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Evaluation of maize (*Zea mays* L.) accessions using line x tester analysis for aluminum and manganese tolerance

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ABSTRACT

Soil acidity is a limiting factor severely affecting the growth and yield of maize. The present study aimed at estimating the breeding value of inbred lines and to assess the test-cross performance of the hybrid maize under acid soil conditions. A line x tester analysis involving 63 test-crosses generated by crossing 20 maize inbred lines with 3 testers and between testers themselves, and 1 standard check was investigated during the cropping season 2012 in two contrasted regions with aluminum and manganese toxicity in Cameroon. Both treatments, acid soil and non-acid soil, using dolomitic lime were conducted in a randomized complete block design with 3 replications. Seven hybrids producing high grain yield (4.27 to 9.88t/ha), with high specific combining ability (SCA) and slow rate of yield loss were discovered such as tolerant for both types of acidic soils. Likewise, four inbred lines (ATP-46, 87036, and Cam Inb gp117, C4SRRA7) with high general combining ability (GCA) were retained as good progenitors. The GCA and SCA effects showed that the tolerance to aluminum toxicity was controlled by additive effects of genes while on acid soil with manganese toxicity, the contribution of non-additive effects of genes was dominant.

Keywords: Inbred lines, hybrids, acid soil, GCA, SCA, humid forest zones.

INTRODUCTION

Maize (*Zea mays* L.) is widely consumed in Central and West Africa, and serves as raw materials for the food industry. Several millions of people in developing countries consume maize as a stable food deriving their energy requirements. Maize is cultivated in all of the five agro-ecological zones of Cameroon, with some constraints related to soil acidity. Humid forest zones covering 21.7 million hectares of the area of Cameroon are composed of 75 to 100% of

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acid soils (Bindzi-Tsala, 1987; Ambassa-Kiki, 2002). These soils are characterized by an excess of Al^{3+}, Mn^{2+} and H^{+} with deficiencies in Ca^{2+}, Mg^{2+} and $PO4^{3+}$, reducing root growth of plants and the absorption of the essential nutrients (Kochian et al., 2005; Krstic et al., 2012). In the humid forests zones of Cameroon, acidity is the main limiting factor of the soil productivity (Ngonkeu, 2009). In many developing countries, this factor reduces maize yields of about 70% over 8 million hectares of tropical soils (Welcker et al., 2005) and causes yield losses of about 38% in Cameroon (Tandzi et al., 2015a).

For an acceptable agricultural production, Thé et al. (2006b) showed that an amendment of soil with lime (2 t/ha) increases grain yields of tolerant and susceptible varieties. Also, Ngonkeu (2009) showed that the use of improved maize varieties coupled to biological processes in soil fertility of certain species of arbuscularmycorrhizal fungi has the capacity to improve the tolerance of plants to acid soils with aluminum and manganese toxicity. However, these solutions are expensive for poor resource farmers. Furthermore, Thé et al. (2006a) identified the two best hybrids (Cam Inb gp1 17 x 87036 and Entrada x 87036) and six good progenitors (Cam Inb gp1 17, $ATPS_4 25W$, CMLci-IDR-STR, 87036, M131 and CML357) for tolerance to soil acidity. Unfortunately, they have not been popularized and are not available to Cameroonian farmers. In addition, the variety ATP-SR-Y (4 t/ha on acid soil) developed since 1999, has been considered as the best tolerant variety. However, it still records losses in yield of up to 57%, due to soil acidity (Thé et al., 2006b). Recently, 24 maize hybrids (3.91- 6.12 t/ha) were developed (Tandzi et al., 2015a) and 5 tolerant inbred lines were identified (Tandzi et al., 2015b) essentially under acid soil with aluminum toxicity.

However, the impacts of climate change and especially acid soils with aluminum and manganese toxicity increase yield losses in maize. Thus it is necessary to develop other varieties adapted in many areas that consider these constraints in order to provide farmers with maize cultivars which offer ecological, economical and a permanent solution, contributing to sustainable crop production in acid soils (Welcker et al., 2005). So, line x tester is useful in deciding the relative ability of female and male lines to produce desirable hybrid combinations (Kempthorne, 1957). Also, it provides information on genetic components and enables the breeder to choose appropriate breeding methods for hybrid variety or cultivar development programs (Girma et al., 2015). Moreover, data on combining ability effects helps the breeder in choosing the parents with high general combining ability and hybrids with high specific combining. The present investigation was carried out to estimate breeding value of inbred lines and to assess the test cross performance of the hybrid maize under acid soil conditions.

