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QUANTITATIVE GENETIC PARAMETERS OF GRAIN SORGHUM TRAITS CONTRIBUTING TO LOW-N TOLERANCE

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ABSTRACT

Four grain sorghum restorer lines (two tolerant and two sensitive to low-N) were crossed onto four cms lines (one tolerant and three sensitive) to obtain 16 F_1 fertile hybrids in 2003 season. Field evaluation of the 24 genotypes was conducted at Sids under high and low-N in 2004 season. The main objectives were to study the genotypic differences in nitrogen use efficiency traits and estimate quatitative genetic parameters for such traits. Mean squares due to genotypes, N levels and genotypes X N levels interactions were highly significant for all studied traits. Low-N stress (no fertilizer applied) caused a significant reduction in grain yield (dry matter)/plant (DM_g) of 17.9 and 15.2% for parental lines and their F_1's, respectively. This reduction was associated with reductions in dry matter weight of leaves (DM_l), stems (DM_{st}), and whole plant (DM_t). Economic (NUE_e) and biological (NUE_b) nitrogen use efficiency, nitrogen translocation efficiency (NTRE), nitrogen uptake efficiency (NUPE), plant, grain and biomass nitrogen utilization efficiency ($NUTE_p$, $NUTE_g$ and $NUTE_b$, respectively) and harvest index (HI) were significantly increased due to low-N . The lines B-91003, R-93002 and RTX-86 and the crosses A-1 X R-89022, A-47 X R-90001 and A-91003 X RTX-86 showed maximum low-N tolerance. Under low-N, DM_g was superior for tolerant (T) than susceptible (S) lines and F_1's by 56. 2 and 40. 2%, respectively, while NUE_e, NUE_b, grain, leaf, stem and total plant nitrogen (N_g, N_l, N_{st}, N_t, respectively) NUPE, DM_l, DM_{st}, DM_t and HI were significantly higher in T than in S genotypes. DM_g, DM_t and HI were the best predictors of NUE_e, NUE_b and NTRE, respectively. Moreover, N_g and N_t were the best predictors for any of NUPE, $NUTE_p$, $NUTE_g$ or $NUTE_b$ traits. Both general (GCA) and specific (SCA) combining ability effects were highly significant for all traits under both low- and high-N. Contribution of the SCA variance to the total variation was greater than that due to GCA variance for 9 traits (NUE_e, NUE_b, N_g, N_l, N_t, NUPE, DM_g, DM_l and DM_t) under low-N. The best parents for GCA effects and the best crosses for SCA effects and heterobeltiosis under low and high N were identified.Heterobeltiosis differed between studied traits, with the highest average shown by Ng (75.2% under low N) . Under N-stress , dominance (δ^2_D) was greater than additive(δ^2_A) variance for 12 traits and the opposite was true for the remaining 8 traits. The type of dominance prevailing in F_1's under N-stress was overdominance for 12 traits, complete dominance for 2 traits and partial dominance for 6 traits. Heritability

in narrow-sense estimates ranged from zero (NUE$_e$, NUE$_b$, DM$_l$, DM$_g$ and DM$_t$) to 84.8% (NUTE$_b$) under low-N. Better progress from direct selection is expected to be realized under low-N than under high-N for improving N$_g$, N$_b$, NTRE, NUPE, NUTE$_p$, NUTE$_g$, NUTE$_b$ and HI, i.e for most traits contributing to low-N tolerance.

Key words :***Grain sorghum, Sorghum bicolor, Nitrogen use efficiency NUE, Nitrogen uptake efficiency NUPE, Nitrogen utilization efficiency NUTE, Harvest index HI, Low-N tolerance, Genetic parameters*** .

INTRODUCTION

Nitrogen is the most important nutritive element for the production of cereals including grain sorghum (*Sorghum bicolor* L. Moench). It is mostly supplied to the soil in the form of inorganic fertilizers. A considerable portion of fertilizer N is lost through gaseous plant emissions; soil denitrification, surface runoff, ammonia volatilization, and leaching that may lead to ground water contamination (Raun and Johnson 1999). In contrast, the rates of N fertilizers in most developing countries are considerably low because of the limited access to fertilizers and the low purchasing power of small farmers due to a high fertilizer/cereal grain price ratio. The limited use of N fertilizer in many developing countries results in much cereals especially grain sorghum being grown in N – deficient soils producing considerably low yields. There is, therefore, a need to have grain sorghum plants that will use fertilizer and soil N more efficiently for grain production. Nitrogen-use efficiency (NUE) has been described in various ways, but these definitions generally describe two types of efficiency, either uptake efficiency or utilization efficiency (Youngquist *et al* 1992).

Genotypic differences in N-uptake, N partitioning and N use efficiency have been reported for several crops including corn (Bruetsch and Estes 1976, Chevalier and Schrader 1977, Moll *et al* 1982 and Hageman and Below 1984), pearl millet Alagarswamy and Bidinger 1987 and Alagarswamy *et al* 1988), bread wheat (Desai and Bhatia 1978) and grain sorghum (Maranville *et al* 1980, Onken *et al* 1985 and Gardner *et al* 1994). Producing new cultivars through selective breeding that can yield adequately with limited soil N seems possible (Atlin and Frey 1990). Effective improvement in obtaining more yield from any incremen of applied nitrogen (N), or in sustaining more productivity at moderate to extreme soil N stresses, can occur through breeding most rapidly if metabolic /physiological processes of N use efficiency are understood (Maranville and Madhavan 2002). Knowledge of agronomic and physiological factors that contribute to improved NUE in sorghum is limited (Buah *et al* 1998). Further studies are therefore needed in sorghum genotypes to determine their mechanisms of coping with limited supplies of N. Moreover, to the best of our knowledge no information in the literature are available on the type of gene action, combining ability and heterosis for tolerance to low–N stress in sorghum.

Determining N uptake and utilization efficiencies of crops can be costly and time consuming. When hundreds or thousands of individuals need to be evaluated, it may be difficult to obtain the necessary data for determining selections in time for the next season. By substituting an alternative criterion in ranking nitrogen efficient genotypes in sorghum breeding programs, substantial saving in time and resources with a fair level of confidence in the selections could be realized.

The objectives of the present investigation were to: (i) examine the differences among sorghum genotypes in nitrogen use efficiency, (ii) to evaluate alternative screening criteria for selecting nitrogen use-efficient genotypes and (iii) to estimate quantitative genetic parameters to design and optimize breeding programs for cultivars with improved N-use efficiency.

MATERIALS AND METHODS

Eight grain sorghum lines were selected out of fourty eight lines to be used as parents of this study based on their divergence in absolute and relative yields and visual performances under low-N (stress) and non-stress environments in a preliminary experiment conducted at two locations (South Tahrir and Sids Agric. Res. St. , ARC) in 2002 season ; three parents were tolerant and 5 were not.The lines consisted of 4 cytoplasmic male sterile (cms) and 4 male fertile restorer lines. The pedigree, origin and status of the parental lines are presented in Table (1).

Table 1. Parental lines of grain sorghum used in this study

No.	Pedigree	Designation	Origin	Tolerance to low-N
	Male sterile (cms) lines			
1	ICSB-1	(1)	ICRISAT	S
2	ICSB-47	(2)	ICRISAT	S
3	ICSB-88005	(3)	ICRISAT	T
4	ICSB-91003	(4)	ICRISAT	T
	Restorer (R) lines			
5	ICSR-89022	(5)	ICRISAT	S
6	ICSR-90001	(6)	ICRISAT	S
7	ICSR-93002	(7)	ICRISAT	S
8	RTX-86-EO-361 (sis)	(8)	Texas	T

T=tolerant S= sensitive Texas= Texas A&M Univerisity,U. S. A.
ICRISAT= International Crop Research Institute for Semi-Arid Tropics-India

The selected 8 parents were sown on the 25 th of June, 2003 at Giza Agric. Res. Station, FCRI, ARC. Each line was grown in two ridges of 5 meters long and 70 cm width. The four restorers (R-lines) were crossed onto the four A-lines to make 16 F_1 fertile hybrids. The seeds of the 8 parent lines (B and R lines) were also increased in 2003 season by selfing.

In 2004 season, evaluations of 24 genotypes (8 parents, 16 F_1's) were conducted at Sids under two N treatments (i. e non-stress and low N stress). Sowing was done on the 25 th of June at Sids. A split- plot design was used with 3 replications. The two N treatments were allotted to the main plots and the genotypes were devoted to sub –plots. Each experimental sub-plot consisted of one ridge of 5 meters long and 70 cm wide with a total area of 3.5 square meters. Sowing was done in hills of 20 cm apart along the ridges. Thinning was done before 1 st irrigation (i. e after 20 days from sowing) and two plants were left in each hill to reach a plant density of 60.000 plants/feddan. The recommended N fertilization (120 Kg N/fed.) in the form of granual ammonium nitrate (33. 5 % N) was added to the control. The N fertilizer was splitted into two doses; the first dose (one third of the N fertilizer) was added just before sowing irrigation, while the second dose (two thirds) was added just before the 1 st irrigation. The low-N stress treatment was conducted through non-applying of any nitrogen fertilizer. The previous crop was bread wheat (*Triticum aestivum* L.) preceded by corn (*Zea mays* L.) at Sids. The soil texture was clay-loam with pH of 7. 6 and organic matter of 1. 36%.

Immediately before N application, 30 random soil samples (from 0 to 15 cm depth) were collected in each replication of main plots and composited to determine N concentration at Sids. The amount of available nitrogen in Kg / feddan was then calculated and found to be 42. 45 Kg N / fed. Therefore, the available nitrogen in the soil (N_S) was 0.707 and 2.707 g N/plant for low-N stress and non-stress environments, respectively.

