nitrogen use efficiency, biological nitrogen use efficiency, nitrogen uptake efficiency, nitrogen translocation efficiency, plant nitrogen utilization efficiency and grain nitrogen utilization efficiency traits with selective alternative criteria (grain nitrogen content, total nitrogen content, grain dry matter, total dry matter and harvest index) are presented in Table (6). When soil N is constant, economic nitrogen use efficiency, biological nitrogen use efficiency and nitrogen uptake efficiency traits are expected to be determined by measuring grain dry matter, total dry matter and total nitrogen content, respectively. Consistent with expectations, genetic correlation was significant and very high in magnitude (Table 6) between these three nitrogen use efficiency traits and the three alternative criteria. It could therefore be concluded that grain dry matter, total dry matter and total nitrogen content were the best predictors of genotypic performance for economic nitrogen use efficiency, biological nitrogen use efficiency and nitrogen uptake efficiency, respectively. Moreover, very high and significant genetic correlation coefficients were also found between economic nitrogen use efficiency and total dry matter, and between biological nitrogen use efficiency and grain dry matter under both N levels, suggesting also that total dry- matter and grain dry-matter could also be used as alternative criteria for measuring NUE_e and biological nitrogen use efficiency, respectively. Furthermore, under low-N conditions, a significant and highly r_g value was also obtained between grain nitrogen content and each of economic nitrogen use efficiency and biological nitrogen use efficiency, indicating also that grain nitrogen content could be used as an alternative criterion for measuring economic nitrogen use efficiency and biological nitrogen use efficiency under low-N. Under both environments, a strong association was found between nitrogen translocation efficiency and grain nitrogen content, indicating that grain nitrogen content could be suggested as an alternative criterion for nitrogen translocation efficiency under high- and low-N conditions. Very high and significant r_g value was found between harvest index and each of economic nitrogen use efficiency and biological nitrogen use efficiency under both N environments.

Table 6. Genetic correlation coefficients ($P< 0.01$) between nitrogen efficiency traits and selective alternative criteria in maize genotypes.

Trait	NUE_e	NUE_b	NUPE	NTRE	$NUTE_p$	$NUTE_g$
			High-N environment			
GN	0.13	0.16	0.22	0.91†	-0.66	0.63
TN	0.73†	0.81†	0.89†	0.96†	-0.61	0.44
GDM	0.99†	0.94†	0.74†	-0.76†	0.96†	0.98†
TDM	0.96†	0.97†	0.66	-0.55	0.46	0.39
HI	0.95†	0.98†	0.77†	0.65	0.83†	0.57
			Low-N environment			
GN	0.86†	0.76†	0.20	0.95†	0.27	0.53
TN	0.56	1.00†	0.80†	1.00†	0.47	0.37
GDM	1.00†	0.92†	0.67†	-0.42	0.76†	0.82†
TDM	0.92†	0.99†	0.59	-0.33	0.36	0.33
HI	0.76†	0.88†	0.69†	0.26	0.66	0.48

† Estimate exceeds its standard error twice.

Nitrogen utilization efficiency traits ($NUTE_p$ and $NUTE_g$) showed strong genetic correlations with grain dry matter under both environments. Grain dry matter could also be considered as a good predictor of the two studied N-utilization efficiency traits. This indicated that grain dry matter could be used as a good selective criterion for measuring all nitrogen efficiency traits under both high- and low-N. This conclusion was also supported by Youngquist *et al* (1992). Analyzing for grain dry matter would allow faster and more economic evaluation of a large number of maize genotypes. By substituting an alternative criterion in ranking nitrogen efficient genotypes in maize breeding programs, substantial savings in time and resources could be realized with a fair level of confidence in the selection. Alagarswamy and Seetharma (1983) concluded that selection, in grain sorghum, for biomass and harvest index is sufficient to ensure high-N uptake and translocation. Traore and Maranville (1999) reported that shoot and grain nitrogen concentration were correlated with biological nitrogen use efficiency while grain and shoot N contents were correlated with plant nitrogen utilization efficiency. Moreover, Harada *et al* (2000) reported a strong correlation between grain dry matter and N uptake efficiency.

The best use of the alternative screening criteria mentioned in this study would be as pre-screening tools to eliminate the poorest genotypes. This would alleviate the need to whole plant analysis on a large number of samples, yet permit a fair level of confidence in making final selections.

