https://doi.org/10.1590/1678-4499.20180196

PLANT BREEDING - Article

Selection of maize top-crosses for different nitrogen levels through specific combining ability

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ABSTRACT: An alternative to increase yield without raising the production costs and minimizing the dependence of agricultural inputs is the development of maize genotypes presenting high nitrogen (N) use efficiency under low N level conditions. Thus, the objective of this study was to estimate the specific combining ability of maize top-crosses under high and low nitrogen (N) conditions and to select high-yielding hybrids for both conditions. The grain yield of 110 top-cross hybrids was evaluated in 2012 in two locations in the Brazilian Midwest. Partial diallel analysis was performed with the adjusted means of each of the individual top-cross analyses. Specific combining ability (SCA) of the hybrids and their interaction with N levels was estimated for each location. The mean grain yield of the 11 hybrids selected by the highest SCA estimates for high and low N was higher than the controls mean in approximately 330 and 241 $kg \cdot ha^{-1}$. These results demonstrate that the selection for each environment was efficient and reveals the possibility of developing new hybrids for the Brazilian Cerrado region.

Key words: *Zea mays* L., diallel, hybrid combination, nitrogen use efficiency.

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Received: May 28, 2018 – Accepted: Aug. 1, 2018

INTRODUCTION

Nitrogen (N) fertilizer is usually applied to maize (*Zea mays* L.) fields, resulting in marked increases in yield. Low N availability is a major cause of yield loss in maize in developing countries (Oliveira et al. 2017). This occurs because of high prices of nitrogen fertilizer and farmers' low purchasing power in these countries, which results in most maize farming conducted under nitrogen deficiency conditions. Therefore, developing maize cultivars with tolerance to low N is the most effective and sustainable approach to mitigate the problem of low N (Ribeiro et al. 2018).

An alternative to increase yield without raising the production cost and minimizing the dependence of agricultural inputs is the development of maize genotypes presenting high nitrogen use efficiency under low N level conditions, allowing greater farming sustainability. Maize cultivars more efficient in N use can be obtained by the selection of superior genotypes, since there is genetic variability for the nitrogen use efficiency in maize (Silva et al. 2008; Soares et al. 2009; Souza et al. 2008; Souza et al. 2009).

Obtaining and evaluating inbred lines is the costliest and most time consuming step in any maize hybrids development program (Miranda Filho and Viégas 1987). One way to speed up the process and reduce program costs is by obtaining top-cross hybrids from partially inbred lines. It is possible to reduce the time and cost of achieving these hybrids, since the production system requires fewer successive self-fertilizations and a smaller area for obtaining and multiplying the lines, reaching the market faster and maintaining higher yield when compared with inbred lines.

After acquiring the lines, they must be evaluated for the combining ability. The relative merit of partially inbred lines can be evaluated by means of top-cross, which allow to select superior agronomic performance lines when crossed with a common tester, making the development of hybrids more rational and efficient (Ferreira et al. 2010; Cancellier et al. 2011; Guedes et al. 2011), with the advantages of ease in obtaining the crosses and being able to evaluate a large number of lines occupying smaller area (Ferreira et al. 2009).

Given this scenario, the objective of this study was to estimate the specific combining ability of partially inbred lines under high and low nitrogen (N) conditions and to select promising lines for obtaining high-yielding hybrids for both conditions.

MATERIAL AND METHODS

Five base populations were evaluated, from which partially inbred lines were extracted (Table S1). Of these, 11 partially inbred S_1 progenies were extracted from each base population using the self-fertilization method, as described by Borém (2009). In each population, 100 S_0 plants were selected, based on vigor and type, and later self-fertilized, with only upright plants being harvested. In each population, the top 11 S_1 lines were selected to be evaluated in top-cross. The process of self-fertilization of the plants was carried out during the 2011 off-season.

