Journal of Experimental Agriculture International
14(6): 1-15, 2016; Article no.JEAI.29333
Previously known as American Journal of Experimental Agriculture
ISSN: 2231-0606

SCIENCEDOMAIN *international*
www.sciencedomain.org

Screening of Maize *(Zea mays* L.) Genotypes for Adaptation on Contrasted Acid Soils in the Humid Forest Zone of Cameroon

C. L. Petmi[1], E. L. M. Ngonkeu[1,2*], N. L. Tandzi[2], Z. Ambang[1], O. Boyomo[1], J. M. Bell[1], H. Tekeu[1], H. Mafouasson[2], D. Malaa[2] and W. Noé[2]

[1]University of Yaoundé I, B.P 812 Yaoundé, Cameroon.
[2]Institute of Agricultural Research for Development (IRAD), BP. 2067 Yaoundé, Cameroon.

Authors' contributions

This work was carried out in collaboration between all authors. Authors ELMN, NLT, ZA and OB designed the study. Authors WN and ELMN reviewed the experimental design, enabled the practical realization of this work, performed physical and chemical soil analysis. Authors JMB, HT and DM performed the statistical analysis. Authors CLP, NLT, HM and ELMN wrote the protocol and the first draft of the manuscript. Authors CLP and NLT managed the analyses of the study. Authors CLP and WN managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2016/29333
Editor(s):
(1) Slawomir Borek, Department of Plant Physiology, Adam Mickiewicz University, Poland.
Reviewers:
(1) Eric Etchikinto Agoyi, Makerere University, Uganda.
(2) K. Narasimha Swamy, Osmania University, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/17157

Original Research Article

Received 3rd September 2016
Accepted 30th November 2016
Published 7th December 2016

ABSTRACT

Soil acidity is a major limiting factor for maize productivity in the humid forest zone of Cameroon. A yield loss of up to 60% has been reported in acid tolerant population. The objective of this study was to determine the level of tolerance of some selected inbred lines under Aluminum and Manganese toxicities on chosen experimental site soils and to classify them into specific pools. The experiment was laid out in a Split-plot design and genotypes were completely randomized within the blocks. Three replications were used. An assessment of 52 inbred lines of maize which consisted of 25 IRAD Cameroon lines, 3 IITA lines and 24 lines from CIMMYT-Colombia was then carried out in a contrasted acidic soil with Al (Nkoemvone site) and Mn (Nkolbisson site) toxicities

**Corresponding author: E-mail: ngonkeu@yahoo.fr;*

based on six agro-morphological parameters. Soil correction was made up by the application of 2 t ha^{-1} of dolomite lime. The soil analysis revealed that, at Nkolbisson plot there was Mn toxicity of 90. 6 (ug/g), while at Nkoemvone Al toxicity was more presented with 2.32 (cmol (+) kg). At Nkolbisson, 5.76% of the genotypes proved to be efficient, 9.43% were tolerant, 75% were susceptible and 15.09% were negative control. At Nkoemvone, 7.54% of inbred lines expressed themselves as efficient, 3.77% were tolerant, 75.47% were susceptible, 13.20% were negative control and 5.66% of the genotypes presented floral abnormalities called "mentle". ATP S5 30Y-1 and CML 535 distinguished themselves as ubiquitous and CML 304 was the most susceptible variety to both agro-ecologies. The dendrogram obtained by the non-hierarchical classification analysis of endogamous genotypes showed three groups of maize genotypes at Nkolbisson and four groups at Nkoemvone. The best genotypes at Nkolbisson were: ATP-14 (4.08 t/ha), Camlnb1 17 F (3.93 t/ha), ATP S9 30Y-1 (3.86 t/ha), CML 437 (2.72 t/ha) and CML 535 (2.54 t/ha) and at Nkoemvone were: Clgp1 17 (3.9 t/ha), CML 322 (2.24 t/ha), CML 479 (2.24 t/ha) and CML 533 (2.05 t/ha). Diffusion of these acid-tolerant genotypes offers a sustainable strategy to increase yield productivity of acids soils in the humid forest zones.

Keywords: Aluminum toxicity; manganese toxicity; phytotoxicity; soil correction; Acid-soil tolerant maize; lime.