At physiological maturity stage, five random plants were removed from each sub-plot by cutting at the soil surface. The plants were bulked as one sample per sub-plot and separated into leaf blades, stalks and panicles (i. e demarcated by the lowest panicle branch) (stalks included leaf sheaths only). Samples were dried at 70 $^{\circ}$C in a forced-air oven for at least 72 hours and weighed. Panicle fractions from each sub-plot were threshed and seed sub-samples were weighed. Dry matter of each fraction (leaves, stalks and grains) per plant was recorded.

Samples of different dried aboveground plant fractions were ground and used to determine nitrogen concentration and nitrogen content of each fraction (g N plant part^{-1}). Nitrogen determination was caried out at the laboratory of Forage Research Section, FCRI, ARC. Kjeldahl method was used to determine N concentration; the catalyst being metallic mercury 0.1 g and 4 ml concentrated H_2SO_4. After clearing, digestion was continued for 3 h and titration was performed with 0. 01 N H_2SO_4 according to A.O. A.C. (1980). Total N content (g N plant part $^{-1}$) was calculated by adding N contents of aboveground plant fractions.

Data were collected on the following traits: 1- grain dry matter weight per plant (DM_g) in g, 2- leaves dry matter per plant (DM_l) in g, 3- stem dry matter per plant (DM_{st}) in g, 4 - total dry matter per plant (DM_t) in g, 5- dry matter partitioning to grains (harvest index, HI%)= DM_g / DM_t X 100, 6- dry matter partitioning to leaves (DMP_l%)= DM_l / DM_t X 100, 7- dry matter partitioning to stems (DMP_{st}%)=DM_{st} / DM_t X 100, 8- economic nitrogen use efficiency (NUE $_e$) according to Moll *et al* (1982) where: NUE $_e$= DM $_g$ / N_s, 9- biological nitrogen use efficiency (NUE_b) in g DM_t /g N_s at flowering stage according to Moll *et al* (1982) where: NUE $_b$ = DM $_t$ / N $_s$, 10 - nitrogen content in leaves/plant (N_l) in g, 11- nitrogen content in stems/plant (N_{st}) in g, 12- nitrogen content in grains / plant (N $_g$) in g, 13- total nitrogen content/plant (N_t) in g where: N_t= N_l+N_{st}+N_g, 14- nitrogen partitioning to leaves (NP_l) in % where:NP_l = (N_l / N_t) X 100, 15- nitrogen partitioning to stems (NP_{st}) in % where:NP_{st} = (N_{st} / N_t) X 100, 16- nitrogen translocation efficiency (NTRE) in % according to Moll *et al* (1987) where: NTRE = (N_g / N $_t$) X 100, 17- nitrogen uptake efficiency (NUPE) in % according to Moll *et al* (1982) where:NUPE = (N_t / N_s) X 100, 18- plant nitrogen utilization efficiency ($NUTE_P$) in g / g according to Moll *et al* (1982) where: $NUTE_P$ = DM_g / N_t, 19-grain nitrogen utilization efficiency ($NUTE_g$) in g/g according to Moll *et al* (1987) where: NUTE $_g$ =DM $_g$ / N $_g$ and 20- biomass nitrogen utilization efficiency ($NUTE_b$) in g/g according to Maranville *et al* (1980) where: $NUTE_b$ = DM $_t$ / N $_t$.

Data were subjected to a regular analysis of variance of a split plot design according to Federer (1963). Data of each treatment separately were further subjected to a normal analysis of variance of the randomized complete block design. Genotypes degrees of freedom were partitioned into parents, crosses and parents *vs* crosses. Line by tester analysis according to kempthorne (1957) was parcticed for each treatment, i. e non-stress and low nitrogen stress separately to estimate general and specific combining ability variances and effects. Additive and dominance variances were estimated according to Cockerham (1956).

Average degree of dominance " a" was calculated from the following equation "a" = $(2\ \delta^2_D / \delta^2_A)^{1/2}$ where δ^2_D = dominance variance, δ^2_A = additive variance, when "a" = 0 indicates no dominance, "a"< ± 1 indicates positive or negative partial dominance, "a"= ± 1 indicates positive or negative complete dominance and "a" > ± 1 indicates positive or negative overdominance. Narrow sense heritability (h_n^2) was calculated according to Hallauer and Miranda (1981). Expected genetic advance (GA) from selection was calculated according to Becker (1984) using 10 % selection intensity. Genetic correlation coefficients were calculated among pairs of all studied traits, under each nitrogen treatment.

RESULTS AND DISCUSSION

Analysis of variance

Data on analysis of variance (not presented) for all studied traits of 24 grain sorghum genotypes (4 females, 4 males and their 16 crosses) evaluated under two nitrogen levels (high-and low-N), revealed highly significant differences among genotypes and among nitrogen treatments. Mean squares due to genotypes X nitrogen treatments interaction were also highly significant for all studied traits, suggesting that these traits of sorghum genotypes vary with nitrogen supply. Separate analysis of variance under each nitrogen treatment showed also highly significant mean squares due to parents, F_1 crosses and parents vs F_1's for all studied traits under both high-and low-nitrogen environments.

Mean performance

A comparative summary of means and ranges of all studied traits for parental lines and F_1 hybrids under the two nitrogen levels is presented in Table (2). Mean grain yield/plant (in g dry matter) was significantly reduced because of low-N stress by 17.9 and 15.2 % for parents and F_1 hybrids, respectively. Grain yield dry matter under control ranged from 44. 8 to 71. 3 g/plant under high-N (non-stress) and from 73.0 to 66. 4 g/plant under low-N (stress) for parental lines and from 37. 0 to 104. 8 g/plant under high-N and from 62. 3 to 93. 2 g/plant under low-N for F_1 crosses.

As a result of low-N stress all dry matter (DM_g,DM_l, DM_{st} and DM_t) and nitrogen content (N_g, N_l, N_{st} and N_t) traits were significantly reduced, with the greatest decline shown by N_{st} (59. 6% for parents and 55. 4% for crosses) followed by DM_{st} (43. 8 and 47. 0% for parents and crosses, respectively). Reduction (%) in DM_g, N_g, N_l, N_{st} and N_t was greater in parents than in hybrids, indicating that the hybrids might accord higher tolerance to low-N stress than their parental lines for these traits.

Table 2. Summary of means and ranges (minimum and maximum) for studied traits of grain sorghum genotypes evaluated under high-and low-N environments and increase/decrease of low-N relative to high N (%) at Sids, 2004.

