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ALTERNATIVE SCREENING CRITERIA FOR SELECTING NITROGEN-USE EFFICIENT GENOTYPES OF MAIZE

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ABSTRACT

Developing nitrogen-use efficient (NUE) genotypes of maize (Zea mays L.*) could reduce crop N fertilizer requirement. However, determining N uptake and utilization efficiencies can be costly and time consuming. The main objective of this investigation was to evaluate alternative criteria for determining N-use efficiency traits in maize genotypes in an attempt to save time and reduce expenses in selection for N-use efficiency. The results showed that under low-N, genetic correlation coefficient (r_g) was significant, positive and very high in magnitude for economic nitrogen use efficiency (NUE_e) vs. grain dry matter (GDM) ($r_g = 1.00$), biological nitrogen efficiency (NUE_b) vs. total dry matter (TDM) ($r_g = 1.00$), nitrogen uptake efficiency (NUPE) vs. each of GDM ($r_g = 1.00$) and TDM ($r_g = 1.00$). Furthermore, the genetic correlation between plant nitrogen utilization efficiency ($NUTE_p$) and each of GDM and harvest index (HI) under low-N was positive and very strong ($r_g = 1.00$). A positive and significant r_g value was found between HI and nitrogen translocation efficiency (NTRE) (0.82). Therefore, grain dry matter, total dry matter and harvest index could be considered as good alternative screening criteria for NUE_e, NUPE, and NTRE (or $NUTE_p$) traits respectively. These results indicate that grain nitrogen content (GN) could also be used as an alternative selective criterion for measuring most nitrogen efficiency traits, especially under low-N conditions. Under low-N, broad–sense heritability (h^2_b) of the two alternative screening criteria: GN (88.84 %) and HI (77.65 %) was much higher than that of NUPE (30.44 %) and NTRE (50.82 %) or $NUTE_p$ (6.42 %) and that of GDM (80.60 %) was comparable to that of NUE_e (80.61 %). Results suggest that future research should focus on the incorporation of some secondary traits such as GN and GDM traits in the selection programs along with NUE_e trait in order to maximize the genetic gain from selection for improving NUE_e.*

Key words: *Zea mays, N-use efficiency, N-uptake, N-utilization, N-translocation, Low-N tolerance, Selection criteria, Heritability, Genetic advance.*

INTRODUCTION

Low soil nitrogen is among the major abiotic stresses threatening maize production and limiting food security and economic growth (Banziger and Diallo 2001). The incidence of low-N stress may increase, due partly to global climate changes, declines in soil organic matter and reduction in soil fertility and water holding capacity (Banziger *et al* 2000). One approach to reducing the impact of N deficiency on maize production may be to select cultivars that are superior in N-use efficiency, either due to enhanced uptake capacity or because of more efficient use of absorbed N in grain production (Lafitte and Edmeades 1994).

Nitrogen-use efficiency has been described in various ways, but these definitions generally describe two types of efficiency, either uptake efficiency or utilization efficiency. Nitrogen uptake efficiency (NUEP) has been defined as total plant nitrogen content per unit N available in the soil. Nitrogen utilization efficiency (NUTE) was described by Siddiqi and Glass (1981) as the grain production per unit N concentration in the plant. Maranville *et al* (1980) defined biomass production (total aboveground dry matter) per unit plant nitrogen as NE1, and grain production (grain dry weight) per unit plant N as NE2. In soils with limited available N, utilization efficiency has been found to be more important than uptake efficiency in contributing to genotypic differences in grain production (Van Sanford and MacKown 1986). Utilization efficiency coupled with economic yield is a desired characteristic in crop plants if minimum depletion of soil N is a goal. Moll *et al* (1982) recommended the development of genotypes with both high uptake and high utilization efficiencies.

Determining N uptake and utilization efficiencies of maize crop can be costly and time consuming. Whole plant samples must be ground and analyzed for N content. When hundreds or even thousands of individuals or treatments need to be evaluated, it may be difficult to obtain the necessary data for determining selections in due time for the next season. Therefore, the objectives of the present study were to evaluate alternative criteria for determining N-use efficiency in maize genotypes in an attempt to save time and reduce expenses in selection for N-use efficiency and estimate heritability and expected genetic advance from selection for such criteria.

