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Research Application Summary

Impact of introduced inbred lines on maize tolerance to acidic soils

Tandzi, N. L.,[1,4] Youmbi E.,[2] Ngonkeu, M. E. L.,[2,3] Zonkeng, N. C.,[3] Meka, S.S.,[3] Mafouasson, H.[3] & Mutengwa, C.S.[4]
[1]University of Ghana, P.O. Box LG 25, Legon, Ghana
[2]University of Yaounde I, P. O. Box 812, Yaounde, Cameroon
[3] Institute of Agricultural Research for Development (IRAD), P.O. Box 2067, Yaounde, Cameroon
[4]University of Fort Hare, Department of Agronomy, P. Bag X1314 Alice 5700, South Africa
Corresponding Author: tnliliane@yahoo.fr

Abstract

A total of 66 half diallel hybrids from 12 lines of maize and 16 top cross hybrids from four IRAD lines and four composites were evaluated on acid soils in Cameroon at Nkoemvone in 2004. The 12 lines consisted of five from IRAD, one from IITA, four from CIMMYT-Colombia and two from CIMMYT Mexico. The objectives of the study were to evaluate the genetic potential of introduced maize inbred lines for yield improvement to identify high yielding crosses under high Al toxicity (O) conditions and to study the gene effect. The trials were conducted under native acidic soils with high Al toxicity (O) and a control (T). Among the best 20 single cross hybrids on acid soils, 70% had at least one introduced parent while only 30% had locally adapted parents. One top cross hybrid was the best performer (5.01 t/ha) compared to the best open pollinated variety under stress environment (O).The study revealed that maize tolerance to acidic soils was controlled by non-additive gene action.

Key words: Acidity, diallel, hybrid, line, tolerant

Résumé

Au total, 66 hybrides d'un diallèle partiel entre 12 lignées endogames de maïs et 16 hybrides top cross provenant de 4 lignées de l'IRAD et 4 composites ont été évalués sur sol acide de Nkoemvone en 2004. Des 12 lignées utilisées, 5 provenaient de l'IRAD, 1 lignée de l'IITA, 4 du CIMMYT –Colombie, et 2 du CIMMYT Mexico. Les hybrides ont été évalués sur sol acide (O) et sur control (T). Les objectifs étaient d'évaluer la contribution des lignées introduites à l'amélioration des génotypes de maïs sur O, d'identifier les hybrides à haut rendement pouvant sur O, d'étudier le mode d'action des gènes. Des 20 meilleurs hybrides simples identifiés sur O, 70% contenaient au moins un parent introduit et 30 % étaient issus des lignées de l'IRAD. Un hybride top cross a donné un meilleur rendement (5.01 t/ha) comparativement au meilleur composite. La tolérance à l'acidité est sous la prédominance des gènes à effets non additifs.

Mots clés: Hybride, acidité, lignée, diallèle, tolérance.

Introduction

Maize (*Zea mays* L.) is one of the most important staple foods in the world. In Cameroon, maize is the most cultivated and consumed cereal crop. Despite efforts at increasing maize production in Cameroon, yields remain low because of some biotic and abiotic constraints. Soil acidity is one of the major yield-limiting factors for maize production. This abiotic stress decreases grain yield by up to 73%, depending on the location and year. Acid soil is generally characterized by low pH (usually < 5.0), toxic level of Al, Mn and Fe, and / or deficiency or unavailability of N, P, Ca, Mo, Si and Mg which inhibits root development, reduces water uptake and decreases yield consistently (Mossor-Pietraszewska, 2001; Tandzi *et al.,* 2018). In most of the acid soils, lime is applied to reduce exchangeable Al, increase exchangeable Ca, P and Mg and therefore raise the soil pH. In Ebolowa for example, 4 t ha^{-1} of dolomite was used to neutralize Al in the soil (Tandzi, 2011). However, the proposed correction method is costly, environmentally unfriendly and has temporary effect (Thé *et al.,* 2001). Alternatively, wood ash could be used as a substitute for lime; however 4 t ha^{-1} of wood ash is required to significantly improve yield in soils of low pH (Salazar *et al.,*1997). Hence using wood-ash it is not always practical (Mbah *et al.,*2010). Therefore, the development of acid tolerant maize genotypes is the sustainable way to raise the production under acidic environments.