Trait	High-N (control)			Low-N (stress)			$LSD_{.05}$ N-levels	Increase / decrease (-) %
	Mean	Min.	Max.	Mean	Min.	Max.		
Parental lines								
NUE_e (g/g)	21. 7	16. 5 (6)	26. 4 (4)	68. 1	52. 6 (1)	93. 9 (4)	2. 22	213. 8
NUE_a (g/g)	40. 2	31. 6 (6)	49. 8 (3)	118. 1	97. 6 (1)	154. 7 (4)	4. 59	193. 8
N_g (mg)	712. 1	463. 6 (7)	1040. 9 (4)	492. 8	297. 4 (7)	734. 1 (4)	43. 80	(-30. 8)
N_l (mg)	249. 4	161. 8 (1)	368. 6 (4)	158. 6	94. 7 (7)	235. 1 (3)	16. 40	(-36. 4)
N_{st} (mg)	301. 6	173. 8 (7)	450. 1 (3)	120. 9	66. 7 (7)	194. 5 (4)	27. 30	(-59. 9)
N_t (mg)	1263	810. 6 (7)	1794. 1 (4)	772. 3	458. 8 (7)	1221. 2 (4)	46. 10	(-42. 0)
NP_l (%)	19. 7	17. 4 (1)	22. 5 (7)	20. 5	17. 2 (4)	22. 6 (5)	0. 67	4. 1
NP_{st} (%)	23. 9	22. 5 (4)	28. 8 (3)	15. 7	11. 3 (8)	21. 5 (5)	0. 93	(-34. 3)
NTRE (%)	56. 4	54. 7 (3)	58. 1 (4)	63. 8	55. 9 (5)	66. 7 (8)	1. 86	13. 1
NUPE (g/g)	0. 47	0. 30 (7)	0. 66 (4)	1. 1	0. 65 (7)	1. 59 (4)	0. 07	134. 0
$NUTE_p$ (g/g)	48. 4	39. 8 (4)	36. 7 (7)	65. 4	52. 9 (3)	90. 2 (7)	2. 76	34. 6
$NUTE_g$ (g/g)	85. 9	68. 5 (4)	111. 1 (7)	92. 7	80. 4 (3)	138. 8 (7)	5. 21	7. 9
NUTEb (g/g)	89. 9	71. 1 (4)	116. 1 (7)	114. 7	85. 8 (3)	155. 2 (7)	4. 22	27. 6
DM_g (g)	58. 7	44. 8 (6)	71. 3 (4)	48. 2	37. 2 (1)	66. 4 (4)	1. 56	(-17. 9)
DM_l (g)	22. 7	15. 3 (1)	28. 1 (8)	19. 9	16. 2 (1)	23. 2 (8)	0. 95	(-12. 3)
DM_{st} (g)	27. 4	21. 2 (7)	38. 3 (3)	15. 4	11. 9 (8)	21. 6 (4)	1. 05	(-43. 8)
DM_t (g)	108. 8	85. 5 (6)	134. 8 (3)	83. 5	69. 0 (1)	109. 4 (4)	2. 27	(-23. 2)
DMP_l (%)	20. 9	17. 4 (1)	22. 5 (7)	23. 8	19. 5 (4)	26. 8 (6)	0. 97	13. 9
DMP_{st} (%)	25. 2	2. 5 (4)	28. 8 (3)	18. 4	12. 9 (8)	24. 4 (5)	1. 01	(-26. 9)
HI (%)	54. 0	51. 4 (3)	56. 0 (1)	57. 8	50. 0 (5)	61. 9 (8)	1. 11	7. 0s
Crosses								
NUE_e (g/g)	32. 1	26. 9 (3X8)	38. 7 (1X5)	104. 4	88. 1 (3X8)	131. 8 (2X6)	2. 05	225. 2
NUE_a (g/g)	54. 1	44. 4 (3X8)	64. 6 (1X5)	159. 4	129 (3X8)	205. 5 (1X5)	4. 25	194. 6
N_g (mg)	139	1079 (2X6)	1965 (4X8)	1005	706 (1X7)	1510 (4X8)	40. 5	(-27. 6)
N_l (mg)	401	246 (1X7)	684 (4X8)	274	165 (2X6)	440 (4X8)	15. 2	(-31. 7)
N_{st} (mg)	457	241 (4X6)	634 (2X8)	204	116 (4X6)	350 (1X5)	25. 3	(-55. 4)
N_t (mg)	2247	1861 (4X7)	3154 (4X8)	1483	1149 (1X7)	2169 (4X8)	42. 6	(-34. 0)
NP_l (%)	18. 8	14. 1 (1X7)	24. 5 (4X7)	18. 5	14. 1 (2X6)	25. 4 (4X6)	0. 62	(-1. 6)
NP_{st} (%)	21. 8	12. 2 (4X6)	31. 5 (2X5)	13. 7	8. 8 (3X5)	22. 7 (1X7)	0. 86	(-37. 1)
NTRE (%)	59. 4	57. 6 (2X8)	66. 5 (4X6)	67. 8	61. 4 (1X7)	73. 8 (2X6)	1. 72	14. 1
NUPE (g/g)	0. 83	0. 69 (2 X5)	1. 17 (4X8)	2. 1	1. 6 (1X7)	3. 1 (4X8)	0. 06	153. 0
$NUTE_p$ (g/g)	39. 1	32. 7 (2X8)	44. 4 (1X7)	51. 2	38. 6 (4X8)	72. 2 (2X6)	2. 56	30. 9
$NUTE_g$ (g/g)	63. 2	52. 6 (4X8)	71. 4 (1X7)	76. 0	55. 4 (4X8)	97. 8 (2X6)	4. 82	20. 2
NUTEb (g/g)	65. 9	53. 7 (4X8)	76. 0 (1X7)	78. 4	57. 1 (4X8)	101. 3 (2X6)	3. 90	18. 9
DM_g (g)	87. 0	73. 0 (3X8)	104. 8 1X5)	73. 8	62. 3 (1X8)	93. 2 (2X6)	1. 45	(-15. 2)
DM_l (g)	27. 4	20. 5 (1X7)	38. 0 (4X8)	21. 9	18. 0 (3X8)	27. 8 (3X5)	0. 88	(-20. 1)
DM_{st} (g)	32. 1	17. 2 (4X6)	47. 8 (2X6)	17. 0	9. 7 (4X6)	29. 2 (1X5)	0. 98	(-47. 0)
DM_t (g)	146	120. 3 (3X8)	174.9(1X5)	112. 7	91. 1 (3X8)	145. 3 (1X5)	2. 1	(-23. 1)
DMP_l (%)	18. 7	14. 1 (1X7)	24. 5 (4X7)	19. 4	14. 1 (2X6)	25. 4 (4X6)	0. 82	3. 7
DMP_{st} (%)	21. 9	12. 2 (4X6)	31. 5 (2X5)	15. 1	8. 8 (3X5)	22. 7 (1X7)	0. 91	(-31. 0)
HI (%)	59. 4	53. 9 (2X5)	64. 1 (4X6)	65. 5	59. 4 (1X7)	71. 3 (2X6)	1. 02	10. 3

1=B-1, 2= B-47, 3= B-88005, 4= B-91003, 5= R-89022, 6=R-90001, 7=R-93002 and 8= RTX -86

On the other hand, all nitrogen use effeciency traits (NUE_e, NUE_b, NTRE, NUPE, $NUTE_p$, $NUTE_g$, $NUTE_b$, DMP_l and HI) increased significantly due to low-N stress by 213.8, 193.8, 13.1, 134.0, 34.6, 7.9, 27.6, 13.9 and 7.0 %, respectively for parents and 225.2, 194.6, 41.1, 153.0, 30.9, 20.2, 18.9, 3.7 and 10.3 %, respectively for hybrids (Table2). The highest increases due to low-N stress were exhibited by NUEe followed by NUE_b and NUPE traits. This is logic, since calculating these traits depends on available soil nitrogen content (Ns), which is much lower under N stress than under non-stress conditions. It is also interesting to mention that increases due to low-N stress were significantly higher in crosses than in parental lines for NUE_e,NTRE, $NUTE_g$ and HI, suggesting that hybrids were also more nitrogen use efficient than their parental lines.

Genotypic differences

When an advantage in both absolute value under stress and relative value to control was taken as an index of low-N tolerance, the parental lines B-91003, R-93002 and RTX-86 could be regarded as the most tolerant and B-1, R-89022, B-88005, B-47 and R-90001 could be regarded as the most susceptible parental lines (Table 2) as expected. The parent B-91003 was superior in NUEe, NUE_b, NUPE, N content (N_g, N_{st} and N_t) and dry matter (DM_g, DM_{st} and DM_t) traits. The parental line R-93002 was superior in the three nitrogen utilization efficiency traits ($NUTE_p$, $NUTE_g$ and $NUTE_b$). The parent RTX-86 was superior in nitrogen partioning (NTRE) and dry matter partitioning (HI) to grains. This indicates that tolerant lines of this study exhibited superiority by different mechanisms of low-N tolerance. The sensitive lines also exhibited different mechanisms, i. e B-1 exhibited the lowest estimates of NUE_e, NUE_b and all dry matter traits, B-88005 was the lowest for the 3 NUTE traits and R-89022 was the lowest for NTRE and HI (nitrogen and dry matter partitioning to grains, respectively).

Moreover, the crosses A-47 X R-90001, A-1 X R-89022 and A-91003 X RTX-86 could be considered the most low-N tolerant hybrids in this experiment. Mechanisms of superiority were NUE_e, NTRE, $NUTE_p$, $NUTE_g$, $NUTE_b$, DM_g and HI for A-47 X R-90001, NUPE, N_g, N_l and N_t for A-91003 X RTX-86 and NUE_b, DM_t, N_{st} and DMst for A-1 X R-89022. On the contrary, the crosses A-1 X R-93002, A-1 X RTX-86 and A-88005 X RTX-86 were the most-susceptible ones to low-N stress.

To describe the differences between low-N tolerant (T) and sensitive (S) sorghum genotypes, data were averaged for two groups of genotypes differing in low-N tolerance by definition, namly in both absolute and relative grain yield dry matter under stress (Table 3). The low-N tolerant genotypes were the 3 parental lines B-91003, R-93002 and RTX-86 and the 3 hybrids A-1 X R-89022, A-47 X R-90001 and A-91003 X RTX-86. The low-N susceptible genotypes were the 3 lines B-1, B-88005 and R-89022 and the3 hybrids A-1 X R-93002, A-1 X RTX-86 and A-88005 X RTX-86.

Grain yield (DM_g)/plant under low-N stress was superior for tolerant than for susceptible parental lines and F_1 crosses by 56.2 and 40.2 %, respectively. The advantage of T over S in grain yield dry matter under low-N stress would allow to expect greater N contents (N_g, N_l, N_{st} and N_t), dry matter contents (DM_g, DM_l, DM_{st} and DM_t) and NUE traits (NUE_e, NUE_b, NTRE, NUPE, $NUTE_b$, $NUTE_g$ and $NUTE_b$, and HI) in T than in S parental lines and F_1 crosses.

Consistent with expectation, under low-N stress, NUE_e, NUE_b, N_g, N_l, N_{st}, N_t, NUPE, DM_l, DM_{st}, DM_t and HI were significantly higher in T than in S by 56.3, 40.4, 108.8, 87.0, 57.8, 95.5, 94.9, 29.7, 12.2, 40.9 and 11.2 %, respectively in parental lines and 40.2, 33.8, 25.6, 20.8, 13.3, 22.9, 24.4, 25.5, 40.2, 33.8 and 4.7 % in F_1 crosses. On the other hand, nitrogen partitioning to leaves (NP_l) and stems (NP_{st}), dry matter partitioning to leaves (DMP_l) and to stems (DMP_{st}), nitrogen utilization efficiency traits $NUTE_p$, $NUTE_g$ and $NUTE_b$ were lower in T than in S parental lines by 4.7, 18.5, 22.4, 26.5, 29.9, 8.0 and 21.2 % under low-N stress. Moreover, under stress NP_l, NP_{st}, NTRE, DMP_l and DMP_{st} traits were lower in T than in S crosses by 4.4, 10.0, 3.6, 6.2 and 10.1%. Results in Table (3) indicated that superiority of T over S under low-N stress was more pronounced in the parental lines than their F_1 crosses for most studied traits, which could be attributed to the much lower mean estimates for susceptible lines as compared to susceptible F_1 crosses under low-N stress conditions.

Genotypic differences in N uptake, N partitioning and N use efficiency traits have also been demonstrated by several investigators for grain sorghum (Sinclair and de Wite 1975, Maranville *et al* 1980; Onken *et al* 1985, Youngquist and Maranville 1992, Gardner *et al* 1994, Borrell and Douglas 1997, Buah *et al* (1988), Traore and Maranville 1999, Nakamura *et al* 2002, Maranville and Madhavan 2002 and Maranville *et al* 2002).