MATERIALS AND METHODS

In order to determine the reliability of alternative criteria, data from 28 maize hybrids and populations were evaluated in 2009 and 2010 seasons at the Experimental Station of the Faculty of Agriculture, Cairo University, Giza, Egypt. Seeds of the 28 cultivars and populations of maize were sown under two nitrogen levels, i.e. high-N by adding 120 Kg N /fed in two equal doses in the form of urea (46.5 % N) before 1st and 2nd irrigations and low-N where no N fertilizer was applied. Available soil nitrogen (N_s) was analyzed immediately before sowing and found to be 3.949 and 4.200 g N / plant under low-N and 8.949 and 9.200 g N / plant under high-N in 2009 and 2010 season, respectively. The soil of the experimental site was clayey loam. A split-plot design with randomized complete blocks arrangement in three replications was used. Main plots were devoted to nitrogen levels (high-N and low-N) and sub-plots were assigned to the 28 genotypes. Each sub-plot consisted of two ridges of 3 m length and 0.7 m width, i.e. the experimental plot area was 4.2 m^2. Each main plot was surrounded with a wide ridge (1.5 m width) to avoid interference between the two N treatments. Sowing date was April 30 in the 1st season and April 4 in the 2nd one. Seeds over sown in hills at 25 cm apart, thereafter (before the 1st irrigation) were thinned to one plant/hill.

The following traits were measured: number of ears per plant (EPP), number of kernels per plant (KPP), 100-kernel weight (100KW) (g) and grain yield per plant (GYPP) (g). At physiological maturity, three random guarded plants were removed from each plot by cutting at the soil surface. The plants were bulked as one sample per plot. These plants were separated into leaf blades, stalks (including leaf sheathes + tassels) and grains. Samples were dried at 70 °C to a constant weight and each part was weighed separately. The following traits were recorded: grain dry matter (GDM) (g), total above ground dry matter plant^{-1} (TDM) (g), harvest index (HI) (%) as 100 × (GDM/TDM), economic nitrogen use efficiency (NUE$_e$) (g/g) as GDM/N$_s$ and biological nitrogen use efficiency (NUE$_b$) (g/g) as TDM/N$_s$.

Dried samples were ground and used to determine nitrogen concentration % and nitrogen content in mg of each fraction. Nitrogen determination was carried out at the Laboratory of Micro-elements, at the National Research Center, using Kjeldahl method to determine N concentration % according to A.O.A.C (1990). N content (mg) of each part was calculated by multiplying % N concentration by dry matter weight of each individual plant part i.e. N content (mg) of leaves (LN), N content (mg) of stem (SN), and N content (mg) of grains (GN). The following N parameters were estimated: grain nitrogen content (GN) (mg), total plant nitrogen content (TN) (mg), nitrogen uptake efficiency (NUPE) (%) as 100 × (TN/N$_s$), nitrogen translocation efficiency (NTRE) (%) as 100 × (GN/TN), plant nitrogen utilization efficiency (NUTE$_p$) (g/g) as GDM/TN, grain nitrogen utilization efficiency (NUTE$_g$) (g/g) as GDM/GN and biomass nitrogen utilization efficiency (NUTE$_b$) (g/g) as TDM/TN. Nitrogen efficiency parameters were estimated according to Moll *et al* (1982).

Combined analysis of variance across the two years of study was performed if the homogeneity test was non-significant and LSD values were calculated and used to test the significance of differences between means according to Snedecor and Cochran (1989). Each main plot (N levels) was analyzed across years to determine the genotypic and phenotypic variance, using expected mean squares from the respective ANOVA table according to Hallauer and Miranda (1988).