Top-cross hybrids were obtained from two isolated cross fields, where the lines were intercalated with the testers. Two testers (T1, commercial single hybrid with good yield potential; and T2, equal mixture of S_1 progenies) were used. Top-cross hybrids were obtained during the 2011/2012 harvest. We obtained 110 hybrid progenies, called top-crosses, which were used in the evaluation trials together with the five base populations and six controls. The controls used were the BR 106 variety and BRS 1010, XB 9003, XB 8010, DKB 390 and Omega hybrids, in addition to each of the populations initially used.

The trials were installed in the 2012 off-season, in the municipalities of Dourados and Caarapó, State of Mato Grosso do Sul. In Dourados, trials were installed at the Experimental Farm of Agricultural Sciences of the Federal University of Grande Dourados (UFGD), located at

Table S1. Cycle, texture and grain color and company holding the base populations used for extracting inbred progenies.

Population	Material	Type	Cycle	Grain color	Grain type	Company
BP (01)	UFGD 1	Variety	Early	Yellow/Orange	Semi-dent	–
BP (02)	BRS Sol-da-manhã	Variety	Early	Orange	Flint	Embrapa
BP (05)	BRS 3035	Triple hybrid	Super-early	Orange	Semi-dent	Embrapa
BP (07)	DKB 789	Double hybrid	Early	Yellow/Orange	Semi-flint	Dekalb
BP (13)	AG 30A91	Single hybrid	Early	Orange	Semi-flint	Agromen

Lat 22° 14' 02" S, Long 54° 59' 17" W and 406 m of altitude. In Caarapó, the trials were conducted at Urtigão Farm, located at Lat 22° 38' 45" S, Long 55° 00' 28" W and 482 m of altitude. According to Köppen classification, the climate in this region is Cwa, characterized by a humid mesothermic climate with warm summers and dry winters, with temperatures below 18 °C in the coldest month and exceeding 22 °C in the hottest one, and an average cumulative rainfall of 1,427 mm.

The high N environment was characterized by fertilization of 120 kg·ha^{-1} N, applying 20 kg·ha^{-1} at sowing and 100 kg·ha^{-1} as top-dressing. To the low N environment, a fertilization of 20 kg·ha^{-1} N at sowing was performed. In every situation it was not used topdressing. The experimental design was 11 × 11 lattice with two replicates. The experimental unit consisted of five-meter lines, spaced 0.90 m between rows and 0.20 m between plants, for the trials in Dourados. In Caarapó, the spacing was 1.0 m between rows and 0.18 m between plants. The difference between row spacing and plant density at each site occurred in function of the seeder used. However, the plant population remained constant at both sites (55,556 plants·ha^{-1}).

The experimental area of Dourados was in tillage system and the sowing was performed manually on February 15, 2012, using two seeds per groove. The experimental area of Caarapó was grown under no-tillage system, and the sowing was carried out in succession to soybean crop. Sowing was performed manually on March 9, 2012, using two seeds per groove. In both locations, sowing fertilizer with 20 kg·ha^{-1} N, 50 kg·ha^{-1} K and 50 kg·ha^{-1} P were carried out, according to the recommendations made by Sousa and Lobato (2004), using the formulated 08 – 20 – 20 + 0.4% Zn. The thinning of the crop was performed to maintain a stand of 55,000 plants·ha^{-1}. The first nitrogen top-dressing was performed when the maize plants had four to five fully expanded leaves, and the second when the plants had eight to ten fully expanded leaves. The other cultural practices were carried out according to the technical recommendations for maize growing (Alvarenga et al. 2010).

To evaluate the grain yield (GY, kg·ha^{-1}), the ears of the central rows were harvested manually and threshed to determine the grain weight and humidity, correcting the humidity to 13%.