Table 3. Nitogen and dry matter traits averaged over the 3 most tolerant and the 3 most susceptible parental lines and F_1 crosses.

Trait	Susceptible			Tolerant			Superiority% over susceptible
	High-N	Low-N	Deviation (fold)	High-N	Low-N	Deviation (fold)	
Parental lines							
NUE_a (g/g)	17.9	54.5	2.76	25.7	85.2	3.31	56.3
NUE_b (g/g)	32.9	98.9	3.01	48.3	138.9	2.87	40.4
N_g (mg)	496.7	339.3	-1.46	961.5	708.6	-1.36	108.8
N_l (mg)	169.3	116.0	-1.46	340.3	216.9	-1.57	87.0
N_{st} (mg)	209.6	94.3	-2.22	413.3	148.8	-2.78	57.8
N_t (mg)	875.6	549.6	-1.59	1715.1	1074.3	-1.59	95.5
NP_l (%)	19.5	21.2	1.08	19.8	20.3	1.03	(-4.7)
NP_{st} (%)	23.8	16.8	-1.42	24.2	13.7	-1.77	(-18.5)
NTRE (%)	56.7	62.1	1.09	56.1	66.0	1.18	6.3
NUPE (g/g)	0.3	0.8	2.44	0.63	1.52	2.41	94.9
$NUTE_p$ (g/g)	55.8	72.4	1.29	40.7	56.2	1.39	(-22.4)
$NUTE_g$ (g/g)	98.0	116.0	1.18	72.6	85.2	1.17	(-26.5)
NUTEb (g/g)	102.6	130.6	1.27	89.3	91.6	1.02	(-29.9)
DM_g (g)	48.5	38.6	-1.26	69.6	60.3	-1.15	56.2
DM_l (g)	18.3	17.5	-1.04	27.4	22.7	-1.22	29.7
DM_{st} (g)	22.2	13.9	-1.59	33.6	15.6	-2.19	12.2
DM_t (g)	89.0	70.0	-1.27	130.6	98.6	-1.32	40.9
DMP_l (%)	20.5	25.0	1.22	21.0	23.0	1.09	(-8.0)
DMP_{st} (%)	25.1	19.8	-1.27	25.6	15.6	-1.64	(-21.2)
HI (%)	54.4	55.2	1.01	53.4	61.4	1.80	11.2
Crosses							
NUE_a (g/g)	29.8	89.4	3.00	37.7	125.3	3.32	40.2
NUE_b (g/g)	50.4	140.9	2.79	63.6	188.5	2.96	33.8
N_g (mg)	1320.0	943.7	-1.39	1656.0	1185.3	-1.39	25.6
N_l (mg)	353.3	257.3	-1.37	472.6	310.7	-1.52	20.8
N_{st} (mg)	491.3	218.7	-2.25	542.7	247.7	-2.19	13.3
N_t (mg)	2165.3	1419.7	-1.52	2671.0	1743.3	-1.53	22.9
NP_l (%)	16.3	18.0	1.10	17.3	17.2	-1.01	(-4.4)
NP_{st} (%)	22.5	16.0	-1.41	20.7	14.4	-1.44	(-10.0)
NTRE (%)	61.2	66.0	1.08	62.0	68.4	1.10	(-3.6)
NUPE (g/g)	0.80	2.01	2.51	0.99	2.5	2.52	24.4
$NUTE_p$ (g/g)	37.7	45.6	1.21	38.8	53.7	1.34	17.8
$NUTE_g$ (g/g)	61.5	69.9	1.14	62.6	78.3	1.25	12.0
$NUTE_b$ (g/g)	33.0	17.2	-1.92	38.4	20.6	-1.86	19.8
DM_g (g)	80.6	63.2	-1.27	102.1	88.6	-1.15	40.2
DM_l (g)	22.9	19.2	-1.19	31.6	24.1	-1.31	25.5
DM_{st} (g)	33.0	17.2	-1.92	38.4	20.6	-1.86	19.8
DM_t (g)	136.5	99.6	-1.37	172.1	133.3	-1.29	33.8
DMP_l (%)	17.0	19.3	1.13	18.4	18.1	-1.02	(-6.2)
DMP_{st} (%)	23.8	16.9	-1.41	22.3	15.2	-1.47	(-10.1)
HI (%)	59.2	63.7	1.07	59.3	66.7	1.12	4.7

Maranville and Madhavan (2002) compared high NUE_b Chinese lines of sorghum with low NUE_b lines from U.S.A for their tolerance to an imposed N stress. They found that assimilation efficiency indices were significantly greater for the Chinese lines than the U.S.A. lines at both low and high soil nitrogen levels by about two-folds. It is worthy to note that in the present study in general low-N tolerant genotypes also exhibited the highest performance for all studied traits under high soil nitrogen treatments, and the opposite was true for susceptible genotypes. This means that the tolerant genotypes identified in this study are also responsive genotypes to high-N. Buah *et al* (1998) concluded that specific selection for high NUE sorghums will not diminsh responsiveness to applied N.

Alternative screening criteria for NUE traits

Genetic correlation coefficients of NUE_e, NUE_b, NUPE, NTRE, $NUTE_p$, $NUTE_g$ and $NUTE_b$ traits with possible alternative criteria (N_g, N_t,DM_g, DM_t and HI) are presented in Table (4). Alternative criteria that had nonsignificant or small correlations (either positive or negative) with a N-use efficiency trait were omitted from Table (4) .

When soil N is constant (as was considered in this experiment) NUE_e, NUE_b and NUPE traits are expected to be determined by measuring grain dry matter (DM_g), total plant dry matter (DM_t) and total plant nitrogen (N_t). Consistent with expectation, the genetic correlation in the present study was very high (1.0) and significant at 1% level of propability (Table 4) between these three NE traits and the three alternative criteria. It could therefore be concluded that DM_g, DM_t and N_t were the best predictors of genotypic performance for economic nitrogen use efficiency (NUE_e), biological (NUE_b) and nitrogen uptake efficiency (NUPE), respectively. Moreover, very high and significant genetic correlation coefficients were also found between NUE_b vs DMg (0.97 and 0.96 under high and low-N, respectively)and NUPE vs N_g (0.99) under both N levels, suggesting also that DM_g and N_g could also be used as alternative criteria for measuring NUE_b and NUPE, respectively.

The calculated value DM_g/DM_t is often reffered to as harvest index (HI), a commonly measured trait. High and significant correlation coefficient (0.90) was found between nitrogen translocation efficiency (NTRE) and HI under both high and low-N supply. Greater partitioning of photosynthate to grain, as indicated by a high HI, should also result in higher NTRE. Harvest index (HI) trait could also be recommended as the best predictor of nitrogen translocation efficiency (NTRE).

Table 4. Genetic correlation coefficients (P < 0. 01) between nitrogen efficiency (NE) traits and selective alternative criteria in sorghum genotypes.

NE trait		Selective alternative criteria				
		N_g	N_t	DM_g	DM_t	HI
NUE_g	High-N	0.94	0.93	0.99	0.97	0.65
	Low-N	0.82	0.82	0.99	0.97	0.78
NUE_b	High-N	0.88	0.89	0.97	1.00	0.44
	Low-N	0.74	0.77	0.96	1.00	0.60
NUPE	High-N	1.00	0.99	0.93	0.89	0.63
	Low-N	1.00	0.99	0.82	0.77	0.71
NTRE	High-N	0.65	0.53	0.66	0.48	0.90
	Low-N	0.63	0.53	0.59	NS	0.90
$NUTE_p$	High-N	-0.80	-0.84	-0.63	-0.62	-0.43
	Low-N	-0.76	-0.79	NS	NS	NS
$NUTE_g$	High-N	-0.89	-0.90	-0.75	-0.69	-0.64
	Low-N	-0.86	-0.86	-0.53	-0.44	-0.60
$NUTE_b$	High-N	-0.87	-0.89	-0.72	-0.66	-0.65
	Low-N	-0.88	-0.88	-0.60	-0.52	-0.65

* All values are highly significant except NS that indicates non-significance.

Nitrogen utilization efficiency traits ($NUTE_p$, $NUTE_g$ and $NUTE_b$) showed strong negative correlation coefficients with both Ng and N_t traits under both high and low-N conditions, ranging between – 0.76 and – 0.90. Grain and total plant nitrogen could be considered as good predictors of the three studied N-utilization efficiency traits. High correlations were found in our data (not presented) between N_t and N_g (0.99) and between DM_g and DM_t (> 0.95) and in the literature (Ajakaiye 1984, Herron *et al* 1963, Muchow 1988 and Onken *et al* 1986 and Youngquist *et al*1992). This indicates the possibility of using N_g as a substitute for Nt in calculating N uptake and N utilization efficiency traits and DM_g as a substitute for DM_t in calculating NUE_b. This conclusion was also supported by Youngquist *et al* (1992). Analyzing for N_g would allow faster and more economic evaluations, as sorghum grain can be analyzed as whole kernels in the Kjeldahl method without significant loss in precision from analysis of ground samples providing the whole kernel sample size is large. By substituting an alternative criterion in ranking nitrogen efficient genotypes in sorghum breeding programs, substantial savings in time and resources could be realized with a fair level of confidence in the selections. Alagarswamy and Seetharama (1983) concluded that selection in grain sorghum for high biomass and HI is sufficient to insure high N uptake and translocation. Traore and Maranville (1999) reported that grain sorghum shoot and grain N concentration were correlated with NUE1 ($NUTE_b$) while grain and shoot N contents were correlated with NUE2 ($NUTE_p$). Moreover, Harada *et al* (2000) reported a strong correlation between yield dry matter (DM) and N uptake in sorghum.