Heritability (%) in the broad sense (h^2_b) was estimated according to Singh and Chaudhary (2000) using the formula $h^2_b \% = 100 \times (\delta^2_g / \delta^2_p)$. The coefficient of genotypic correlation (r_g) was calculated between each pair of studied traits under each environment (high- or low-N) according to Singh and Chaudhary (2000) using the following formula: $r_g = \delta^2_{gxy} / (\delta^2_{gx} . \delta^2_{gy})^{1/2}$, where δ^2_{gxy} = the genotypic covariance of the two traits, X and Y, respectively and 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 each studied trait under each environment (high- or low-N) was also calculated according to Singh and Chaudhary (2000) as follows $GA = 100\ k\ h^2\ \delta_p / \bar{\chi}$, where $\bar{\chi}$ = general mean of the appropriate N level, δ_p = square root of the denominator of the appropriate heritability under N level, h^2 = the applied heritability and k = selection differential (k = 1.76, for 10 % selection intensity, used in this study). Indirect correlated response (CR_j) in NUE_e trait from selection in a secondary trait was estimated according to Falconer (1989) as $CR_j = 100\ i\ H^{½}_j\ H^{½}_k\ r_{gjk}\ \delta_p / \bar{\chi}_j$, where, CR_j = correlated response in NUE_e j, $H^{½}_j$ and $H^{½}_k$ = square roots of heritabilities of traits j and k, respectively, r_{gjk} = genetic correlation among traits j and k and $\bar{\chi}_j$ = general mean of NUE_e.

RESULTS AND DISCUSSION

Analysis of variance

Analysis of variance for 28 maize hybrids and populations evaluated under high- and low- nitrogen conditions combined across years (data not presented) showed that mean squares due to N levels for all studied characters were significant ($p \leq 0.01$), indicating that low- N has an obvious effect on all studied traits. Mean squares due to maize genotypes were highly significant for all studied traits, indicating presence of genetic differences among studied hybrids and populations for all studied characters under both high- and low- N levels. Mean squares due to genotypes × N levels interaction were highly significant for all studied traits, suggesting that genotypes behaved differently under different N supply conditions and the possibility of selection for improved performance under a specific soil nitrogen environment, as proposed by Al-Naggar *at al* (2006 and 2009). Mean squares due to genotypes × years interaction were significant ($p \leq 0.01$) for all studied traits, except for 100KW, indicating that genotypes vary with years for most studied traits. Moreover, mean squares due to genotypes × N levels × years were significant ($p \leq 0.01$) for all studied traits, except for EPP and 100KW, suggesting that performance of maize genotypes vary with years and nitrogen supply for such traits, confirming previous results (Presterl *et al* 2003).

Means and ranges

A comparative summary of means and ranges of all studied traits across years and genotypes subjected to low- and high-N conditions is presented in Table (1). Mean grain yield / plant (GYPP) was significantly decreased due to low-N by 48.59 %. Consistent to these results, reduction in grain yield due to N stress was reported by several investigators (Bertin and

Gallais 2000 and Presterl *et al* 2003). Reduction in grain yield / plant due to low-N could by attributed to reductions in number of ears / plant (EPP), number of kernels / plant (KPP) and 100-kernel weight (100KW), i.e. all yield components. Reductions in yield components caused by low-N were maximum (37.23 %) for kernels / plant and minimum (13.30 %) for 100-kernel weight. This indicates that number of kernels / plant is the most determinating component of grain yield / plant under low-N. These results are in full agreement with those reported by Al-Naggar *et al* (2009).

Moreover, low-N caused a highly significant reduction in all dry matter traits, i.e. GDM (48.59 %), TDM (35.68 %) and HI (19.25 %), all nitrogen content traits, i.e. GN (65.87 %) and TN (61.08 %) and the nitrogen efficiency traits NUPE (13.50 %) and NTRE (12.08 %). In this respect, Sinclair and Horie (1989), Muchow and Sinclair (1994), Al-Naggar *et al* (2008 and 2009) and Atta (2009) found that low-N limits crop dry matter and grain yield potential.

Table 1. Summary of means and ranges of studied traits for 28 maize cultivars and populations under high- and low-N conditions combined across the two years.