Change due to selection

a. Change in grain yield plant^{-1}

One cycle of S_1 recurrent selection for grain yield using either low-N or high-N as a selection environment caused a significant actual improvement in grain yield of the newly-developed populations Giza 2-LN and Giza 2-HN over their original population Giza-2 of 21.88 and 23.22%, respectively under low-N conditions (Table 7).

Table 7. Actual progress in grain yield plant^{-1} *via* one cycle of S_1 recurrent selection.

Selection environment	Genetic advance	
	Absolute (g/plant)	% of generation mean
	Direct selection	
High-N	2.00	1.44
Low-N	21.20**	21.88
	Indirect selection (selection vs target environment)	
LN *vs* HN	4.60	3.30
HN *vs* LN	22.50**	23.22

Selection under both high- and low-N was found of high efficiency under low-N target environment, because of the observed high heritability under both selection environments for most studied traits (Table 3). This conclusion was confirmed by other investigators (Arboleda-Rivera and Compton 1974, Lafitte and Edmeades 1994 a and b, Banziger *et al*, 1997 and Al-Naggar *et al* 2004).

b. Change in the unselected traits

Selection improvement in grain yield of Giza 2-LN over Giza-2 was associated with a significant increase in ear plant^{-1} (11.43%), 100-kernel weight (13.96%), grain dry matter (14.99%), total dry matter (20.71), grain nitrogen (38.5%), economic nitrogen use efficiency (15.5%), biological nitrogen use efficiency (20.8%), nitrogen translocation use efficiency (38.94), plant nitrogen utilization efficiency (10.72) and grain nitrogen utilization efficiency (12.63%) and a significant decrease (favorable) in days to silking (7.22%) and ASI (33.09) under low-N conditions (Table 8). Moreover, superiority of Giza 2-LN over Giza-2 in grain yield shown under

Table 8. Actual change in unselected traits due to one cycle of S_1 recurrent selection for high grain yield in the two improved populations Giza 2-HN and Giza 2-LN in absolute (AC) and relative (RC%) values as compared to the original population (Giza-2) under high- and low-N.

Trait	Giza 2 HN				Giza 2 LN			
	High N		Low N		High N		Low N	
	AC	RC %	AC	RC %	AC	RC %	AC	RC %
EPP	0.00	0.00	0.02	2.02	0.15**	21.43	0.08**	11.43
KPP	2.90	0.70	26.70*	6.46	70.6**	21.02	22.9	6.82
100KW	0.28	0.83	-1.05	-3.11	0.72	2.49	4.03*	13.96
DTS	-1.50*	-2.49	-1.50*	-2.49	-5.00**	-7.60	-4.75**	-7.22
ASI	-0.25	-20.00	0.00	0.00	-1.14**	-42.38	-0.89*	-33.09
LS	0.00	0.00	1.41**	75.76	-0.38**	-14.34	0.00	0.00
GDM	8.80**	7.35	8.00*	6.68	15.78**	17.41	13.58**	14.99
TDM	3.50	1.58	7.00	3.16	26.50**	16.78	32.70**	20.71
HI	3.06**	5.66	1.84	3.40	0.31	0.54	-2.72**	-4.74
GN	0.20*	22.99	0.15	17.24	0.92**	46.0	077**	38.50
TN	0.92*	7.84	0.04	0.34	0.89**	7.88	0.53	4.69
NUE_e	1.46**	10.01	1.62**	11.10	11.78*	17.42	10.18*	15.05
NUE_b	0.47	1.57	0.95	3.17	19.8**	16.81	24.5**	20.80
NTRE	1.07	14.56	0.78	10.61	8.47**	52.19	6.32**	38.94
NUPE	0.02**	1.89	0.03**	2.37	0.02	1.47	0.03	2.21
$NUTE_p$	5.17*	5.43	2.62	2.75	7.19**	16.72	4.61**	10.72
$NUTE_b$	3.9	2.90	3.10	2.31	0.81*	0.90	11.29**	12.53
$NUTE_g$	45.3**	13.93	11.40	2.31	8.60	4.70	14.5**	12.63

*and** indicate significance at 0.05 and 0.01 levels of probability, respectively.

high-N was associated with a significant favorable change in ears plant^{-1} (21.43%), kernels plant^{-1} (21.02%), days to silking (7.60%), ASI (42.38%), grain dry matter (17.41%), total dry matter (16.78%), nitrogen translocation efficiency (52.19%) and plant nitrogen utilization efficiency (16.72%).