The joint analysis of variance was performed according to the statistical model below (Eq. 1):

$$Y_{ijk} = \mu + T_i + E_l + B_{j(kl)} + R_{k(l)} + TxE_{il} + {}_{eijk}l \quad (1)$$

where Y_{ijk} is the observation in the j-th block within the k repetition, evaluated in the i-th treatment and l-th environment; μ is the overall mean of the trial; T_i is the effect of the i-th treatment considered as fixed; E_l is the effect of the l-th environment considered as random; $B_{j(kl)}$ is the effect of the j block within the k repetition within the j environment; $R_{k(l)}$ is the effect of the k repetition within the l environment; TxE_{il} is the random effect of the interaction between i treatments and l environment; e_{ijk} is the random error associated with the Y_{ijkl} observation.

In the joint analysis, the source of variation for entries was partitioned into top-cross, controls and their contrast, and the interaction of these with the environments were deployed. Moreover, the sums of squares of top-cross were partitioned for each of the testers and the contrasts between them. The interactions between these and N levels were performed. The sums of squares of the environment were partitioned into locations and N levels and their contrasts. Furthermore, it was estimated specific combining ability (SCA) for the top-cross × location and top-cross × N interactions according to method 4 of Griffing (1956), adapted for partial diallel in multiple environments (Ferreira et al. 1993). Subsequently, the index of coincidence was calculated among the 11 top-crosses evaluated under high and low nitrogen availability (N) at both sites. Analysis of variance were performed using the SAS statistical software (Sas Institute Inc. 2004), while the diallel analysis was performed using the Genes software (Cruz 2013).

RESULTS AND DISCUSSION

Entries effects (ET) was partitioned into top-cross (TC), controls (C) and TC × C interaction effects (Table 1). There was significance for TC, C and TC × C, indicating that, on average, the top-cross differed from controls for grain yield. Medici et al. (2005), Fernandes et al. (2005), Cancellier et al. (2011) and Guedes et al. (2011) found similar results. There was significant effect for environments (E), reflecting on significant location (L) and N levels (N) effects; however, there was no significant contrast for L vs N. This indicates that the L and N influence the yield grain of the genotypes, although there is no association between these effects. The ET × E interaction was not significant. However, it is important to mention that this effect was tested with the presence of 11 commercial controls recommended for the region. Thus, this interaction was partitioned into TC × L, TC × N, C × L and C × N. The TC × L interaction was not significant, which, according to Locatelli et al. (2002), is advantageous, since it reduces the correlation between the phenotype and its genotype by restricting the validity of inferences about the behavior from the point of view of breeding and quantitative traits inheritance.

There was significant interaction only between TC × N, which indicates differential performance of the top-cross hybrids in response to the N availability, a fact confirmed by the significant SCA × N interaction. This shows that the parents have, among themselves, an appreciable degree of gene complementation in relation to the frequencies of the alleles in the loci that have dominance (Cruz et al. 2012). Similar results were found by Medici et al. (2005), who reported the existence of the interaction "genotype × levels of N" to the maize grain yield. According to these authors, in environments with high N availability, additive genetic effects show slightly more importance than non-additive genetic effects, and additive and non-additive genetic effects show similar importance in environments with low availability of N.

Table 1. Joint analysis of variance for grain yield (kg·ha^{-1}) of 110 top-cross hybrids and six controls evaluated in low and high nitrogen (N) conditions in Dourados-MS and Caarapó-MS.

Sources of variation	Degrees of freedom	Mean Square
Environments (E)	3	65381495.40**
Locations (L)	1	110377265.75**
Levels (N)	1	79751670.13**
L vs N	1	6015550.41^{ns}
Entries (ET)	120	4078829.50**
Top-cross (TC)	109	2564267.90**
Controls (C)	10	20995433.00**
TC vs C	1	54038598.05**
ET x E	360	982137.10^{ns}
Top-cross (TC) x L	109	1077616.33^{ns}
SCA x L	109	874913.47ns
Top-cross (TC) x N	109	1902442.27*
SCA x N	109	2572482.79*
Controls (C) x L	10	342637.10^{ns}
Controls (C) x N	10	386971.95^{ns}
Error	480	1242473.00
Location		Low N
Caarapó		4069.54
Dourados		4887.92
Mean		4478.73
Location		High N
Caarapó		4767.61
Dourados		5287.69
Mean		5027.65
Overall mean		4748.09
Coefficient of variation (%)		19.47
Lattice efficiency	Location	High/Low (N)
	Caarapó	129.73/136.72
	Dourados	121.91/116.22

^{ns}, ** and *: not significant and significant at 1 and 5% probability level by the F test, respectively.