Trait	Mean			Range		$LSD_{0.05}$		
	Hi-N	Lo-N	Red %	High-N	Low-N	G	N	G×N
GYPP (g)	118.5	60.94	48.59	64.2-162.5	33.16-96.66	6.2	1.7	8.7
EPP	1.07	0.85	20.56	1.00-1.57	0.69-1.00	0.05	0.01	0.08
KPP	601	377	37.23	400.6-942.3	194.3 -538.8	30.5	8.1	43.1
100KW (g)	29.93	25.95	13.30	24.00-35.85	19.87-32.68	0.3	0.09	0.5
GDM (g)	100.1	51.49	48.59	54.3-137.3	28.02-81.67	5.2	1.4	7.4
TDM (g)	238.5	153.4	35.68	163.8-329.6	95.7-217.2	10.2	2.7	14.5
HI (%)	41.61	33.6	19.25	27.46-58.24	24.56-45.96	2.2	0.6	3.05
GN (mg)	1450	494	65.87	559-2594	130-1070	82.1	21.9	116.2
TN (mg)	2874	1118	61.08	1431-4269	635-1763	113.8	30.4	160.9
NUE_e (g/g)	11.04	12.61	-14.22	5.97-15.14	6.86-20.02	0.8	0.2	1.2
NUE_b (g/g)	26.29	37.64	-43.17	18.05-36.32	23.46-53.31	1.8	0.5	2.5
NUPE (%)	31.71	27.43	13.50	15.71-47.19	15.84-43.6	1.6	0.4	2.3
$NUTE_p$ (g/g)	36.67	47.85	-30.49	26.14-58.62	34.47-70.24	2.4	0.7	3.4
$NUTE_g$ (g/g)	79.35	119.2	-50.26	49.4-147.6	73.8-259.2	0.01	0.04	0.01
$NUTE_b$ (g/g)	89.05	144.9	-62.73	65.2-139.4	108.9-193.5	2.7	0.7	3.6
NTRE (%)	49.16	43.22	12.08	26.71-67.51	19.51-58.49	2.3	0.6	3.2

Red = Reduction = 100 × (High-N – Low-N) / High-N, N = Nitrogen levels, G = Genotypes, Hi-N = High-N and Lo-N = Low-N.

On the contrary, low-N stress caused increases in the means of the 28 maize genotypes for NUE_e (14.22 %), NUE_b, (43.17 %), $NUTE_p$ (30.49 %), $NUTE_g$ (50.26 %) and $NUTE_b$ (62.73 %) (Table 1). It is believed that under low-N conditions, maize plants are forced to improve their NUE ability as a means of coping with N- stress conditions, though this increase differed from one genotype to another. In this respect, Anderson *et al* (1984), Pandey *et al* (2001), Al-Naggar *et al* (2008 and 2009) and Atta (2009), reported that NUE increased as soil-N decreased. It is interesting to mention that reductions in means of the 28 maize genotypes due to low-N were accompanied by reductions (narrowness) in their ranges for grain yield $plant^{-1}$ and all yield components, except 100KW all dry matter and nitrogen content traits and NTRE trait. On the other hand, increases in means of the studied maize genotypes due to N-stress were accompanied by increases (broadness) in their ranges for the nitrogen efficiency traits NUE_e, NUPE, $NUTE_p$, $NUTE_g$ and $NUTE_b$ and the yield trait 100 KW. Broadness of ranges of these traits under low-N conditions is beneficial for maize breeder in order to achieve more efficient selection for improving such traits.

Alternative screening criteria for N efficiency traits

Genetic correlation coefficients (r_g) between N efficiency traits (NUE_e, NUE_b, NUPE, $NUTE_p$, $NUTE_g$, $NUTE_b$ and NTRE) and dry matter traits (GDM, TDM and HI) under both high- and low-N across years are presented in Table (2). When soil N is constant, NUE_e and NUF_b traits are expected to be determined by measuring GDM and TDM, respectively. Consistent with expectations, r_g was significant, positive and very high in magnitude (1.00) for NUE_e *vs.* GDM and NUE_b *vs.* TDM under both high- and low-N. This indicates that grain dry matter (GDM) and total plant dry matter (TDM) could be considered as good alternative screening criteria for economic nitrogen use efficiency (NUE_e) and biological nitrogen efficiency (NUE_b), respectively.

Moreover, a very high, positive and significant, r_g value was found between harvest index and NTRE (0.82) suggesting that HI is a good selection criterion for nitrogen translocation efficiency. Furthermore, the genetic correlation between plant nitrogen utilization efficiency ($NUTE_p$) and each of GDM, and HI under low-N was positive and very strong (r_g = 1.00), indicating that grain dry matter and harvest index could be suggested as alternative criteria for $NUTE_p$. Moreover, under low-N, a very high positive and significant r_g estimate (1.00) was obtained between NUPE and each of GDM and TDM, suggesting that any of grain and total dry matter traits could be used as a good selective criterion for measuring N uptake efficiency trait. A very high and significant positive r_g estimate was also found between NUE_e, and GN under both N levels, suggesting that grain nitrogen is a good predictor of genotypic performance for economic

Table 2. Genetic correlation coefficients (r_g) between nitrogen efficiency traits and selective alternative criteria in maize (n=168).