Significant changes in the unselected traits of Giza 2-HN over Giza 2 included an increase in kernels plant^{-1} (6.46%), grain dry matter (6.68%), economic nitrogen use efficiency (11.10%) and nitrogen uptake efficiency (2.37%) and a decrease in days to silking (2.49%) under low N and an increase in grain dry matter (7.35%), harvest index (5.66%), grain nitrogen content (22.99%), total nitrogen content (7.84%), economic nitrogen use efficiency (10.01%), nitrogen uptake efficiency (1.89%) and plant nitrogen utilization efficiency (5.43%) under high N conditions (Table 8).

Actual *vs* predicted progress

For grain yield plant^{-1}, predicted gain by direct selection was higher under low-N (79.40%) than that under high-N (28.66%) (Table 4). The corresponding actual gain from selection in this study as a result of practicing one cycle of S_1 recurrent selection (Table 7) was much lower than that of the predicted progress. This could be attributed to the over estimation 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 actual progress obtained in the present study due to practicing one cycle of S_1 recurrent selection and expressed in the newly-improved populations (Giza 2-LN and Giza 2-HN) using both low- and high-N as selection environments was considerably high (21.88 and 23.22%, respectively) when evaluated under low-N. This progress assures the efficiency of the selection procedure used in this study for developing new populations (Giza 2-LN and Giza 2-HN) which were superior to their original population (Giza 2) in grain yield under low-N. Lafitte and Banziger (1997) found an average progress in grain yield of 4.50% cycle^{-1} of full-sib recurrent selection under low-N. A similar response was reported by Salah *et al* (1997) after three cycles of full-sib recurrent selection. Omoigui *et al* (2006) reported an actual grain cycle^{-1} in grain yield of 2.30% under low-N and 1.90% under high-N after three cycles of full-sib recurrent selection. Ajala *et al* (2007) predicted a minimum yield gain of 2.34% cycle^{-1} of S_1 recurrent selection. The higher gain in grain yield from selection cycle^{-1} achieved in the present study as compared to that reported by other investigators might be attributed to the use of S_1 instead of full-sib recurrent selection used in other studies, which utilizes the additive genetic variance in a better way than other intra-population improvement methods. The use of S_2 versions of selected S_1 lines, in the present study, for recombination might increase parental control and consequently selection gain.

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التحسين الوراثي للذرة الشامية لتحمل النيتروجين المنخفض باستخدام الانتخاب الدوري لأنسال الجيل الذاتي الأول

أحمد مدحت محمد النجار[1] ، محمد رضا على شبانه[1] ، عاطف عبد القادر محمود[2] ، شابون عبد العزيز شابون[2]

1 قسم المحاصيل، كلية الزراعة، جامعة القاهرة، الجيزة.

2 قسم بحوث الذرة الشامية، معهد بحوث المحاصيل الحقلية، مركز البحوث الزراعية .