Grain dry matter (DM_g), total plant dry matter (DM_t) and harvest index HI in the present study were the best predictors of genotypic performance for NUEe, NUE_b and NTRE, respectively. Total plant or grain nitrogen are the best predictors for NUPE, $NUTE_p$, $NUTE_g$ or $NUTE_b$. Because of the high correlations between N_g vs N_t and DM_g vs DM_t, grain dry matter (DM_g) could be used as a screening criterion for NUE_e and NUE_b. Moreover, grain nitrogen content (N_g) could be used as a screening criterion for NUPE, $NUTE_p$, $NUTE_g$ or $NUTE_b$. The best use of the previous alternative screening criteria would be as prescreening 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.

Heterobeltiosis

The contrast between parents and crosses (ANOVA data not presented) was significant for all studied traits, suggesting significant non-additive gene effects (heterosis). The expression of useful heterosis (heterobeltiosis) i. e the degree of superiority of the F_1 over the better parent differed for the different studied traits (Table 5). Grain nitrogen content (N_g) showed maximum heterobeltiosis (71.7 and 75. 2%) followed by nitrogen uptake efficiency, NUPE (57.7 and 66. 7%) and total plant nitrogen content, N_t (57.5 and 66.7%). and grain yield dry matter /plant, DM_g (37.1 and 41.4%) under high and low-N, respectively. Minimum average of positive heterobeltiosis was shown by HI (7.9%) followed by NTRE (8.1%) and DM_l (9.9%) under high-N and NTRE (3. 3%) followed by DMP_l (3. 6%), DMP_{st} (5. 8%) and HI (9. 8%) under low-N. On the other hand, negative averages of heterobeltiosis were shown by NP_l (-15. 5 and-16. 4%), NP_{st} (-16.7 and –20.4%), $NUTE_p$ (-25.5 and –28.9%), $NUTE_g$ (-32.2 and –33. 8%) and $NUTE_b$ (-32. 5 and –38. 8%) under high- and low-N, respectively, DMP_l (-14. 4%) and DMP_{st} (-16. 6%) under high-N and DM_l (-23.8%) and DM_{st} (-27.2%) under low-N. The widest ranges of heterobeltiosis estimates were shown by N_g, N_t, N_{st} and NUPE under both high and low N and NUE_e, N_l and DM_g under low-N stress.The cross A-1 X R-89022 was amongst the best 3 crosses for heterobeltiosis under low-N stress regarding 15 out of 20 studied traits, i. e NUE_e, NUE_b, N_l, N_{st}, N_g, N_t, NUPE, $NUTE_p$, $NUTE_g$, $NUTE_b$, DM_l, DM_{st}, DM_g, DM_t and HI. In the second rank came the cross A-47 X R-90001, which showed superiority in heterobeltiosis under low-N

Table 5. Heterobeltiosis (%) estimates (average, range and the highest 3 crosses) for studied traits of sorghum F_1's tested under high- and low- nitrogen environments at Sids in 2004.

Trait	High-nitrogen					Low-nitrogen				
	Average	Range	Highest 3 crosses			Average	Range	Highest 3 crosses		
			1st	2nd	3rd			1st	2nd	3rd
NUE_e (g/g)	36.5	5.3-87.8	1x5	1x6	1x7	39.7	0.0-128.5	1x5	2x6	1x6
NUE_b (g/g)	25.2	(-7.2)-78.5	1x6	1x5	2x6	29.2	(-8.3)-86.5	1x5	1x7	2x6
N_g (mg)	71.7	11.1-137.7	1x6	1x5	2x6	75.2	9.0-180.3	1x5	2x6	1x6
N_l (mg)	35.7	(-10.6)-93.8	1x6	4x8	3x6	48.1	10.6-114.7	1x5	4x8	2x7
N_{st} (mg)	37.6	(-26.6)-128.5	2x6	1x6	2x5	50.2	(-40.1)-143.0	1x5	2x8	2x7
N_t (mg)	57.5	3.7-127.1	1x6	2x6	1x5	66.7	6.1-162.7	1x5	2x6	1x6
NP_l (%)	-15.5	(-37.3)-.01	3x5	4x6	4x7	-16.4	(-42.7)-11.2	4x6	3x5	4x7
NP_{st} (%)	-16.7	(-52.9)-28.7	2x5	2x8	2x7	-20.4	(-62.8)-11.5	2x8	1x7	2x7
NTRE (%)	8.1	1.4-16.3	3x6	4x6	3x8	3.3	(-5.3)-10.8	2x6	3x6	3x7
NUPE (g/g)	57.7	4.5-125.0	1x6	1x5	2x6	66.7	5.7-163.1	1x5	2x6	4x8
$NUTE_p$ (g/g)	-25.5	(-39.2)-(-11.8)	4x5	1x5	3x8	-28.9	(-46.1)-(-24.1)	4x6	4x5	1x5
$NUTE_g$ (g/g)	-32.2	(-44.4)-(-22.8)	4x5	2x5	1x5	-33.8	(-50.1)-(-17.7)	2x6	2x5	1x5
$NUTE_b$ (g/g)	-32.5	(-44.9)-(-21.5)	2x5	1x5	4x5	-38.8	(-53.8)-(-24.9)	2x6	2x5	1x5
DM_g (g)	37.1	5.3-87.8	1x5	1x6	2x6	41.4	0.0-128.5	1x5	2x6	1x6
DM_l (g)	9.9	(-27.0)-39.8	1x5	1x6	4x8	-23.8	(-22.4)-36.0	1x5	3x5	4x6
DM_{st} (g)	10.7	(-44.6)-78.3	2x6	1x6	1x7	-27.2	(-55.1)-59.0	1x7	1x5	4x6
DM_t (g)	25.2	(-0.9)-78.5	1x6	1x5	2x6	25.7	(-8.1)-86.5	1x5	1x6	1x7
DMP_l (%)	-14.4	(-37.4)-9.8	4x6	4x7	3x5	3.6	(-47.4)-(5.2)	4x6	3x5	4x8
DMP_{st} (%)	-16.6	(-53.0)-27.5	2x5	2x8	2x6	5.8	(-63.5)-0.4	1x7	2x8	2x7
HI (%)	7.9	(-1.7)-18.7	3x6	3x8	4x6	9.8	2.3-21.9	2x6	1x6	1x5

1=B-1, 2= B-47, 3= B-88005, 4= B-91003, 5= R-89022, 6=R-90001, 7=R-93002 and 8= RTX –86

for 10 traits (NUE_e, NUE_b, N_g, N_t, NTRE, NUPE, $NUTE_g$, $NUTE_b$, DMg and HI). The cross A-1 X R-90001 was amongst the highest three crosses for heterobeltiosis under low-N in six traits (NUE_e, N_g, N_t, DM_g, DM_t and HI). After that, heterobeltiosis superiority under low-N stress was shown by A-1 X R-93002 (for NUE_b, DM_{st}, DM_t, NP_{st} and DMP_{st}), A-91003 X R-90001 (for NP_l, $NUTE_p$, DM_l, DM_{st} and DMP_l), A-47 X R-93002 (for N_l, N_{st}, NP_{st} and DMP_{st}), A-47 X RTX-86 (for N_{st}, NP_{st} and DMP_{st}), A-91003 X RTX-86 (for N_l, NUPE and DMP_l), A-88005 X R-89022 (for NP_l, DM_l and DMP_l), A-47 X R-89022 (for $NUTE_g$ and $NUTE_b$)and A-91003 X R-93002 (for NP_l).

Relative contribution to total variance

Mean squares (not presented) under both high-N and low-N treatments, due to males and females in their respective crosses were highly significant for all studied traits, indicating that estimates of general combining ability (GCA) effects were significant ($P<0.01$) for both parental males and females for all traits.

Moreover, variation due to male X female interaction i.e specific comining ability (SCA) was also highly significant for all studied traits in grain sorghum under both control and low-N stress conditions. This suggests that SCA effects for studied traits were also significant at the 0.01 probability level under nitrogen stress and non-stress conditions.

Contribution of the variance due to males X females interaction (SCA variance) to the total variation was greater than that due to males or females (i. e greater than GCA variance) for 8 out of 20 traits under high-N treatment (NUE_e, NUE_b, N_g, N_t, NUPE, DM_l, DM_g and DM_t) and 9 out of 20 traits under low-N stress treatment (NUE_e, NUE_b, N_l, N_g, N_t, NUPE, DM_l, DM_g and DM_t) (Table 6). Out of these 9, two traits (N_l and N_g) under low-N stress, males X females intraction was less than 50% of the total variance, suggesting that SCA variance was less important than GCA variance in the inheritance of these two traits under the nitrogen stress environment. Moreover, for N_t and NUPE traits under low-N stress, variance due to males X females interaction contributed approximately 50% to the total variance, indicating equal importance of GCA and SCA variances for these two traits.

Table 6. Proportional contribution (%) of males (M), females (F) and males X females to the total variance for studied traits under high and low –N environments at Sids,2004.