Conventional breeding makes use of heterosis, heterotic patterns, and heterotic groups, as well as combing ability to develop high-yielding and tolerant maize hybrids to low soil pH (Tandzi *et al.,* 2018). A lot of progress has been made in breeding maize for acid soil tolerance through recurrent selection. The effects of climate change has been demonstrated to reduce agricultural production, worsen food and water security, and increases incidence of both biotic and abiotic stresses for crop production (APF, 2007). In Cameroon, it has been projected that the total maize production will reduce by 14 % by 2055 due to climate change (Jones and Thornton, 2003). This means that the climate change may reinforce the acidity of the soils. Researchers should develop more low soil pH tolerant genotypes to overcome this challenge. The Acid Tolerant Population (ATP) has been developed over the years in Cameroon with material having different level of tolerance to soil acidity. There is need to raise the breeding potential of the Cameroonian ATP with desired introduced genes. The main objective of this study was to identify the best performing acid tolerant maize germplasm and to determine their combining abilities, and gene effects for Al tolerance, so as to inform future breeding strategies.

Material and methods

The experiment was carried out in Cameroon at Nkoemvone (12^0 24^0 E, 2^0 40^0 N) a village located at 25 km from the city of Ebolowa in the humid forest zone with an altitude of 615 m above sea level, an average temperature of 24 ^{0}C in a bimodal rainfall distribution with annual rainfall of 1800 mm (The *et al.,* 2001). The soil is oxisol and typically kandiudox clay with high Al toxicity (Thé *et al.,* 2005). The average soil pH is 4.6 with a concentration of Al up to 1.6 Meq per 100g of soil.

Two trials were laid out. The first was a half diallel of 12 inbred lines collected from Institute of Agricultural Research for Development (IRAD), The International Institute of Tropical Agriculture (IITA) in Nigeria, CIMMYT Colombia and International Maize and Wheat Improvement Center (CIMMYT) Mexico. The lines were planted on 11th of May 2004 in a Randomised Complete Block Design (RCBD) with two replications under a native acidic soil (O) and a limed or control environment (T).

The second trial of 16 top crosses coming from crosses between four lines selected from the 12 inbred lines and four open pollinated varieties from IRAD and IITA (Tuxpeno sequia, ATP-SR-Y, ATP-S5-Y and ATP-SynD-Y) were also evaluated in the same experimental site at the same period. The trail was laid out in a RCBD with two replications under native acid soil (O) and a control (T).

In the control environment of each of the two trials, 2 t ha^{-1} of dolomitic lime and 4 t ha^{-1} of poultry manure were applied. The experimental unit was a row of five metres long with 11 planting stations each with 0.5m between plants. Two consecutive rows were separated by 0.75m. Two border rows were planted at the beginning and the end of each block and between replications. On 29th May 2004, 100 kg ha^{-1} of 14N-24P-14K and 50 kg ha^{-1} of Urea (56% of N) was applied. Further, 50 kg ha^{-1} of Urea was applied on 22nd May 2004. Manual weeding was conducted on 4th June 2004 using hoes and on 23rd June, a herbicide (Gramoxone) was applied. Harvesting was done on 15th September 2004. Data were recorded on plant stand, ear and plant heights (from the soil surface to the node of the top ear and the flag leaf, respectively). All plants in a plot were hand harvested. Grain yield (t ha^{-1}) was determined using 80% shelling percentage and adjusted to a standard 155 kg ha^{-1} grain moisture. Yield loss due to soil acidity was calculated using the following formula:

((Yield under corrected acid soil – Yield under acid soil) / Yield under corrected acid soil)*100

Soil treatments (O and T) were considered as random effects and pooled as environmental effects. Hybrids were considered as fixed effects. Statistical analysis of variance was performed using the GLM procedure of SAS. The statistical model used to calculate GCA and SCA effects in single environment was as follows:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

Where Yijk is the k^{th} replication of the i x j^{th} progeny, μ is the experimental mean, gi is the effect of the i^{th} line, gj is the effect of the j^{th} tester, sij is the interaction effect of the i^{th} and j^{th} tester, and eijk is the effect error associated with ijk^{th} observation.

Results

Diallel results. The analysis of variance showed significant difference between crosses for yield and plant height under acid soil (Table 1). The mean yield of hybrids under acid soil ranged from 0.07 t ha^{-1} to 4.3 t ha^{-1} obtainedwith CLA 18 X 9450 and 91105 x Cam Inb gp1 17, respectively. The mean yield of the trial was 1.41 t ha^{-1} on acid soil.