Trait	Alternative criteria			
	GN	GDM	TDM	HI
		High-N		
TN	0.89†	0.89†	0.98†	0.46†
NUE$_e$	1.00†	1.00†	0.80†	0.82†
NUE$_b$	0.91†	0.80†	1.00†	0.31
NUPE	0.89†	0.90†	0.98†	0.46†
NUTE$_p$	0.48†	0.34	-0.19	0.76†
NUTE$_g$	-0.29	-0.45	-0.46†	-0.14
NUTE$_b$	-0.57†	-0.78†	-0.75†	-0.50†
NTRE	0.60†	0.70†	0.22	0.89†
		Low-N		
TN	0.76†	1.00†	0.78†	0.20
NUE$_e$	1.00†	1.00†	0.70†	0.63†
NUE$_b$	0.82†	0.69†	1.00†	-0.11
NUPE	0.76†	1.00†	1.00†	0.21
NUTE$_p$	1.00†	1.00†	-0.16	1.00†
NUTE$_g$	-0.51†	-0.78†	-0.54†	-0.60†
NUTE$_b$	0.71†	-0.78†	0.55†	0.67†
NTRE	0.79†	0.70†	0.17	0.82†

†Estimate exceeds twice its standard error.

nitrogen use efficiency. Under low-N, grain dry matter could be considered as a good predictor of TN (r_g = 1.00†), NUE$_e$ (r_g = 1.00†), NUPE (r_g = 1.00†), NUTE$_p$ (r_g = 1.00†), NUTE$_g$ (r_g = - 0.78†), NUTE$_p$ (r_g = - 0.78†),

NTRE (r_g = 0.70†) and NUE$_b$ (r_g = 0.69†), i.e. all studied nitrogen efficiency traits. Total dry matter came in the second rank after grain dry matter, as a good predictor of N efficiency traits, since it showed significant r_g estimates with TN (0.78), NUE$_b$ (1.00) NUPE (1.00), NUE$_e$ (0.70), NUTE$_g$ (-0.54) and NUTE$_b$ (0.55). These conclusions are consistent with Youngquist *et al* (1992) in sorghum and Al-Naggar *et al* (2009) in maize. Analyzing grain or total 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 selection. Alagarswamy and

Seetharama (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 permits a fair level of confidence in making final selections. It is interesting to mention that grain nitrogen content (GN) especially under low-N showed a significant r_g estimate with each of NUE_e (1.00), $NUTE_p$ (1.00), NUE_b (0.82), NTRE (0.79), NUPE (0.76) and $NUTE_b$ (0.71), i.e. with almost all studied N efficiency traits (Table 2). These results indicate that grain nitrogen content could also be used as an alternative selective criterion for measuring most nitrogen efficiency traits, especially under low-N conditions.

Heritability

Under low-N, broad-sense heritability (h^2_b) of the alternative screening criteria TDM (88.84 %) and HI (77.65 %) was much higher than that of NUPE (30.44 %) and NTRE (50.82 %) or $NUTE_p$ (6.42 %) and that of GDM (80.60 %) was comparable to that of NUE_e (80.6 %) (Table 3). The same trend of higher h^2_b values of alternative criteria than those of N-use efficiency traits was also observed under high-N conditions. It is obvious from the results that h^2_b estimates are generally higher under high-N than those under low-N conditions; 8 out of 12 studied traits showed higher h^2_b under high-N as compared to low-N. Similar to these results, some researchers found a decrease in heritability under stressed environments (Frey, 1964, Subandi and Compton 1974, Ordas and Stucker 1977, Shabana *et al* 1980 and Asay and Johnson 1990). Others reported that genetic variance and consequently heritability was increased in stressful environments (Russell 1969, Stuper and Moll 1977, Richards 1982, Troyer and Rosenbrook 1983, Laffitte and Edmeades 1994 and Al- Naggar *et al* 2009). Low heritability (h^2_b) estimates for $NUTE_p$, $NUTE_g$ and $NUTE_b$, i.e. all nitrogen utilization efficiency traits under both high- and low-N conditions, could be attributed to the small genotypic variance or the large genotype × year interaction variances as reported by Hamblin *et al* (1980) and Smith *et al* (1990).