Trait	High – N			Low – N		
	M	F	M x F	M	F	M x F
NUE_e	6.2	18.1	75.7	13.8	19.2	66.9
NUE_b	17.9	14.0	67.9	14.8	20.9	64.3
N_g	8.9	25.9	65.1	22.7	33.4	43.9
N_l	47.8	14.3	37.9	38.5	19.4	42.1
N_{st}	71.9	15.3	12.8	57.1	15.2	27.6
N_t	1.9	34.5	63.6	15.9	34.9	49.2
NP_l	82.0	0.5	17.4	57.7	1.6	40.8
NP_{st}	87.1	1.5	11.4	76.7	9.2	14.1
NTRE	57.9	16.8	25.2	66.0	10.9	23.1
NUPE	2.0	34.7	63.3	16.0	35.0	49.0
$NUTE_p$	12.0	78.3	9.7	39.6	46.1	14.3
$NUTE_g$	29.1	62.8	8.2	40.1	48.8	11.1
$NUTE_b$	30.6	60.7	8.7	41.6	47.5	11.0
DM_g	42.5	6.0	51.6	18.8	13.5	66.9
DM_l	6.2	18.1	75.7	13.8	19.2	67.8
DM_{st}	90.6	0.4	8.9	72.9	10.8	16.3
DM_t	17.9	14.0	67.9	14.8	20.9	64.3
DMP_l	0.5	82.0	17.5	1.6	57.7	40.7
DMP_{st}	1.5	87.1	11.4	9.2	76.7	14.1
HI	3.6	73.5	22.9	10.1	66.3	23.6

Contribution of male parents to the total variation (Table 6) was greater than the contribution of females for 9 out of 20 traits under high - N (NUE_b, N_l, N_{st}, NP_l, NP_{st}, NTRE, DM_g, DM_{st} and DM_t), indicating that without N stress most of the GCA variance was due to males GCA effects for these traits. On the other hand, under N-stress conditions, most of the total GCA variance was due to females GCA variance for 13 traits (NUE_e,NUE_b,N_g, N_t, NUPE. $NUTE_p$, $NUTE_g$, $NUTE_b$, DM_l DM_t,DMP_l, DMP_{st} and HI), suggestimg that most of the total GCA variance for these 13 traits was due to the females GCA effects.

General combining ability effects

Analysis of GCA effects showed that the cms line B-47 was the best combiner for 9 out of 20 traits (NUE_e, NUE_b, NP_l, NTRE, DM_l, DM_{st}, DM_g, DM_t and HI) under high-N treatment and for 6 traits (NUE_e, NP_l, NTRE, DM_g, DMP_l and HI) under low-N stress (Table 7).

Table (7): The best female (F) and male (M) in GCA effects and the best three hybrids (F X M) in SCA effects for studied traits under high and low nitrogen environments at Sids, 2004 season.

Traits	High – N					Low-N				
	GCA		SCA (F x M)			GCA		SCA (F x M)		
	F	M	1st	2nd	3rd	F	M	1st	2nd	3rd
NUE_e	2	5	4x8	1x5	3x6	2	6	4x8	1x5	2x6
NUE_b	2	5	4x8	1x5	3x6	1	6	4x8	1x5	2x7
N_g	4	8	4x8	1x5	3x6	4	7	4x8	2x7	1x5
N_l	4	7	4x8	1x7	1x5	4	7	4x8	1x7	3x6
N_{st}	4	6	4x8	2x6	3x7	4	5	1x5	4x6	2x7
N_t	4	7	4x8	1x5	1x7	4	7	4x8	1x5	2x7
NP_l	2	8	3x8	1x7	1x5	2	8	2x8	1x7	3x6
NP_{st}	3	6	1x8	1x6	2x5	3	5	1x6	4x7	3x5
NTRE	2	8	3x6	1x5	2x8	2	7	2x6	4x5	1x7
NUPE	4	7	4x8	1x5	1x7	4	7	4x8	1x5	2x7
$NUTE_p$	3	1	4x7	2x8	3x5	3	6	4x7	2x6	3x5
$NUTE_g$	3	6	4x7	1x6	3x5	3	6	4x7	1x6	2x6
$NUTE_b$	3	6	4x7	1x6	3x5	3	6	4x7	1x6	3x5
DM_g	2	5	4x8	1x5	3x6	2	6	4x8	1x5	2x6
DM_l	2	8	4x8	1x5	1x7	1	8	4x8	1x5	3x6
DM_{st}	2	6	4x8	2x6	3x7	1	5	1x5	4x8	1x6
DM_t	2	1	4x8	1x5	3x6	1	6	4x8	1x5	2x7
DMP_l	2	8	3x8	1x7	1x5	2	8	2x8	1x7	3x6
DMP_{st}	3	6	1x8	1x6	2x5	3	5	1x6	4x7	3x5
HI	2	7	3x6	2x8	1x5	2	7	2x6	1x8	4x5

1=B-1, 2= B-47, 3= B-88005, 4= B-91003, 5= R-89022, 6=R-90001, 7=R-93002 and 8= RTX -86

The cms line B-91003 (tolerant) was the best general combiner for increasing N_l, N_{st}, N_g, N_t, NTRE and NUPE in its F_1 hybrids under both nitrogen stress and non-stress conditions. The cms line B-88005 was the best general combiner for increasing NP_{st}, DMP_{st}, $NUTE_p$, $NUTE_g$ and $NUTE_b$ in its F_1 crosses under both high-and low-N treatments and DMP_{st} under low-N stress only. Moreover, the cms line B-1 was the best general combiner under low-N conditions for NUE_b, DM_l, DM_{st} and DM_t (Table 7).

The restorer line R-90001 which was one of the best general combiners for grain yield (Al-Naggar *et al* 2002), showed superiority as the best general combiner for increasing N_{st}, NP_{st}, $NUTE_g$, $NUTE_b$, DM_{st} and DMP_{st} under high-N and NUE_e, NUE_b, $NUTE_p$, $NUTE_g$, $NUTE_b$, DM_g and DM_t under low-N treatment (Table 7).

The restorer line R-89022 showed the best general combiner for NUE_e, NUE_b, $NUTE_p$, DM_g and DM_t under control and N_{st}, NP_{st}, DM_{st} and DMP_{st} under low-nitrogen stress. The restorer R-93002 was the best combiner for N_l, N_t, NUPE and HI under high-N and N_l, N_g,N_t, NTRE , NUPE and HI under low-N. Moreover, the restorer RTX-86 (tolerant) was the best general combiner for Ng, NPl, NTRE and DM_l under high-N and NP_l, DM_l and DMP_l under low-N stress.

In general, the best general combiners amongst all males and females under low-N stress were R-90001 for 7 traits (DM_g, DM_t, NUE_e, NUE_b, $NUTE_p$, $NUTE_g$ and $NUTE_b$), R-93002 for 5 traits (N_g, N_t, NTRE, NUPE and HI) and B-47 for 4 traits (DM_g, NUEe, NTRE and HI). It is worthy to mention that line R-93002 is one of the most tolerant lines *per se* in this study beside its superiority in producing tolerant F_1 crosses to low-N stress.

Specific combining ability effects

The highest and most favourable SCA effects for the greatest number of studied traits under low-N stress (Table 7) were obtained from the crosses A-91003 X RTX-86 (for NUE_e, NUE_b, N_l, N_g, N_t, NUPE, DM_l, DM_{st},DM_g and DM_t), A-1 X R-89022 (NUE_e, NUE_b, N_{st}, N_g, N_t, NUPE, DM_l, DM_{st}, DM_g and DM_t), A-47 X R-93002 (NUE_b, N_{st}, N_g, N_t, NUPE and DM_t), A-47 X R-90001 (NUE_e, NTRE, $NUTE_p$, $NUTE_g$ and DM_g and HI), A-91003 X R-93002 (NP_{st}, $NUTE_p$, $NUTE_g$, $NUTE_b$ and DMP_{st}), A-1 X R-90001 (NP_{st}, $NUTE_g$, $NUTE_b$, DM_{st} and DMP_{st}), A-88005 X R-90001 (N_l, NP_l, DM_l and DMP_l), A-1 X R-93002 (N_l, NP_l,DMP_l and NTRE) and A-47 X RTX-86 (NP_l and DMP_l).

The case where crosses were superior for SCA effects under both low-N stress and non-stress conditions were A-91003 X RTX-86 (NUE_e, NUE_b, N_l, N_g, N_t, NUPE, DM_g, DM_t, DM_l and DM_{st}), A-1 X R-89022 (NUE_e, NUE_b, N_g, N_t, NUPE, DM_g, DM_t and DM_l), A-1 X R-90001 (NP_{st}, DMP_{st}, $NUTE_g$ and $NUTE_b$), A-91003 X R-93002 ($NUTE_p$, $NUTE_g$ and $NUTE_b$) and A-1 X R-93002 (N_l, NP_l and DMP_l).

Type of gene action

Estimates of variance components (Table 8) were obviously greater for dominance (δ^2_D) than additive (δ^2_A) variance for twelve traits (NUE_e, NUE_b, NUPE, N_g, N_l, N_t, DM_g, DM_l, DM_t, N_{st}, NP_l and DMP_l) under N-stress and for nine traits (NUE_e, NUE_b, NUPE, N_g, N_l, N_t, DM_g, DM_l and DM_t) under non-stress conditions. These results poit to the importance of non-additive genetic variance in the inheritance of these traits. All estimates of average degree of dominance "a" (Table 8) for these traits were higher

Table 8. Additive (δ^2_A) and dominance (δ^2_D) variance, average degree of dominance "a", narrow sense heritability (h^2_n) and expected genetic advance (GA%) from selection of the best 10 % for studied traits of sorghum under high and low nitrogen environments (Sids,2004).