MATERIALS AND METHODS

Experimental sites

Trials were set up in two bimodal humid forest zones of Cameroon (Figure 1): Nkolbisson site is located at an altitude of 650 m above sea level. Its annual average temperature is 23.5 °C, it has a rainfall with an annual average of 1560 mm. The soil texture is clay loam with a strong tendency for waterlogging, manganese toxicity and belongs to the Kandiudox type. At Ebolowa, the site (Nkoemvone) is located 25 km away from the city, at an altitude of 615 m above sea level. Its annual average temperature is 24 °C, a climate of Guinean type and a rainfall whose annual average is 1875 mm. The soil texture is clayey and aluminum toxicity, classified in the Kandiudox type and belonging to oxisols (Welcker et al., 2005).

Plant material

The plant material consisted of 63 single hybrids derived from "line x tester" crosses between 20 tropical inbred lines with three testers (Cam inbgp117, 88069 and 9450) and between testers themselves, and 1 standard check variety (ATP-SR-Y). Crosses were made during 2011 and the evaluation of genotypes was performed during the raining season 2012. These varieties were crossed according to their broad genetic basis, different levels of tolerance to soil acidity, geographical diversities and varied colors, responding to the user's choice (Table 1).

Experimental design

Experiments were conducted in a randomized complete block design with three repetitions, installed in an area of 1,620 m^2. Planting was done at a density of 53,333 plants/ha. Main plots involved treatments O (uncorrected acid soil: 0 t/ha of dolomitic lime) and T (corrected soil acidity: 2 and 4 t/ha of dolomitic lime applied respectively on soils with manganese and aluminum toxicity). The experimental unit was a line of 4 m, with a distance of 0.5 m separating one plant from another. Field trials have received the recommended rate of fertilizer in split application, which consists of a basal dose of 37 N, 24 P2O5 and 14 K2O kg/ha applied 7 days after planting and the remaining 126 kg N/ha applied 30 days after planting (Tandzi et al., 2015b).

Data collection

Data were recorded on different traits including: seedling emergence rate, ear aspect recorded visually and scale (1-5), prolificacy of plants, number of harvested plants, number of harvested ears, weight of ears, moisture content of grains and grain yield. Grain yield (GY) was adjusted to 15% of moisture using the formula of CIMMYT (1985): GY (t/ha) = [Grain Weight (kg/plot) x 10 x (100-MC)/ (100-15) / (Plot Area)], where MC = Grain Moisture Content and plot area = row length x 0.75 (4x0.75 = 3m). The rate of yield loss (R) due to soil acidity was calculated as follows: R (%) = [GY (corrected acid soil) – GY (uncorrected acid soil)]/ [GY (corrected acid soil)].

Statistical analyses

Data were subjected to analysis of variance using SAS software, 9.0., following the procedure Generalized Linear Model and the separation of means was made by the Student Newman Keuls test at 5%. Line x tester analysis was done for traits using the adjusted means based on the method described by Kempthorne (1957). General combining ability (GCA) and specific combining ability (SCA) effects for grain yield and other agronomic traits were estimated through line x tester model using XLSTAT 2013 software.

Figure 1: Map of Cameroon showing the field sites used in this study (Ngonkeu, 2009).

RESULTS

Chemical composition of soil

In both experimental sites, soils were very acidic (pH<5.5). In Nkolbisson, the pH was 5.12 whereas in Ebolowa, it hardly exceeded 4.33 (Table 2). Also, the studied soils presented low values of available phosphorus. At Nkolbisson and Ebolowa, the saturation rates were 39.25% and 32.84% respectively from which their acidity was characterized by the manganese and aluminum toxicity.

In the farmers' fields, the common responses of plants against the acidity related to aluminum toxicity at Ebolowa were decreases of the photosynthetic activity leading to necrosis and chlorosis of the leaves, of the plant height, of the leaves number, and aerial biomass. Other symptoms observed were similar to those of phosphorous and calcium deficiency. At Nkolbisson, the symptoms of the manganese toxicity were mainly leaf yellowing, the appearance of red-purple spots on the leaves inducing the development of chlorosis (Figure 2).