تم إجراء التجارب الحقلية لهذه الدراسة خلال خمسة مواسم للأعوام من 2004 حتى 2007 فى محطة البحوث الزراعية بسدس التابعة لمركز البحوث الزراعية ، حيث تم تكوين 121 نسلا من أنسال الجيل الذاتى الأول المستمده من الصنف المحلى المركب (جيزة-2) فى موسم 2004 ثم قيمت الأنسال فى موسم 2005 تحت كل من ظروف نيتروجين التربة المرتفع (بإضافة 135كجم نيتروجين للفدان) والمنخفض (بدون إضافة للسماد). وبناء على ذلك تم انتخاب أفضل 18 نسلا من هذه الأنسال (على اساس محصول الحبوب للنبات) تحت ظروف النيتروجين المرتفع وظروف النيتروجين المنخفض (كل على حدة) واجرى لها إخصاب ذاتى للحصول على أنسال الجيل الذاتى الثانى (مجموعتين من السلالات الأولى منتخبه تحت النيتروجين العالى والأخرى تحت النيتروجين المنخفض) . وفى الموسم المبكر لعام 2006 تم زراعة هاتين المجموعتين من الأنسال فى حقلين معزولين وتم عمل كل التهجينات الممكنة بين أنسال كل مجموعة على حده وتم الحصول على عشيرتين جديدتين (Giza 2-LN و Giza 2-HN) وفى الموسم المتأخر لعام 2006 تم زراعة هاتين العشيرتين فى حقلين معزولين وتركت نباتات كل منهما للتزاوج عشوائياً للوصول إلى الاتزان الوراثى وتم حصاد بذور كل عشيرة على حده . وفى موسم 2007 تم تقييم العشيرتين الجديدتين مع عشيرة الأساس (جيزة-2) تحت ظروف كل من البيئتين (النيتروجين العالى والنيتروجين المنخفض) . كانت أهداف الدراسة هى: تقدير فعالية الانتخاب عن طريق مقارنة التحسين الفعلي بالتحسين المتوقع بناء على تقديرات التباين وكفاءة التوريث فى أنسال الجيل الذاتى الأول وتحديد معايير تصفية بديلة سريعة وغير مكلفة ودقيقة لانتخاب تراكيب وراثية ذات كفاءة عالية في استخدام النيتروجين. أشارت النتائج إلى وجود تباين وراثى كبير بين أنسال الجيل الذاتى الأول لمعظم الصفات المدروسة تحت كلا من ظروف البيئتين . كانت كفاءة التوريث بمعناها العام أعلى تحت ظروف النيتروجين المنخفض عنها تحت ظروف النيتروجين المرتفع (فى ثمانية من تسعة صفات) وأظهرت صفه كفاءة استخدام النيتروجين أعلى كفاءة توريث (81.99%) تحت ظروف النيتروجين المنخفض. كما أشارت النتائج إلى أن الانتخاب لقصر الفترة بين نثر اللقاح وخروج الحريرة ونقص درجة شيخوخة الأوراق يمكن أن يوصى بهما كمعيارين انتخابيين جيدين لزيادة كفاءة الانتخاب لتحمل `قص النيتروجين . أقترحت نتائج التحسين المتوقع بالانتخاب فى أنسال الجيل الذاتى الأول لصفة محصول الحبوب أن الانتخاب يعطى تحسيناً أفضل عندما يجرى تحت كل من ظروف نيتروجين التربة المنخفض والمرتفع. أظهرت نتائج الدراسة كذلك أن التحسين الحقيقى فى محصول الحبوب كان أعلى عندما أجري الانتخاب تحت ظروف كل من النيتروجين المنخفض و النيتروجين المرتفع فقد أعطت العشيرتان الجديدتان Giza2 LN و Giza 2-HN تفوقاً فى المحصول عن العشيرة الأصلية (جيزة-2) قدره 21.88% و 23.22تحت ظروف النيتروجين المنخفض، على التوالي. كان التحسين الحقيقى فى محصول الحبوب مصحوباً بتغيرات معنويه (مرغوبة) فى معظم الصفات غير المنتخبة المدروسة. أظهرتحليل الارتباطات الوراثية أن صفات الوزن الجاف لمحصول حبوب النبات والوزن الجاف الكلى للنبات والمحتوى الكلى للنيتروجين بالنبات هى أحسن المعايير للتنبؤ بصفات كفاءة استخدام الأزوت الاقتصادية والبيولوجية وكفاءة امتصاص النيتروجين من التربة. أظهرت كذلك صفة الوزن الجاف لمحصول حبوب النبات أنها معيارا بديلا جيدا لقياس كل صفات كفاءة استخدام النيتروجين.

النيتروجين المرتفع. كان التحسين الحقيقى فى محصول الحبوب مصحوباً بتغيرات معنويه (مرغوبة) فى معظم الصفات غير المنتخبة المدروسة (١٤ من ١٧ صفه). أظهرتحليل الارتباطات الوراثية أن صفات الوزن الجاف لمحصول حبوب النبات والوزن الجاف الكلى للنبات والمحتوى الكلى للنيتروجين بالنبات هى أحسن المعايير للتنبؤ بصفات كفاءة استخدام الأزوت الاقتصادية والبيولوجية وكفاءة امتصاص النيتروجين من التربة. أظهرت كذلك صفة الوزن الجاف لمحصول حبوب النبات أنها معيارا بديلا جيدا لقياس كل صفات كفاءة استخدام النيتروجين.

المجله المصريه لتربية النبات ١٢ (٢): ٢٥٥ – ٢٧٧ (٢٠٠٨)