Trait	δ^2_A	δ^2_D	"a"	h^2_n (%)	GA %
			High-N		
NUE_g	-0.77	17.83	α	0.0	–
NUE_b	-1.05	42.71	α	0.0	–
N_g	-827.37	50236.22	α	0.0	–
N_l	6149.8	8429.11	1.66	42.1	39.42
N_{st}	14625.00	3079.17	0.65	82.2	52.55
N_t	-1405.35	118271.13	α	0.0	–
NP_l	11.87	3.84	0.80	75.6	31.07
NP_{st}	34.79	6.43	0.61	84.2	45.35
NTRE	4.02	2.25	1.06	63.2	5.88
NUPE	0.00	0.02	α	0.0	–
$NUTE_p$	15.08	2.21	0.54	86.5	16.18
$NUTE_g$	36.69	4.55	0.50	88.8	15.08
$NUTE_b$	55.40	6.75	0.49	88.1	17.75
DM_g	-5.68	130.66	α	0.0	–
DM_l	5.53	26.98	3.12	17.0	16.04
DM_{st}	102.99	14.27	0.53	87.7	58.59
DM_t	-7.66	312.98	A	0.0	–
DMP_l	11.87	3.84	0.80	75.6	31.07
DMP_{st}	34.79	6.43	0.61	84.3	45.36
HI	5.18	2.46	0.97	66.9	6.95
			Low-N		
NUE_g	-4.42	204.36	α	0.0	–
NUE_b	-5.69	409.81	α	0.0	–
N_g	17022.00	37006.63	2.08	31.4	27.53
N_l	2321.00	4341.26	1.93	34.7	36.08
N_{st}	2291.00	1544.39	1.16	59.4	47.08
N_t	20652.00	74938.53	2.69	21.6	20.31
NP_l	3.30	5.52	1.83	37.1	15.22
NP_{st}	17.99	4.30	0.69	80.2	46.32
NTRE	8.90	4.29	0.98	66.6	7.93
NUPE	0.04	0.15	2.47	21.1	20.16
$NUTE_p$	87.62	20.57	0.68	77.9	29.45
$NUTE_g$	219.75	36.96	0.58	84.6	30.65
$NUTE_b$	232.08	38.46	0.57	84.8	29.63
DM_g	-2.21	102.15	α	0.0	–
DM_l	-0.35	14.59	α	0.0	–
DM_{st}	31.87	9.32	0.76	77.1	60.36
DM_t	-2.84	204.85	α	0.0	–
DMP_l	3.29	5.52	1.83	37.1	15.20
DMP_{st}	18.00	4.30	0.69	80.3	46.43
HI	7.45	3.70	0.99	65.8	7.64

than unity indicating that overdominance was the type prevailing in the crosses.

On the contrary , estimates of variance components were greater for additive (δ^2_A) than dominance (δ^2_D) variance for remaining traits (i.e NTRE, HI, $NUTE_p$, $NUTE_g$, $NUTE_b$, DM_{st}, DMP_{st} and NP_{st} under N-stress and NTRE, HI, $NUTE_p$, $NUTE_g$, $NUTE_b$, DM_{st}, DMP_{st}, NP_{st}, N_{st}, NP_l and DMP_l under non-stress conditions) indicating the importance of additive genetic variance in the inheritance of these traits. Under both N levels, estimates of "a" were very close to unity for NTRE and HI traits only, suggesting that complete dominance was the type prevailing in the crosses for these two traits. Regarding all traits that showed greater estimates of additive than dominance variance either under N-stress or non-stress conditions (except NTRE and HI), the "a" estimates were lower than unity indicating partial dominance.

Heritability

Estimates of heritability in the narrow sense (h^2_n) are presented in Table (8). Under low-N stress the h^2_n estimates ranged from zero % for NUE_e, NUE_b, DM_l, DM_g and DM_t to 84.8 % for $NUTE_b$ followed by 84.6 % for $NUTE_g$,. Minimum h^2_n estimates were recorded by NUPE (21.1 %) and N_t (21.6 %) under low-N stress.

Under high-N, h^2_n ranged from zero % for NUE_e, NUE_b, N_g, N_t, NUPE, DM_g and DM_t to 88.8 % for $NUTE_g$ followed by 88.1 % ($NUTE_b$). Minimum h^2_n estimate under high-N was shown by DM_l (17.0 %) .

Estimates of h^2 were higher under high-N than low-N conditions for 13 traits (N_l, N_{st}, NP_l, NP_{st}, NTRE, $NUTE_p$, $NUTE_g$, $NUTE_b$, DM_l, DM_{st}, DMP_l, DMP_{st} and HI), higher under low-N than high-N for 3 traits (N_g, N_t and NUPE) and were equal (0.0 %) in both N levels for 4 traits (NUE_e, NUE_b, DM_g and DM_t).

Predicted gain from selection

The predicted genetic advance (GA) from selection, using a 10 % selection intensity is presented in Table (8). Genetic advance reached its maximum value under low-N stress environment for DM_{st} (60.36%) followed by N_{st} (47.08 %).

Comparing the two environments (stressed and non-stressed) it could be concluded that better progress from selection may be realized under low-N stress for improving the N_g, N_t, NP_{st}, NTRE, NUPE, $NUTE_p$, $NUTE_g$, $NUTE_b$, DM_{st}, DMP_{st} and HI i.e for traits contributing to low-N tolerance. On the other hand, selection under no-stress is expected to improve N_l, N_{st}, NP_l, DMP_l and DM_l in a way better than under low-N stress.

A review by Bramel-Cox *et al* (1991) presented conflicting results regarding the usefulness of selection under non-stress conditions to identifying genotypes of sorghum for use in nutrient stress environments. The amount of genetic progress from selection for broad adaptation in both favourable and adverse production conditions diminishes as the intensity of stress increases in the unfavourable production environments (Bramel-Cox *et al* 1991 and Zavala-Garcia *et al* 1992). Menkir and Ejeta (2003) reported that genetic variance and heritability estimates for grain yield in sorghum in the nutrient stress did not differ significantly from those in the corresponding non-stress environment. They added that for improving yield under stress, indirect selection in high fertility environments was less efficient than direct selection in the corresponding stress environment (low fertility). They concluded that greater gain in performance over contrasting environments may be achieved by selecting for yield in more than one environment, rather than by selecting in any single environment.

In the present study, higher estimates of expected genetic advance from direct selection under low-N (stress) than those from indirect selection under high-N (non-stress) conditions for nitrogen use efficiency components were recorded. To the best of our knowledge these results on the type of gene action, heritability and expected gain from selection for improving traits contributing to low-N tolerance in grain sorghum are believed to be the first record in literature and need further investigations to support them.

REFERENCES

A. O. A. C (1980). Official Methods of Analysis, Association of analytical chemists 13 th ed. Washington D. C – U. S. A.

Ajakaiye, C. O. (1984). Changes in sorghum grain protein content with maturity at four levels of nitrogen. Can. J. Plant Sci. 64: 797-804.

Alagarswamy, G. and N. Seetharma (1983). Biomass and harvest index as indicators of nitrogen uptake and translocation to the grain in sorghum genotypes. Genetic aspects of plant miniral nutrition [edited by Saric, M. R. and B. C. Loughman]. 423-427. Martinus Nijhoff, Netherlands

Alagarswamy, G. and F. R. Bidinger (1987). Genotypic variation in biomass production and nitrogen use efficiency in pearl millet [*Pennisetum americanum* (L.) Leek]. P. 281-286. *In* W. H. Gebelman and B. C. Loughman (ed) : Genetic aspects of plant mineral nutrition. Martinus Nijhoff, Netherlands.

Alagarswamy, G.; J. C. Gardner; J. W. Maranville and R. B. Clark (1988). Measurement of instantaneous nitrogen use efficiency among pearl millet genotypes. Crop Sci. 28:681-685.

Al-Naggar, A.M.; O.O. El-Nagouly and Zeinab S.H. Abo-Zaid (2002). Genetics of some grain sorghum traits under different water-stress conditions. Egypt. J. Plant Breed. 6 (1): 125-141.

Atlin, G. N. and K. J. Frey (1990). Breeding crop varieties for low-input agriculture. Am. J. Alt. Agric. 4: 53-58.

Becker, W. A. (1984). Manual of Quantitative Genetics. 4 th ed. Academic enterprises, Pollman, WA.

Borrell, A. K. and A. C. L. Douglas (1997). Maintaining green leaf area in grain sorghum increases nitrogen uptake under post-anthesis drought. International Sorghum and Millets Newsletters 38:89-92.

Bramel-Cox, P. J., T. Baker, F. Zavala-Garcia, and J. K. Eastin (1991). Selection and testing environments for improved performance under reduced-input conditions. In: Plant Breeding and Sustainable Agriculture: Considerations for Objectives and Methods. Crop Science Society of America, Special Publication No. 18. pp. 29-56.

Bruetsch, T. F. and G. O. Estes (1976). Genotype variation in nutrient uptake efficiency in corn. Agron. J. 68:521-523.

Buah,S. S. J., J. W. Maranville, A. Traore and P. J. Bramel-Cox (1998). Response of nitrogen use efficient sorghums to nitrogen fertilizer. J. Plant Nut. 21 (11) 2303-2318.

Chevalier, P. and L. E. Schrader (1977). Genotypic differences in nitrate absorption and partitioning of N among plant parts in maize. Crop Sci. 17: 897-901.

Cockerham, C. C. (1956). Analysis of quantitative gene action. Brookhaven Symposia in biology. No. 9, Genetics in Plant Breeding 53-66.

Desai, R. M. and C. R. Bhatia (1978). Nitrogen uptake and nitrogen harvest index in durum wheat cultivars varying in their grain protein concentration. Euphytica. 27:561-566.

Federer, W. T. (1963). Experimental Design: Theory and Application. The Macmillan Company, New York.

Gardner J. C., J. W. Maranville and E. T. Paparozzi. (1994). Nitrogen use efficiency among diverse sorghum cultivars. Crop Sci. 34:728-733.