There was no significant among SCA × L interaction, evidencing that the deviations from behavior of hybrids were similar over the evaluated environments. On the other hand, there was a significant SCA × N interaction, indicating that alleles donated by the testers, in a determined N level, cannot contribute in the same way in another N level. Moreover, Fidelis et al. (2007) reports that the alleles in controlling yield under abiotic stress conditions are different from those under optimum conditions.

Table 2 shows the estimates of SCA and grain yield for the 11 top-crosses evaluated under high and low N. Significant estimates of SCA reveal that the hybrid combinations selected showed, in general, significant deviations from the average behavior of the parents, both in low and high N conditions (Cruz et al. 2012; Do Vale et al. 2012). The 11 top-crosses selected presented, in addition to high grain yield, high estimates of significant SCA ($p < 0.01$) in both N availability. High SCA for the grain yield trait is an indication that populations generated from these parents may be useful in interpopulation breeding for obtaining lines that, when crossed, could generate more heterotrophic hybrids (Hallauer and Miranda Filho 1988). The predominance of non-additive effects for this trait has already been reported in the literature (Fuzatto et al. 2002; Pfann et al. 2009).

Only the top-cross hybrid 4 was selected for high and low N, leading to an index of coincidence of 9.1% between the top-crosses selected for each environment. This indicates that the improvement for each N availability should be done separately. This hybrid showed an average grain yield of 4,452.94 kg·ha^{-1} in low N availability, exceeding the mean for the trait when evaluated in high N availability condition (4,328.23 kg·ha^{-1}). This indicates that the top-cross hybrid 4 is not responsive to nitrogen fertilization, being more suitable for cultivation by farmers of low technological level, →

Table 2. Estimates of specific combining ability (SCA) and grain yield (GY, kg.ha^{-1}) for 11 top-crosses evaluated under high and low nitrogen (N) availability at two locations.

High N			Low N		
Top-cross	SCA	GY	Top-cross	SCA	GY
98	820.03**	6085.99	4	709.56**	4452.94
58	718.42**	5688.04	6	700.74**	4754.77
10	711.19**	5868.64	94	647.44**	5209.70
52	707.79**	5071.46	48	608.17**	5130.94
91	642.64**	6010.04	99	583.66**	4658.38
87	628.80**	5232.06	30	548.61**	3263.75
75	593.88**	5407.56	24	543.23**	3851.59
71	536.89**	4912.78	97	531.60**	4406.07
4	520.65**	4328.23	106	461.82**	5220.14
19	446.80**	4931.61	31	436.72**	4767.27
69	427.52**	5812.44	90	436.60**	4064.55
Mean		5395.35	Mean		4525.46
Control mean		5065.88	Control mean		4284.28

**: significant at 1% probability level by the t-test.

or even in low-input agriculture, reducing the production cost (Fageria et al. 2007).

It is important to note that the grain yield mean of the 11 hybrids selected by the highest SCA estimates for high and low N was higher than the controls mean in approximately 330 and 241 kg·ha^{-1}, respectively. These results demonstrate that selection for each N availability was efficient and reveals the possibility of developing new hybrids for the Brazilian Cerrado region.

CONCLUSION

The mean grain yield of the 11 hybrids selected by the highest SCA estimates for high and low N was higher than the controls mean in approximately 330 and 241 kg·ha^{-1}. These results demonstrate that the selection for each environment was efficient and reveals the possibility of developing new hybrids for the Brazilian Cerrado region.

AUTHORS' CONTRIBUTION

Methodology, Gonçalves M. C., Heinz, H. and Teodoro, P. E.; Writing – Review and Editing, Ribeiro, L. P., Bhering, L. L. and Teodoro, P. E.; Supervision, Gonçalves M. C. and Heinz, H.