Agronomic performance of hybrids

Analysis of variance showed highly significant differences between different sites for the emergence rate, prolificacy and grain yield. Highly significant differences were observed for the ear aspect and grain yield between treatments whereas highly significant differences were observed between tested materials for all the traits (Table 3).

Ebolowa site

The analysis of variance on uncorrected acid soil showed highly significant differences between the tested accessions for all traits (Table 4). On uncorrected acid soil, grain yields were ranged from 0.78 t/ha (ATP S6 33Y-1 x 9450) to 11.67 t/ha (ATP-Last x Cam Inb gp1 17) with an average of 4.65 t/ha. 12 varieties have presented grain yields higher than the standard check ATP-SR-Y (5.76 t/ha). On corrected acid soil, grain yields were ranged from 1.77 t/ha (D 506-4 x 88069) to 11.04 t/ha (C4RRSA4 x88069), with an average of 6.30 t/ha. 56 hybrids have shown higher yields than ATP-SR-Y (3.58 t/ha). The percentage of yield loss was 26.19%.

Nkolbisson site

The analysis of variance on uncorrected and corrected acid soil showed highly significant differences between the different accessions for all traits (Table 5). On uncorrected acid soil, yields were ranged from 0.60 t/ha (CLA 154 x Cam Inb gp1 17) to 9.54 t/ha (C4RRSA7 x 9450). The average of test carried out in all of the accessions was 4.74 t/ha. The percentage of yield loss was 21.91%. On corrected acid soil, yields were ranged from 0.73 t/ha (CLA 106 x 88069) to 8.97 t/ha (87036 x 88069). 49 hybrids were more productive than ATP-SR-Y (4.95 t/ha). Accessions had an average yield of 6.07 t/ha.

Breeding value

General Combining Ability

In Ebolowa, on uncorrected acid soil, ten parents have presented the positive GCA (Table 6). Among them, five inbred lines (ATP-Last, ATP-46, Ku1414, ATP-43 and 87036) were being approached as tolerant to acid soil (Table 1), four (D506-4, CLA 154, C4SRRA7 and 88069) were presumed to have an indefinite level of tolerance and one (Cam Inb gp1 17) was susceptible to acidity of soil. On corrected acid soil, eleven accessions had the positive GCA (Table 6). Among them, four (ATPS6 33Y-1, ATP-Last, (Cam Inb gp1 17 (F), and Ku1414) were foreseen as tolerant to acid soils, five (D506-3, CLA154, Cml 322, C4SRRA4 and C4SRRA6) had a level of tolerance presumed undetermined and two (CLA18 and 9450) had an average level of tolerance. In general, three inbred lines (ATP-Last, Ku1414 and CLA 154) had positive AGC in both uncorrected and corrected acid soils.

In Nkolbisson, on uncorrected acid soil, ten parental lines have presented positive GCA (Table 6). Among them, six (ATP S6 33 Y-1, ATP S6 32 Y-1, ATP-46, 87036, CLA 106 and Cam Inb gp1 17) have been foreseen as tolerant to acid soil and four (ATP-14, Cml 322, C4SRRA3 and C4SRRA7) had a presumed undetermined level of tolerance (Table 1). On corrected acid soil, nine accessions presented positive AGC and among them, five (ATP S6 33 Y-1, ATP S6 32 Y-1, ATP-46, 87036 and Cam Inb gp1 17) had been foreseen as tolerant to acid soil and the other four (ATP-14, C4SRRA6, Cml 322 and C4SRRA7) presented a level of tolerance presumed undetermined. Thus, seven lines (ATP-46, ATP S6 32Y-1, ATP-46, 87036, Cml 322, C4SRRA7 and Cam Inb gp1 17) had positive GCA on uncorrected acidic soil as well as in corrected. Four lines (ATP-46, 87036, C4SRRA7 and Cam Inb gp1 17) had positive values of GCA on acid soil with aluminum and manganese toxicity.

Specific Combining Ability

A considerable variability between Specific Combining Ability (SCA) and grain yield were observed between hybrids (Table 7).