Table 1. Mean square of parameters evaluated for single cross hybrids

Source of variation	df	Yield		Ear height		Plant height	
		O	T	O	T	O	T
Rep.	1	0.22 NS	29.66**	1368**	1745.4*	3.65 NS	441.3
Crosses	65	1.35**	3.67 NS	301.9 NS	572.5**	1152.2**	897.7 NS
Error	65	0.6	2.8	251.67	293.15	651.7NS	739.8

** Significant at p<0.01 * Significant at p<0.05 NS Non significant

In the control or corrected acid soil, hybrids (9450 x Cml 247 and 9450 x 87036) yielded 0.28 t ha^{-1} and 5.23 t $ha,^{-1}$ respectively. The mean yield of the trial for hybrids under corrected acid soil was 3.90 t ha^{-1}. The best 20 hybrids on acid soil were selected (Fig. 1). The yield loss due to soil acidity of the best 20 single cross hybrids ranged from 4.6 to 68.2 % for 91105 x Cam Inb gp1 17 and Cam Inb gp1 17 x NCRE gp2 8, respectively. The mean yield loss of the trial was 55.8%. The mean of the insertion of ear was 56.4 and 93.4 cm on acid soil and control, respectively. The mean of plant height was 130.9 and 193.3 cm on acid soil and corrected acid soil, respectively. On corrected acid soil, plant hybrids grew taller than on acid soil. The best hybrid on acid soil had 150 cm height compared to 210 cm height in the control with a yield loss of 4.6 %.

Contribution of introduced inbred lines. Among the top 20 simple hybrids, six (30%) originated from locally adapted x locally adapted (A x A) lines; seven (35%) were developed from crosses between introductions from CIMMYT x locally adapted lines (I x A), and seven (35%) were crosses between two introduced inbred lines (I x I). On average, the A x A crosses had a yield performance of 2.5 t ha^{-1} on acid soil and 4.1 t ha^{-1} on corrected acid soil (4.1 t ha^{-1}); however, they also showed the largest grain yield loss due to soil acidity (33.8 % of yield loss). The I x A hybrids had an average yield of 2.04 t/ha on acid soil and had grain yield loss due to soil acidity of 44.9 t ha^{-1}. Although I x I exhibited the smallest yield reduction (28.3 %) on acid soils, their average yield on acid soil was only 2.3 t ha^{-1}. They were therefore more tolerant than crosses between locally adapted germplasm and introduced lines but much lower yielding. Among the 20 best single cross hybrids, 70 % had at least one introduced parent while only 30 % had locally adapted parents.

Combining abilities. General combining ability and specific combining ability were significantly different for yield, ear height and plant height under acid soil (Table 2). In the control, general combining ability was significant for yield and ear height and non significant for plant height. Specific combining ability was non-significant for yield and plant height under corrected acid soil (T). Only ear height were significant difference among hybrids in the control.

Top cross hybrids results . The analysis of variance showed significant difference between genotypes for yield, ear height, and plant height under acid soil. On corrected acid soil, the

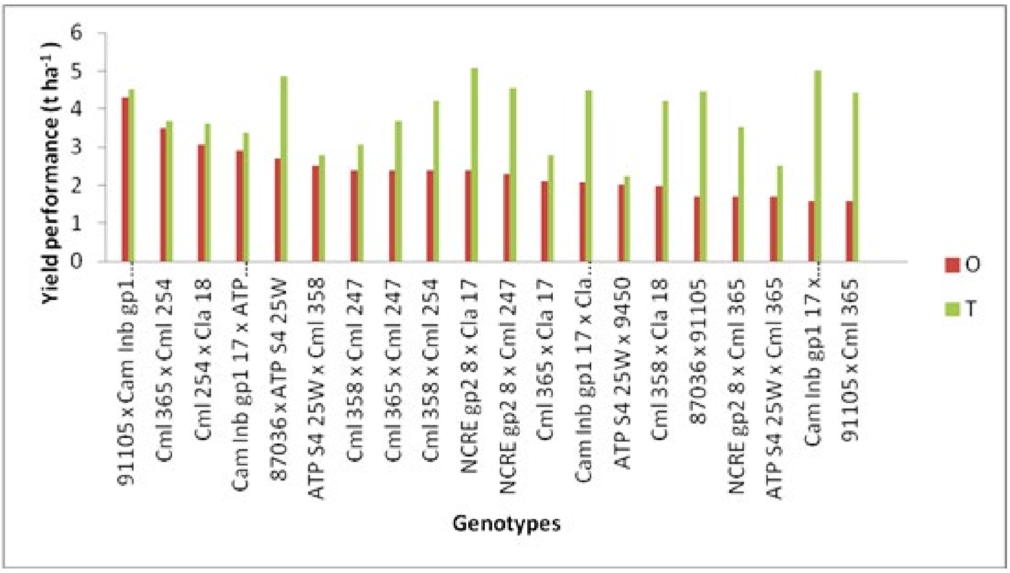

Figure 1. Performance of the top 20 hybrids on acid soil versus control (selection pressure used: 30%)