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REFERENCES

Alvarenga, R. C., Novotny, E. H., Pereira-Filho, I. A., Santana, D. P., Pereira, F. T. F. and Hernani, L. C. (2010). Cultivo do milho. In J. C. C. Cruz (Ed.). Sete Lagoas: Embrapa Milho e Sorgo.

Borém, A. (2009). Hibridação artificial de plantas. Viçosa, MG: Editora UFV.

Cancellier, L. L., Afférri, F. S., Carvalho, E. V., Dotto, M. A. and Leão, F. F. (2011). Eficiência no uso de nitrogênio e correlação fenotípica em populações tropicais de milho no Tocantins. Revista Ciência Agronômica, 42, 139-148. https://doi.org/10.1590/S1806-66902011000100018

Cruz, C. D. (2013). GENES - a software package for analysis in experimental statistics and quantitative genetics. Acta Scientiarum Agronomy, 35, 271-276. https://doi.org/10.4025/actasciagron.v35i3.21251

Cruz, C. D., Regazzi, A. J., Carneiro, A. J. and Souza, P. C. (2012). Modelos biométricos aplicados ao melhoramento genético. Viçosa, MG: Editora UFV.

Do Vale, J. C., Fritsche Neto, R., Bermudez, F. and Miranda, G. V. (2012). Efeitos gênicos de caracteres associados à eficiência no uso de nitrogênio em milho. Pesquisa Agropecuária Brasileira, 47, 385-392. https://doi.org/10.1590/S0100-204X2012000300010

Fageria, N. K., Santos, A. B. and Cutrim, V. A. (2007). Produtividade de arroz irrigado e eficiência de uso do nitrogênio influenciadas pela fertilização nitrogenada. Pesquisa Agropecuária Brasileira, 42, 1029-1034.

Fernandes, F. C. S, Buzetti, S., Arf, O. and Andrade, J. A. C. (2005). Doses, eficiência e uso de nitrogênio por seis cultivares de milho. Revista Brasileira de Milho e Sorgo, 4, 195-204. https://doi.org/10.18512/1980-6477/rbms.v4n02p%25p

Ferreira, D. F., Rezende, G. D. S. P. and Ramalho, M. A. P. (1993). An adaptation of Griffing's method IV of complete diallel cross analysis for experiments repeated in several environments. Brazilian Journal of Genetics, 16, 357-366.

Ferreira, E. A., Paterniani, M. E. A. G. Z., Duarte, A. P., Gallo, P. B., Sawazaki, E., Azevedo Filho, J. A. and Guimarães, O. S. (2009). Desempenho de híbridos top crosses de linhagens S3 de milho em três locais do estado de São Paulo. Bragantia, 68, 319-327. https://doi.org/10.1590/S0006-87052009000200005

Ferreira, E. A., Paterniani, M. E. A. G. Z. and Santos, F. M. C. (2010). Potencial de híbridos comerciais de milho para obtenção de linhagens em programas de melhoramento. Pesquisa Agropecuária Tropical, 40, 304-311. https://doi.org10.5216/pat.v40i3.7017

Fidelis, R. R., Miranda, G. V., Santos, I. C., Galvão, J. C. C., Peluzio, J. M. and Lima, S. O. (2007). Fontes de germoplasma de milho para estresse de baixo nitrogênio. Pesquisa Agropecuária Tropical, 37, 147- 153.

Fuzatto, S. R., Ferreira, D. F., Ramalho, M. A. P. and Ribeiro, P. H. E. (2002). Divergência genética e sua relação com os cruzamentos dialélicos na cultura do milho. Ciência e Agrotecnologia, 26, 22-32.