In Ebolowa, SCA was ranged from 0.26 (ATP S6 33 Y-1 x Cam Inb gp1 17) to 1.81 (ATP-Last x Cam Inb gp1 17). The most tolerant variety for acidic soil (ATP -Last x Cam Inb gp1 17 (11.67 t/ha)) have also presented the highest SCA (1.81). Thus, lines ATP-Last and Cam Inb gp1 17 could be classified into the opposite heterotic pools, in order to serve as a classification base for other lines. Thus, twenty hybrids have been selected regarding their best SCA, their high grain yield and their low rate of yield loss presented under acid soil conditions with aluminum toxicity (Table 7). In Nkolbisson, SCA varied from 0.22 (Cml 358 x 88069) to 0.81 (C4SRRA6 x Cam Inb gp1 17). The hybrid C4SRRA6 x Cam Inb gp1 17 presented the best SCA with a good yield on acid soil. Thus, line C4SRRA6 belongs to an opposite pool of Cam Inb gp1 17. Also, twenty hybrids were selected for their performance under acid soil conditions with manganese toxicity (Table 7).

Lastly, seven accessions were retained according to their SCA (0.22 – 0.91), their grain yield (4.27 to 9.88t/ha) and rate of yield loss observed simultaneously on acid soil with aluminum and manganese toxicity. they were: ATP-46 x Cam Inb gp1 17, Ku1414 x 88069, C4SRRA7 x 9450, Cml 358 x 88069, D506-4 x Cam Inb gp1 17, ATP-43 x 88069 and ATP S6 33Y-1 x Cam Inb gp1 17. Therefore, each of the parents of these hybrids can be classified in different heterotic pools because they are genetically distant from each other. However, low SCA and low yield hybrids can be considered as belonging to the same heterotic pools because they are genetically very close.

Effects of genes

GCA and SCA effects were significant in both uncorrected and corrected acid soils for the grain yield trait (Table 8), indicating the presence of additive effect of genes and non-additive effect of genes in the tolerance to acidic soil for this trait.

In Ebolowa, the effect of GCA was significant for TL (emergence rate) and grain yield (GY) traits in both uncorrected and corrected acid soil. Also, on uncorrected acid soil, the effect due to the AGC was significant for the variable TL, indicating that this trait is controlled by additive effect of genes on acid soil. On corrected acid soil, AGC effect was significant for AE (ear aspect). Furthermore, the effects of SCA were significant for AE on uncorrected acid soil suggesting that this trait is controlled by non-additive effect of genes on acid soil. Thus, for the yield in Ebolowa, the additive effects of genes were dominant over those of the non-additive effect of genes. This superiority was valid on corrected acid soil. In Nkolbisson, the effect of GCA was significant for the variable TL both on uncorrected and corrected acidic soil. Mainly on corrected acidic soil, the effect of GCA was significant for TL, PR, AE and GY, indicating that these traits were controlled by additive effect of genes. In addition, the effect of SCA was significant for TL, TP, AE and GY on acid soil. One can say that on acid soil with manganese toxicity at Nkolbisson, the contribution of non-additive effects of gene was greater than the additive effects of gene.

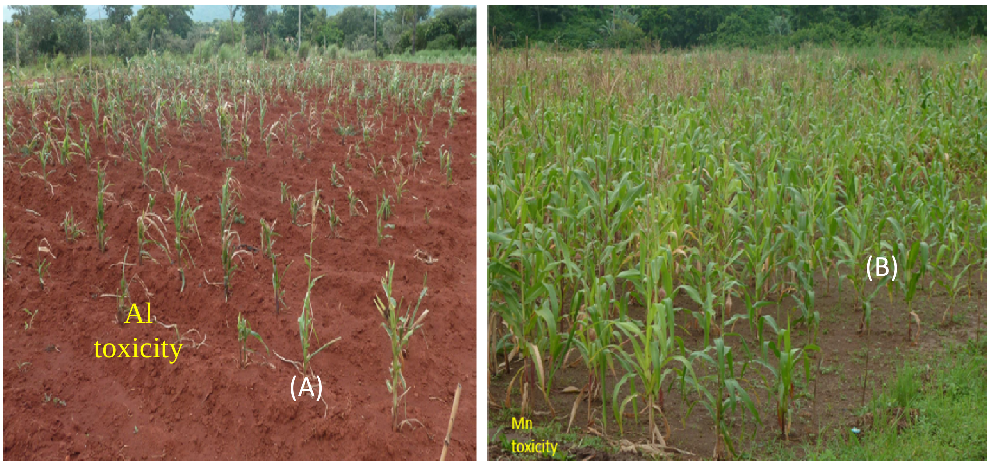

Figure 2: Impact of aluminum toxicity (A) and manganese toxicity (B) on maize plants (65 days after planting) in the fields respectively at Ebolowa and Nkolbisson.