Hageman R. H., and F. E. Below (1984). The role of nitrogen in the productivity of corn. p. 145-156. *In* (ed.) D. Wilkinson and R. Brown. Proc. 39th Ann. Corn and Sorghum Industry Res. Conf., Chicago, IL. 5-6 Dec. 1984. American Seed Trade Assoc., Washington, Dc.

Hallaur, A. R. and J. B. Miranda (1981). Quantitative Genetics in Maize Breeding. 2 nd ed. Iow State Univ. Press, Ames, Iowa.

Harada, H., Y. Yoshimura ; Y. Sunaga and T. Hatanaka (2000). Variations in nitrogen uptake and nitrate nitrogen concentration among sorghum groups. Soil Science and Plant Nutrition. 46: (1), 97-104.

Herron, G. M., D. W. Grimes and J. T. Musick (1963). Effects of a soil moisture and nitrogen fertilization of irrigated grain sorghum on dry matter production and nitrogen uptake at selected stages of plant development. Agronomy J. 55: 393-396.

Kempthorne, O. (1957). An Introduction to Genetic Statistics. John Wiley and Sons, New York.

Maranville, J. W., and S. Madhavan (2002). Physiological adaptations for nitrogen use efficiency in sorghum. Plant and Soil 245:25-34.

Maranville, J. W. ; R. B. Clark, and W. M. Ross (1980). Nitrogen efficiency in grain sorghum. J. Plant Nut. 2:577-589.

Maranville,J. W. ; R. K. Pandey and S. Sirifi (2002). Comparison of nitrogen use efficiency of a newly developed sorghum hybrid and two improved cultivars in the Sahel of West Africa. Commun. Sci. Plant Anal. 33 (9&10): 1519-1536.

Menkir, A. and G. Ejeta (2003). Selection for grain yield in sorghum under moisture and nutrient stress environments. African Crop Science Journal, 11 (2) : 55-64

Moll, R. H. , E. J. Kamprath and W. A. Jackson (1982). Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agron. J. 74:562-564.

Moll, R. H. , E. J. Kamprath and W. A. Jackson (1987). Development of nitrogen-efficient prolific hybrids of maize. Crop Sci. 27:181-186.

Muchow, R. C. (1988) Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semi-arid environment: III. Grain yield and nitrogen accumulation. Field Crops Res. 18:31-43.

Nakamura,T. , J. J. Adu-Gyamfi , A. Yamamoto, S. Ishikawa, S. Nakano and H. O. Ito (2002). Varietal differences in root growth as related to nitrogen uptake by sorghum plants in low-nitrogen environment. Plant and Soil 245 (1): 17-24.

Onken, A. B. , M. J. Lavelle and G. C. Peterson (1985). Improving nutrient use efficiency in sorghums. Pp. 15-27. In: D. Wilkinson (ed.), Proc. 41st Ann. Corn and Sorghum Industry Res. Conf. , Chicago, IL. , 10-11 Dec. 1985. American Seed Trade Assoc. , Washington, DC.

Raun, W. R. and G. V. Johnson (1999). Improving nitrogen use efficiency for cereal production. Agron. J. , 91:357-363.

Sinclair, T. R. and C. T. de Wite (1975). Photosynthate and nitrogen reqirements for seed production by various crops. Science 189:565-567.

Traore, A. and J. W. Maranville (1999). Nitrate reductase activity of diverse grain sorghum genotypes and its relationship to nitrogen use efficiency. Agron. J. 91: 863-869.

Youngquist, J. B. , P. Bramel-Cox and J. W. Maranville (1992). Evaluation of alternative screening criteria for selecting nitrogen-use efficient genotypes in sorghum. Crop Sci. 32, 1310-1313.

Zavala-Garcia, F. , P. J.Bramel-Cox, J. K. Eastin, M. D. Witt and D. J. Andrews (1992). Increasing the efficiency of crop selection for unpredictable evironments. Crop Sci. 32:51-57.

الثوابت الوراثية الكمية للصفات المساهمة في تحمل الذرة الرفيعة للحبوب للآزوت المنخفض

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تم تهجين أربعة سلالات أبوية من الذرة الرفيعة للحبوب المعيدة للخصوبة (اثنتين منها متحملتين لآزوت التربة المنخفض واثنتين حساسة) مع أربعة سلالات أبوية عقيمة الذكر سيتوبلازمياً (واحدة منها متحملة و ثلاثة حساسة) و الحصول على ١٦ هجين فردى خصب في موسم ٢٠٠٣. تم تقييم حقلي للـ ٢٤ تركيب وراثي (٨ آباء + ١٦ هجين) في سدس تحت مستويين من أزوت التربة (منخفض و هو عدم إضافة سماد أزوتي و عالي و هو إضافة سماد أزوتي بمعدل ١٢٠ كيلو جرام أزوت للفدان) في موسم ٢٠٠٤. كانت الأهداف هي دراسة الاختلافات بين التراكيب الوراثية في الذرة في صفات كفاءة استخدام الآزوت و تحديد معايير تصفية بديلة سريعة وغير مكلفة و دقيقة لانتخاب تراكيب وراثية ذت كفاءة عالية في هده الصفات و إمداد المربى بمعلومات عن فعل الجين و كفاءة التوريث و التحسين المتوقع بالانتخاب و قوة الهجين لهذه الصفات. كانت متوسطات المربعات الراجعة للتراكيب الوراثية و لمستويات الآزوت و للتفاعل بينهما عالية المعنوية لكل الصفات المدروسة. تسبب الأزوت المنخفض في التربة في حدوث نقص معنوي في محصول حبوب النبات (مادة جافة) مقداره ١٧,٩ و ١٥,٢% في الآباء و الهجن، على التوالي. كان هذا النقص مصحوباً بنقص معنوي في كل من صفات وزن المادة الجافة للأوراق و السيقان و النبات ككل و زيادة معنوية في كل من صفات كفاءة استخدام الأزوت الاقتصادية و البيولوجية و كفاءة انتقال الآزوت و امتصاصه من التربة و كفاءة الانتفاع بآزوت النبات للمادة الجافة للحبوب و للنبات ككل و كفاءة انتفاع الحبوب بآزوت الحبوب و معامل الحصاد. أظهرت النتائج أن السلالات RTX-86, R-93002, B-91003 و الهجن A-91003 X RTX-86, A-47 X R-90001, A-1 X R-89022 كانت الأكثر تحملاً لنقص الأزوت. اتصفت الآباء و الهجن المتحملة بتفوقها عن الحساسة تحت إجهاد الآزوت بمقدار ٥٦,٢ و ٤٠,٢ % ، على التوالي. كان هذا التفوق مصحوبا" بتفوق في كل صفات كفاءة استخدام الآزوت المدروسة. أظهر تحليل الارتباطات الوراثية أن صفات الوزن الجاف لمحصول حبوب النبات و الوزن الجاف الكلي للنبات و معامل الحصاد هي أحسن المعايير للتنبؤ بصفات كفاءة استخدام الآزوت الاقتصادية و البيولوجية و كفاءة انتقال الآزوت للحبوب، على التوالي، كما كانت صفة محتوى آزوت الحبوب و هي أحسن المعايير للتنبؤ بأي من صفات امتصاص الآزوت من التربة و كفاءة الانتفاع بآزوت الحبوب .

هذه المعايير البديلة يمكن استخدامها في إجراء التصفية الأولية لاستبعاد التراكيب الوراثية الأكثر حساسية للإجهاد الأزوتي ، مما يقلل الحاجة إلي تحليل أزوت النبات ككل في عدد كبير من العينات و يسمح بمستوى جيد من الثقة في تحديد المنتخبات النهائية. اختلفت الصفات فيما بينها من حيث قوة الهجين بالنسبة للأب الأحسن و ظهرت أعلى القيم في صفة محتوى آزوت الحبوب (٧٥,٢%) ثم كفاءة امتصاص آزوت التربة (٦٦,٧ %) وكانت أحسن ثلاثة هجن من حيث قوة الهجين هي A-1 X R-90001، A-47 X R90001, A-1 X R-89022. كانت كل من تأثيرات القدرة العامة و الخاصة على الائتلاف عالية المعنوية لكل الصفات المدروسة. و كان إسهام تباين القدرة الخاصة في التباين الكلي أكبر من إسهام تباين القدرة العامة على الائتلاف في تسعة صفات تحت إجهاد الآزوت المنخفض. كانت أحسن الآباء في قدرتها العامة على الائتلاف هيR-90001 B-47, R-93002 and و أحسن الهجنA-1 X R-93002, A-47 X R-90001, A-91003 XRTX-86. تحت الإجهاد الآزوتي كان التباين غير المضيف أكبر من التباين المضيف في ١٢ صفة و كان التباين المضيف أكبر من غير المضيف في ٨ صفات. كان نوع السيادة السائدة في هجن الـــ F_1 تحت الإجهاد الآزوتي هو السيادة الفائقة لـــ ١٢ صفة و السيادة الكاملة لصفتين و السيادة الجزئية لستة صفات. تراوحت كفاءة التوريث الخاصة بين صفر (لأربعة صفات) و ٨٤,٨% لصفة كفاءة الانتفاع بآزوت النبات في إنتاج المادة الجافة للنبات . أظهر تحليل البيانات أن التقدم الوراثي المتوقع يكون أفضل بالانتخاب تحت ظروف إجهاد الآزوت عن ظروف عدم الإجهاد لتحسين صفات محتوى آزوت الحبوب و النبات ككل و كفاءة انتقال الآزوت للحبوب و كفاءة امتصاص الآزوت وكفاءات الانتفاع بالآزوت و معامل الحصاد (وهي معظم الصفات المساهمة في تحمل الذرة الرفيعة للحبوب للآزوت المنخفض).