Guedes, F. L., Souza, J. C., Costa, E. F. N., Reis, M. C., Cardoso, G. A. and Ematné, H. J. (2011). Evaluation of maize top crosses under two nitrogen levels. Ciência e Agrotecnologia, 35, 1115-1121. https://doi.org/10.1590/S1413-70542011000600011

Griffing, B. A. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Sciences, 9, 463-493.

Hallauer, A. and Miranda Filho, J. D. (1988). Quantitative genetics in maize breeding. Ames. Iowa State University Press, 10, 468. https://doi.org/10.1007/978-1-4419-0766-0

Locatelli, A. B., Federizzi, L. C. and Naspolini Filho, V. (2002). Capacidade combinatória de nove linhagens endogâmicas de milho (*Zea mays* L.) em dois ambientes. Ciência rural. Santa Maria, 32, 365-370. https://doi.org/10.1590/S0103-84782002000300001

Medici, L. O., Pereira, M. B., Lea, P. J. and Azevedo, R. A. (2005). Identification of maize lines with contrasting responses to applied nitrogen. Journal of Plant Nutrition, 28, 903-915. https://doi.org/10.1081/PLN-200055586

Miranda Filho, J. B. and Viégas, G. P. (1987). Milho híbrido. In Parteniani, E. and Viégas, G. P. (Eds.). Melhoramento e produção de milho. Fundação Cargill, Campinas, p. 275-340.

Pfann, A. Z., Faria, M. V., Andrade, A. A., Nascimento, I. R., Faria, C. M. D. R. and Brighentti, R. M. (2009). Capacidade combinatória entre híbridos simples de milho em dialelo circulante. Ciência Rural, 39, 635-641. https://doi.org/10.1590/S0103-84782009000300002

Oliveira, E. P., da Silva, M. G. and Teodoro, P. E. (2017). Initial growth in maize in compliance of Azospirillum brasilense inoculation and nitrogen rates. Bioscience Journal, 33, 1242-1248. https://doi.org/10.14393/BJ-v33n5a2017-36753

Ribeiro, P. F., Badu-Apraku, B., Gracen, V. E., Danquah, E. Y., Garcia-Oliveira, A. L., Asante, M. D., Afriyie-Debrah, C. and Gedil, M. (2018). Identification of quantitative trait loci for grain yield and other traits in tropical maize under high and low soil-nitrogen environments. Crop Science, 58, 321-331. https://doi.org/10.2135/cropsci2017.02.0117

SAS Institute Inc (2004). SAS/STAT 9.1 User's Guide. Cary, NC: SAS Institute Inc.

Silva, R. G., Miranda, G. V., Cruz, C. D., Galvão, J. C. C. and Silva, D. G. (2008). Potencial genético das populações de milho UFVM 100 e UFVM 200 avaliadas em solos com deficiência de nitrogênio. Revista Caatinga, 21, 22-29.

Soares, M. O., Marriel, I. E., Magalhães, P. C., Guimarães, L. J. M., Cantão, F. R. O., Rocha, M. C., Carvalho Júnior, G. A. and Miranda, G. V. (2009). Discriminação de linhagens de milho quanto à utilização de nitrogênio, por meio da avaliação de características do sistema radicular. Revista Brasileira de Milho e Sorgo, 8, 93-103.

Sousa, D. M. G. and Lobato, E. (2004). Cerrado: Correção do solo e adubação. Brasília-DF: Embrapa Informação Tecnológica.

Souza, L. V., Miranda, G. V., Galvão, J. C. C., Eckert, F. R., Mantovani, E. E., Lima, R. O. and Guimarães, L. J. M. (2008). Genetic control of grain yield and nitrogen use efficiency in tropical maize. Pesquisa Agropecuária Brasileira, 43, 1517-1523. https://doi.org/10.1590/S0100-204X2008001100010

Souza, L. V., Miranda, G. V., Galvão, J. C. C., Guimarães, L. J. and Santos, I. C. (2009). Combining ability of maize grain yield under different levels of environmental stress. Pesquisa Agropecuária Brasileira, 44, 1297-1303. https://doi.org/10.1590/S0100-204X2009001000013