Table 1: Origins and characteristics of used maize varieties.

Number	Varieties	Origins	Genetic basis	presumed level of tolerance to toxicity: aluminum-manganese	Seeds color
1	ATP S6 33Y-1	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
2	ATP S6 32Y-1	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
3	ATP-Last	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
4	ATP-46	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
5	ATP-43	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
6	D 506-3	CIMMYT	n.d	n.d	Yellow
7	D 506-4	CIMMYT	n.d	n.d	Yellow
8	Ku 1414	IITA	n.d	Tolerant-Tolerant	Yellow
9	87036	IRAD	TMZsr x pop32	Tolerant-Tolerant	White
10	CLA 154	CIMMYT	n.d	n.d	Yellow
11	CLA 106	CIMMYT	n.d	Tolerant-Tolerant	Yellow
12	ATP-14	IRAD	n.d	n.d	Yellow
13	CLA 18	CIMMYT	n.d	Moderatelytolerant- tolerant	Yellow
14	Cml 322	CIMMYT	n.d	n.d	White
15	Cml 358	CIMMYT	Pop SA3	Tolerant-Tolerant	Yellow
16	9450	IITA	B73	Moderatelytolerant-Tolerant	Yellow
17	88069	IRAD	n.d	n.d	Yellow
18	Cam Inb gp1 17	IRAD	Suwan I-SR	Susceptible-Tolerant	Yellow
19	C4RR SA3	CIMMYT	n.d	n.d	Yellow
20	C4RR SA4	CIMMYT	n.d	n.d	Yellow
21	C4SRR SA6	CIMMYT	n.d	n.d	Yellow
22	C4 SRR A7	CIMMYT	n.d	n.d	Yellow
23	Cam Inb gp1 17 (F)	IRAD	Suwan I-SR	Tolerant-Tolerant	Yellow
24	ATP-SR-Y	IRAD	ATP-SR	Tolerant-Tolerant	Yellow

n.d: no determined; CIMMYT: International Maize and Wheat improvement Center; IRAD: Institute of Agricultural Research for Development. IITA: International Institute of Tropical Agriculture; Pop: population; ATP: Acid Tolerant Population; source: Thé et *al*. (2006b).

Table 2: Chemical characteristics of soils in Nkolbisson and Ebolowa.

Chemical composition of soils	Nkolbisson	Ebolowa
	0-20 cm	0-20 cm
Ca (cmol(+)/kg)	2.68	0.68
Mg (cmol(+)/kg)	0.72	0.2
K (cmol(+)/kg)	0.24	0.24
Na (cmol(+)/kg)	0.05	0.013
Al (cmol(+)/kg)	0.52	2.32
CEC (cmol(+)/kg)	9.4	3.45
Zn (ppm)	4.73	0.533
Cu (ppm)	3.08	1.75
Mn (ppm)	90.6	6.49
Fe (ppm)	414.67	113.35
P (ppm)	4.65	7.55
N total (%)	0.13	0.121
C total (%)	1.81	1.13
C/N	13.86	9.28
$PH_{(H2O)}$	5.12	4.33
Saturation rate (%)	39.25	32.84
Conclusion	Manganesetoxicity	Aluminium toxicity

Table 3: Mean squares from the analysis of variance for the measured traits.

Source of variations	df	ER	PR	AE	GY
Sites	1	4645,70***	1,51***	0,39 ns	3,18 ns
Traitements	1	2829,28*	0,00001 ns	4,97***	443,33***
Accessions	63	522,21***	0,15***	0,76***	11,28***
Error	702	200,81	0,05	0,31	4,75

df: degree of freedom;; ER: Emergence Rate ; PR: prolificity; EA: Ear Aspect; GY: grain yield
***: significant at P< 0.0001; *: significant at P< 0.05; ns: no significant at P>0.05.