Table 3. Heritability (%) in the broad sense (h^2_b) and expected genetic gain (GA %) from direct selection for N-use efficiency and alternative traits of maize under low- and high-N conditions (data are combined across two years).

Trait	h^2_b%		GA %	
	High-N	Low-N	High-N	Low-N
GDM	86.75	80.60	41.60	39.88
TDM	87.19	88.84	26.06	33.03
HI	84.93	77.65	27.55	26.43
GN	40.22	31.22	32.44	27.12
TN	56.27	31.80	32.26	17.89
NUE$_e$	86.78	80.61	41.61	39.98
NUE$_b$	86.98	88.44	26.03	32.99
NUPE	55.28	30.44	31.95	17.53
NUTE$_p$	24.42	6.42	13.09	2.85
NUTE$_g$	7.91	12.43	5.67	9.08
NUTE$_b$	17.57	6.42	8.44	2.76
NTRE	35.67	50.82	15.08	23.70

Predicted selection gain

Direct selection

Genetic advance from direct selection in each environment reached its maximum value under high-N environment for eight traits, i.e. GDM, HI, GN, TN, NUE$_e$, NUPE, NUTE$_p$ and NUTE$_b$ and under low-N for 4 traits, i.e. TDM, NUE$_b$, NUTE$_g$ and NTRE, mainly due to high heritability for these traits observed under the respective environments (Table 3). It was noticed, however, that a trait such as grain dry matter (GDM) could be more important as a secondary trait than total dry matter (TDM). The GDM trait showed similar h^2_b values to that of TDM trait under high-N (86.75 *vs.* 87.19 %). But, GDM revealed very high GA % compared with TDM. Besides, although under low-N TDM showed a relatively higher h^2_b (88.84 %) than GDM (80.60 %), GDM revealed higher genetic advance than TDM (39.88 *vs.* 33.03 %). According to Panse (1957) if the heritability is mainly due to the non-additive gene effects (dominance and epistasis) the genetic gain would be low. By contrast, in case where heritability is mainly due to the additive gene effects, a high genetic advance may be expected. Thus, GDM would show higher response to selection than TDM.

Indirect selection (Secondary traits *vs.* NUE$_e$)

Increases NUE$_e$ *via* selection for secondary traits (GDM, TDM, HI, GN, NUE$_b$, NUPE and NTRE) were calculated and presented in Table (4). Direct selection for NUE$_e$ was more efficient than the predicted genetic advance from indirect selection for secondary traits in most cases at

Table 4. Estimates of expected genetic gain from indirect (secondary trait *vs.* NUE_e) selection in maize under high- and low-N (data are combined across years).

Trait	Indirect selection gain (%) i.e. secondary traits *vs.* NUE_e			
	High-N		Low-N	
	Gain	RE (%)	Gain	RE (%)
GDM	41.60	100.01	39.97	100.24
TDM	20.80	49.99	21.71	54.43
HI	22.83	54.88	16.97	42.54
GN	47.64	114.52	43.57	109.25
NUE_b	20.80	50.00	21.73	54.49
NUPE	36.02	86.59	28.52	71.52
NTRE	16.46	39.56	20.90	52.40

RE = relative efficiency = (predicted gain from indirect selection / predicted gain from direct selection) × 100.

improving NUE_e. This conclusion is based on comparisons between predicted responses of improving NUE_e indirectly *via* a single secondary trait and directly *via* NUE_e by calculating the value of relative efficiency (RE %). These comparisons showed that direct selection for NUE_e was significantly superior to indirect selection *via* any single trait. Exceptions from the previous conclusion in this study indicated that indirect selection, i.e. responses of NUE_e to selection for a secondary trait was more efficient than direct selection for NUE_e for high grain nitrogen (GN) (RE = 114.52 % under high-N and 109.25 % under low-N) and was comparable to direct selection for NUE_e for high GDM (RE = 100.01 and 100.24 % under high- and low-N, respectively). It could therefore be concluded that secondary traits such as GN and GDM are valuable criteria in increasing the efficiency of selection for NUE_e under high- and low-N environments.