Table 2. Mean square of combining abilities of lines on native soils (O) and control (T)

	df	Yield		Ear height		Plant height	
Source of variation		O	T	O	T	O	T
GCA	11	1.22**	6.6*	425.5*	737.3**	1472.1*	1345.3 NS
SCA	54	1.38**	3.08NS	276.7*	538.9**	1088.2*	806.5 NS
Error	65	0.61	2.8	651.7	293.1	651.7	739.8

** Significant at p<0.01 * Significant at p<0.05 NS Non significant

significant difference was observed only on ear height among genotypes. The interaction of crosses and parents (F1 x Parent) was significantly different for ear height and plant height on acid soil. The yield of top cross hybrids ranged from 2.33 to 5.01 t/ha for ATP-SynD-Y x Cml 358 and ATP-SR-Y x 87036, respectively, on acid soil and from 6.06 to 8.91 t ha^{-1} on corrected acid soil for ATP-SynD-Y x9450 and ATP-SR-Y x 87036, respectively. On the other hand, the high-yielding top cross hybrid on acid soil had the highest yield on corrected acid soil. The mean yield of the trial was 3.10 t ha^{-1} on acid soil and 7.45 t ha^{-1} in the control. The yield loss due to soil acidity was in the range of 44 % for ATP-SR-Y x 87036 and 69 % for Tuxpeno x 9450 and ATP-SynD-Y x Cml 358. All the top cross hybrids obtained with one of these two parents as female (Tuxpeno and ATP-SynD-Y) showed an average yield loss of 63 %. The level of tolerance of the two open pollinated varieties was lower than the level of tolerance of other parents (ATP-SR-Y and ATP-S5-Syn-Y). The four open pollinated varieties had a yield range of 1.96 to 3.75 t ha for Tuxpeno and ATP-SR-Y respectively on acid soil. Under corrected acid soil, the yield varied between

5.60 to 7.45 t ha^{-1} for ATP-S5-Syn-Y and ATP-SR-Y, respectively. Their yield loss due to Al toxicity was in the range of 50-69 % for ATP-SR-Y and Tuxpeno with 56%. Heterosis ranged from -26 to 72% given by ATP-SynD-Y x Cml 358 and Tuxpeno x 91105 on acid soil with an average of 12%. But the top cross hybrid expressing high heterosis (Tuxpeno x 91105) on acid soil with a yield loss due to Al toxicity of 51%. Seven top cross hybrids showed negative heterosis on acid acid soil while two negative heterosis were observed in the control. In the control environment the heterosis ranged from -6 to 40% from ATP-SynD-Y x9450 and ATP-S5-Syn-Y x 91105, with an average of 16 %. ATP-SR-Y x 87036 expressed heterosis of 34% on acid soil and 19% on a corrected acid soil.

Discussion

From the results, single cross hybrids and top cross hybrids yielded better than open pollinated varieties. These results confirmed those from earlier research indicating that the best hybrids yielded more than the best open pollinated cultivars since they had stronger roots and greater resistance (Granados, 1993). On acid soils, top cross hybrids yielded better than simple hybrids. This could be explained by the fact that in the stress environment, top cross hybrids perform better than single cross since they are derived from a cross between an adapted open pollinated variety with wide genetic basis used as female and an inbred line used as a male.

Significant difference of GCA and SCA mean squares for yield suggested that tolerance to soil acidity was controlled by additive as well as non additive gene effects with the preponderance of additive gene effects. These results corroborate those of earlier studies (Mossor-Pietraszewska, 2001). Progress could be achieved by subjecting the parental populations from which the inbred lines were developed to recurrent selection for improved performance. In addition, the presence of non-additive gene action suggested that high yielding hybrids on acid soil may be obtained by classifying the inbred lines into different heterotic groups and crossing lines from the different groups to produce new hybrids. This study showed that 70 % of the top 20 hybrids originated from crosses between lines from CIMMYT, lines that originated from IITA-Ibadan, Nigeria and IRAD Cameroon. Therefore, for further studies, heterotic pools could be developed on the basis of CIMMYT and IRAD-IITA inbred lines, respectively.

Conclusion and recommendation

This study showed that maize cultivation on acid soils could lead to grain yield reduction up to 63% or more in tropical environments. The best top cross hybrid was ATP-SR-Y x 87036 which yielded 5.01 t ha^{-1} on acid soils and 8.91 t ha^{-1} on corrected acid soil expressing 34 % hetorosis and 44% yield loss. Even though the genotype was the best, on-farm trails are required to confirm its perfomance in different environments. The top 20 highest-yielding single cross hybrids on acid-soil involved 70% introduced inbred lines from CIMMYT and only 30% from locally adapted inbred lines. Grain yield loss due to soil acidity could be minimized by the development of hybrids from crosses between locally adapted inbred lines and introduced inbred lines from CIMMYT Cali, Colombia acid soil program.

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