Table 4: Mean squares of accessions and error for evaluated traits in Ebolowa.

Source of variation	df	ER		PR		EA		GY	
		O	T	O	T	O	T	O	T
Accessions	63	366,22***	348,65***	0,02***	0,006*	0,67***	0,40***	10,99***	13,33***
Error	128	55,38	125,56	0,006	0,02	0,11	0,14	1,55	4,04

df: degree of freedom;; ER: Emergence Rate ; PR: prolificity; EA: Ear Aspect; GY: grain yield ***: significant at P< 0.0001; *: significant at P< 0.05; ns: no significant at P>0.05.; O: uncorrected acid soil; T: corrected acid soil sol.

Table 5: Mean squares of accessions and error for evaluated traits in Nkolbisson.

Source of variations	df	ER		PR		EA		GY	
		O	T	O	T	O	T	O	T
Accessions	63	570,93***	454,57***	0,20***	0,17***	0,89***	0,90***	12,81***	8,77***
Error	128	152	78,57	0,04	0,03	0,19	0,18	1,87	1,48

df: degree of freedom;; ER: Emergence Rate ; PR: prolificity; EA: Ear Aspect; GY: grain yield
***: significant at P< 0.0001; *: significant at P< 0.05; ns: no significant at P>0.05; O: uncorrected acid soil; T: corrected acid soil sol.

Table 6: General combining ability (GCA) of lines for the grain yield on corrected and uncorrected acid soil in the sites of Ebolowa and Nkolbisson.

Lines / testers	GCA			
	Ebolowa		Nkolbisson	
	O	T	O	T
ATP S6 33Y-1	-0,38	0,11	0,04	0,4
ATP S6 32Y-1	-0,16	-0,3	0,43	0,38
ATP-Last	0,49	0,08	-0,54	-0,39
ATP-46	0,2	-0,35	0,3	0,54
ATP-43	0,13	-0,48	-0,35	-0,09
Cam Inb gp1 17 (F)	-0,32	0,53	-0,12	-0,64
D 506-3	-0,04	0,56	-0,28	-0,15
D 506-4	0,24	-0,69	-0,68	-0,21
Ku 1414	0,85	0,26	-0,42	-0,62
87036	0,42	-0,42	1,09	0,79
CLA 154	0,65	0,75	-0,81	-0,06
CLA 106	-0,12	-0,15	0,09	-0,47
ATP-14	-0,02	-0,21	0,58	-0,09
CLA 18	-0,38	0,11	-0,18	-0,02
Cml 322	-0,32	0,3	0,33	0,11
C4RR SA3	-0,56	-0,81	0,45	-0,07
C4RR SA4	-0,44	0,54	-0,4	-0,03
C4SRR SA6	-0,03	0,82	-0,14	0,28
C4 SRR A7	0,17	-0,26	0,87	0,55
Cml 358	-0,36	-0,39	-0,27	-0,19
9450	-0,13	0,21	-0,02	-0,05
88069	0,1	-0,04	-0,07	0,02
Cam Inb gp1 17	0,03	-0,16	0,1	0,02

GCA: General combining ability; O: uncorrected acid soil; T: corrected acid soil.

Table 7: Twenty (20) best specific combining abilities for grain yield on acid soil in the sites of Ebolowa and Nkolbisson.