Selection for improved performance under low-N based on NUE_e alone has often been considered efficient, but the use of secondary traits can increase selection efficiency (Bolanos and Edmeades 1996). Plant 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 NUE_e and, consequently, grain yield under low-N, future research should focus on the incorporation of secondary traits such as grain nitrogen content and grain dry matter traits in the selection programs along with the NUE_e trait.

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معايير التصفية البديلة لإنتخاب تراكيب وراثية من الذرة الشامية ذات كفاءة استخدام نيتروجين عالية

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إن استنباط تراكيب وراثية من الذرة الشامية ذات كفاءة عالية في استخدام النيتروجين يؤدي لتقليل الإحتياجات السمادية النيتروجينية مع المحافظة على القدرة المحصولية العالية ، ولكن تقدير كفاءة امتصاص النيتروجين وكفاءة استغلاله من الممكن ان يكون مكلفاً ومستهلكاً للوقت وخصوصاً عند استخدام أعداد كبيرة من هذه التراكيب الوراثية تحت العديد من المعاملات. كان الهدف الرئيسي لهذه الدراسة هو تقييم معايير بديلة لتقدير صفات كفاءة استخدام النيتروجين في تراكيب وراثية من الذرة الشامية كمحاولة لتوفير الوقت وتقليل التكاليف عند الانتخاب لكفاءة استخدام النيتروجين. أظهرت البيانات أنه تحت ظروف النيتروجين المنخفض كان معامل الإرتباط الوراثي معنوياً وموجباً وعالياً في المقدار بالنسبة لكفاءة استخدام النيتروجين الاقتصادية مقابل وزن المادة الجافة للحبوب

($r_g = 1.00$) وكفاءة امتصاص النيتروجين مقابل كل من وزن المادة الجافة للحبوب ($r_g = 1.00$) ووزن المادة الجافة للنبات ككل ($r_g = 1.00$) و الكفاءة البيولوجية لاستخدام النيتروجين مقابل وزن المادة الجافة الكلية للنبات ($r_g = 1.00$). كما أن الإرتباط الوراثي بين كفاءة استغلال النيتروجين في النبات وكل من وزن المادة الجافة للحبوب ومعامل الحصاد تحت النيتروجين المنخفض كان موجباً و قويا ($r_g = 1.00$). و وجد معامل إرتباط موجب و معنوي بين معامل الحصاد وكفاءة انتقال النيتروجين ($r_g = 0.82$). لذلك من الممكن اعتبار أن وزن المادة الجافة للحبوب معيار تصفية بديل جيد لصفة الكفاء الاقتصادية كما أن وزن المادة الجافة الكلية للنبات يصلح كمعيار جيد بديل لكفاءة امتصاص النيتروجين و معامل الحصاد كمعيار بديل جيد لكل من كفاءة انتقال النيتروجين وكفاءة استغلاله. دلت النتائج على أن محتوى الحبوب من النيتروجين يمكن أن يستخدم كمعيار تصفية انتخابي لقياس صفات كفاءة استخدام النيتروجين خصوصاً تحت ظروف النيتروجين المنخفض. كانت قيم كفاة التوريث بالمعنى العام للمعايير الإنتخابية البديلة: وزن المادة الجافة للنبات ككل (88.84 %) معامل الحصاد (77.65 %) أعلى كثيراً من تلك القيم لصفات كفاءة امتصاص النيتروجين (20.44 %) و كفاءة انتقال النيتروجين (50.82%) وكفاءة استغلاله (6.42 %) وكانت قيم كفاءة التوريث لوزن المادة الجافة للحبوب (80.60 %) مساوية تقريباً للكفاءة الاقتصادية لاستخدام النيتروجين (80.61 %). تقترح نتائج هذه الدراسة أنه يجب التركيز في الأبحاث المستقبلية على إدخال صفات ثانوية مثل محتوى نيتروجين الحبوب و وزن المادة الجافة للحبوب في برامج الإنتخاب إلى جانب صفة الكفاءة الاقتصادية لاستخدام النيتروجين حتى يمكن تعظيم التحسين الوراثي من الإنتخاب لتحسين الكفاءة الاقتصايية لاستخدام النيتروجين