Ebolowa				Nkolbisson			
Accessions	SCA	GY(t/ha)	R(%)	Accessions	SCA	GY(t/ha)	R(%)
ATP-Last x Cam Inb gp1 17	1,81	11,67	2,14	C4SRR A6 x Cam Inb gp1 17	0,81	7,09	4,41
ATP-46 x Cam Inb gp1 17	0,91	8,1	3,37	ATP-46 x Cam Inb gp1 17	0,8	8,5	5,93
Ku 1414 x 88069	0,78	9,88	86,44	CLA 154 x 9450	0,77	4,57	3,58
CLA 106 x 88069	0,69	6,66	39,14	D 506-3 x Cam Inb gp1 17	0,75	6,5	24,76
Cam Inb gp1 17 (F) x 9450	0,63	5,18	14,16	C4 SRR A7 x 9450	0,74	9,54	-2,09
87036 x Cam Inb gp1 17	0,6	7,85	11,28	C4RR SA4 x 9450	0,59	5,25	12,06
CLA 154 x Cam Inb gp1 17	0,53	8,33	-1,21	CLA 18 x 88069	0,58	5,72	36,16
ATP-43 x 88069	0,52	6,92	33,66	Cml 322 x 88069	0,49	7,03	14,26
C4 SRR A7 x 9450	0,5	6,28	24,47	D 506-4 x Cam Inb gp1 17	0,47	4,45	45,59
ATP S6 33Y-1 x 88069	0,5	5,3	15,25	ATP-43 x 88069	0,46	4,88	12,85
ATP S6 33Y-1 x 9450	0,48	0,78	9,71	CLA 106 x 9450	0,45	6,33	6,92
Cml 358 x 88069	0,47	5,27	44,74	ATP-Last x 9450	0,44	4,39	23,51
C4SRR SA6 x 9450	0,44	5,47	48,25	C4RR SA3 x 9450	0,44	7,37	0,4
CLA 18 x 9450	0,41	4,34	-2,32	Cml 322 x Cam Inb gp1 17	0,43	7,39	2,5
D 506-4 x Cam Inb gp1 17	0,37	6,6	4,46	ATPS633Y-1 x Cam Inb gp1 17	0,42	6,5	13,52
Ku 1414 x 9450	0,35	3,87	53,18	CIgp1 17 (F) x 88069	0,37	5,32	3,34
ATP-14 x 9450	0,3	5,03	13,19	ATP S6 32Y-1 x 9450	0,33	7	13,25
C4RR SA3 x Cam inb gp1 17	0,29	3,94	36,36	Ku 1414 x 88069	0,32	4,27	22,92
C4 SRR A7 x Cam Inb gp1 17	0,27	6,1	13,69	ATP-14 x 88069	0,31	7,25	-2,72
ATP S6 33Y-1 x Cam Inb gp1 17	0,26	4,4	48,21	Cml 358 x 88069	0,22	4,42	23,26

SCA: Specific Combining ability; GY: Grain Yield, R (%): rate of yield loss.

Table 8: Mean Squares issue from "line x tester" analysis for agronomic traits on uncorrected and corrected acid soil in the two sites.

Variables	df	ER				PR				EA				GY			
		Ebolowa		Nkolbisson		Ebolowa		Nkolbisson		Ebolowa		Nkolbisson		Ebolowa		Nkolbisson	
		O	T	O	T	O	T	O	T	O	T	O	T	O	T	O	T
AGC	19	7,3*	13,38*	26,36*	32,39*	8,36*	18,64ns	48,02ns	57,12*	0,02ns	0,01*	0,04*	0,036*	0,39*	0,6*	0,67ns	0,46*
ASC	59	31,2ns	2,7ns	33,17*	4,67ns	11,97ns	19,57ns	174,78*	181,02*	0,04*	0,002ns	0,05*	0,016ns	0,81ns	0,16ns	0,62*	0,33ns
Erreur	120	12,9	24,3	32,2	17,21	8,07	14,79	16,02	17,96	15,9	17,86	19,7	22,4	25,57	30,41	27,6	19,1

df: degree of freedom; GY: grain yield ; ER: Emergence Rate ; PR: prolificity; EA: Ear Aspect; ***: significant at P< 0.0001; *: significant at P< 0.05; ns: no significant at P>0.05; O: uncorrected acid soil; T: corrected acid soil.

DISCUSSION

Chemical and ecological aspects of soil

Chemical analysis showed that the soil pH values were below 5.5, indicating that these soils are very acidic. These results confirmed the statements of some authors (BindziTsala 1987; Ambassa-Kiki et al., 2002) which showed that 75-100% of arable land in Cameroon is acidic. Moreover, these results were similar to data reported in the region of Central-Cameroon by some authors (Thé et al., 2006b; Ngonkeu, 2009) who found that the soils of the humid forest zone in bimodal rainfall were highly acidic (4,52≤ pH≤ 5.12). The soils analysis showed low values of available phosphorus. In general, accessions were more productive on corrected acidic soils compared to uncorrected acid soil, indicating that acidic soils with aluminum toxicity produces the same depressing effects on maize as the manganese toxicity. These results were similar to those found by Thé et al. (2012), who showed that the application of lime increases the grain yield of the tolerant variety (ATP-SR-Y) of 82%, and the susceptible one (Tuxpeñasequia) of 208% under acid soils conditions.

Performance and breeding value of accessions

High significant differences between accessions would mean that under acid soils conditions, maize plants develop different mechanisms of tolerance in specific environments. In Ebolowa, prolificity and grain yield were reduced under acid soil conditions and the tolerant varieties exhibited small reductions, compared to susceptible ones. Similar results were obtained by Welcker et al. (2005). The percentages of yield loss due to soil acidity found (21.91 and 26.19%) were close to the value (38%) found by Tandzi et al. (2015a) and belong to the interval (3-67%) obtained by Thé et al. (2001) on acid soil with aluminum toxicity. Furthermore, Welcker et al. (2005) evaluated populations and maize hybrids in five different environments of three Countries for the aluminum tolerance and have found that these losses were ranged from 46 to 70%, depending on the site location and year. These observations suggested that accessions evaluated in this study showed a high level of adaptation to acidic soil, responding to the improvement of soil fertility in humid forest zones.

Among the selected hybrids on acid soil with aluminum and manganese toxicity, some behaved best on uncorrected acid soil than corrected. Thé et al. (2006a) have also found some maize hybrids having seminal roots longest under acid soil than non-acid soil conditions in the same field sites used in the present study. However, these results were not in accordance with the data reported by Welcker et al. (2005) and Thé et al. (2012). Furthermore, those results could be explained by a mechanism of genetic tolerance because at least one of the parents of each of these hybrids has been identified as good progenitors, through their good GCA. In other words, these results are justified both by the difference of performance existing between the genetic material used in the present study and those used in previous studies, either by soil variability in the field. However, the hybrid Cam Inb gp1 17 (F) x 9450 identified in this study as tolerant under aluminum toxicity conditions was also considered by Tandzi et al. (2015a) as an highest yielding hybrids in acid soil conditions in the same study site. Furthermore, significant effects due to GCA and SCA have shown that tolerance to aluminum toxicity is controlled by genes with additive effects and non-additive, with a dominance of additive effect of genes. Similar results have been reported by some authors (Magnavaca et al., 1987; Thé et al., 2006a). Moreover, on acid soil with manganese toxicity, the contribution of non-additive effects of gene was greater than the additive effects of gene (Borrero et al., 1995). In addition, parents 87036 and Cam Inb gp1 17 retained in this study as good biological parents were also considered in the same category previously (Thé et al., 2006a).

Conclusion

The results showed that seven hybrids producing high grain yield (4.27 to 9.88t/ha), with high specific combining ability and slow rate of yield loss were discovered such as tolerant for both types of acidic soils in humid forest zones. Best progenitors for aluminum tolerance (ATP-Last, ATP-46, Ku1414, 87036, ATP-43, D506-4, CLA 154, C4SRRA7, 88069 and Cam Inb gp1 17), for manganese tolerance (ATP S6 33 Y-1, ATP S6 32 Y-1, ATP-46, 87036, CLA 106, Cam Inb gp1 17, ATP-14, Cml 322, C4SRRA3 and C4SRRA7) and for both types of acid soil (ATP-46, 87036, C4SRRA7 and Cam Inb gp1 17) were identified. Furthermore, tolerance to aluminum toxicity was controlled by genes with additive and non-additive effects, with preponderancy of additive effect of genes while on acid soil with manganese toxicity, the contribution of non-additive effect of genes was greater than the additive gene effects. However, a molecular characterization of the selected varieties will be necessary for a possible extension.

COMPETING INTERESTS

The authors declare that they have no competing interests.

Authors' contributions

HT implemented and monitored the field test, statistical analysis and interpretation of collected data, and was main writer of the article. ELMN and PFD supervised the work and participated in the drafting of the article. LNT, HAM and OB technically and practically assisted during the conduct of the field trial. JMB Participated in the drafting of the article. CLP assisted during the setting up and monitoring of the test. RF assisted during the set-up of the trial.

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