1. INTRODUCTION

Acid soils cover approximately 3950 million ha, which is about 30% of the total ice free land area on the earth [1,2]. In the tropics, more than 8 million ha of acid soils are planted with maize, and 17% of tropical Africa is covered by acid soil [1]. In Cameroon, acid soil covers up to 75% of the soil, and this is mainly in the humid forest zones (HFZ). Acid soils in these zones are characterized by low pH, deficiency in Ca, Mg, P, K and Mo contents and toxic levels of Al and Mn [3]. These characteristics limit the fertility of the soil and inhibit root development, thus leading to low water and nutrient uptake and low maize yields [4]. [5] reported the average yield of maize production ranged from 0.8 – 1 t/ha. However, this production is not sufficient to meet the demand of the population. In 2008, the quantity of maize flour imported was estimated to 24,815 tons [6] and this continue to increase until to date. Moreover, over the past decades, farmers' interest in maize production has increased, and maize has become a cash crop like coffee and cocoa, and is now an important source of income [7,8]. There is an increasing demand for the crop because of its use as feed in animal production and in the brewing industry. The annual demand of maize for human consumption and animal feed in Cameroon was estimated to 870,000 and 320,000 tons, respectively [9]. Maize production in Cameroon has been increasing steadily from an estimated 966,000 metric tons in 2004 [10] to 1,647 036 tons in 2013 [11]. These increases have mainly been due to increases in area harvested (832,400 ha) rather than yield increase per unit area (0.8 – 1t/ha). The HFZ which covers an area of 21.7 million hectares, by virtue of its bimodal rainfall pattern holds promise for increasing the output for maize if the main fertility constraint of low soil pH can be solved. Soil amendment with lime, phosphorus and organic matter has been suggested to bring unproductive acid soil under acceptable agricultural production. However, such solutions are temporary and expensive for the resource-poor farmers [12]. To correct acid soil in one ha area, 2 to 4 tons of dolomitic lime are required and should be applied 2-3 years for better plant growth [13]. Significant genetic variation for tolerance to soil acidity has been reported. Early studies demonstrated qualitative inheritance [14]. Quantitative inheritance to Al resistance was later demonstrated [15,2,16]. Considerable progress has been made in breeding maize for acid soil tolerance through recurrent selection [3,17]. Developing acid-tolerant maize genotypes is an effective and sustainable way of alleviating the impact of Al toxicity in maize production areas. Studies have shown that Al-tolerant maize genotypes outperformed the adapted local and susceptible genotypes by 13% and 61%, respectively [18]. These results suggest that growing Al-tolerant maize genotypes will ensure a high sustained maize productivity. Five maize open pollinated varieties (OPVs) from Cameroon were reported to have some level of tolerance to soil acidity [19]. Three of these (ATP-SR-Y, ATP-S4 SYN Y and ATP SYN I-W) have been found to give 13% increase in grain yield over local varieties in the humid forest area of Cameroon [19]. However, most of the materials used exhibited significant additive genetic variance x environment interaction, suggesting that the materials had specific adaptation [15]. Only ATP SR Y out of these three acid tolerant population is the open-pollinated variety released and commercialized in Cameroon [20]. However, the impacts of climate change Associates to acid soils with aluminum and manganese toxicities increase yield losses in maize [21]. Yield losses of 60% have been reported in this acid tolerant population (ATP SR Y) [19]. There is a need of reducing yield loss due to soil acidity especially Al toxicity and increasing yield productivity per unit area. Thus it is necessary to develop other varieties adapted in many areas that will 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 [22]. To identify and improve varieties that would perform well under acid soil, selections would have to be based on performance across a range of environments. This would lead to germplasm with broader adaptation. One way to obtain such germplasm is by introgression of exotic germplasm to locally adapted cultivars. The objective of this study is to evaluate the genetic potential of introduced inbred lines and identify high yielding and perform one under acid soil conditions and enables the breeder to choose appropriate combinaison for hybrid production or cultivar development programs.

2. MATERIALS AND METHODS

2.1 Study Area

Two experimental sites were used for this study and were situated in a humid forest area of Cameroon, with bimodal rain fall. The first site is located at Nkolbisson (Yaounde) and the second at Nkoemvone (Ebolowa) and they are both separated by a distance of 180 km (Fig. 1.).

At Nkolbisson (11°36'E; 3°44'N), the mean annual temperature is 23.5°C, with an annual mean rain fall of 1560 mm, the vegetation is caducifoliated semi-deciduous forest. The soil has a sandy-clay texture with a strong hydromorphic tendency and with Manganese toxicity of (90.6 c mol (+) kg), a saturation rate of 39.02%, a pH_{H20} of 5.12, an efficient Cation exchange capacity (ECEC) of 4.20 C mol (+) kg and a C/N ratio of 13.86 c mol (+) kg.

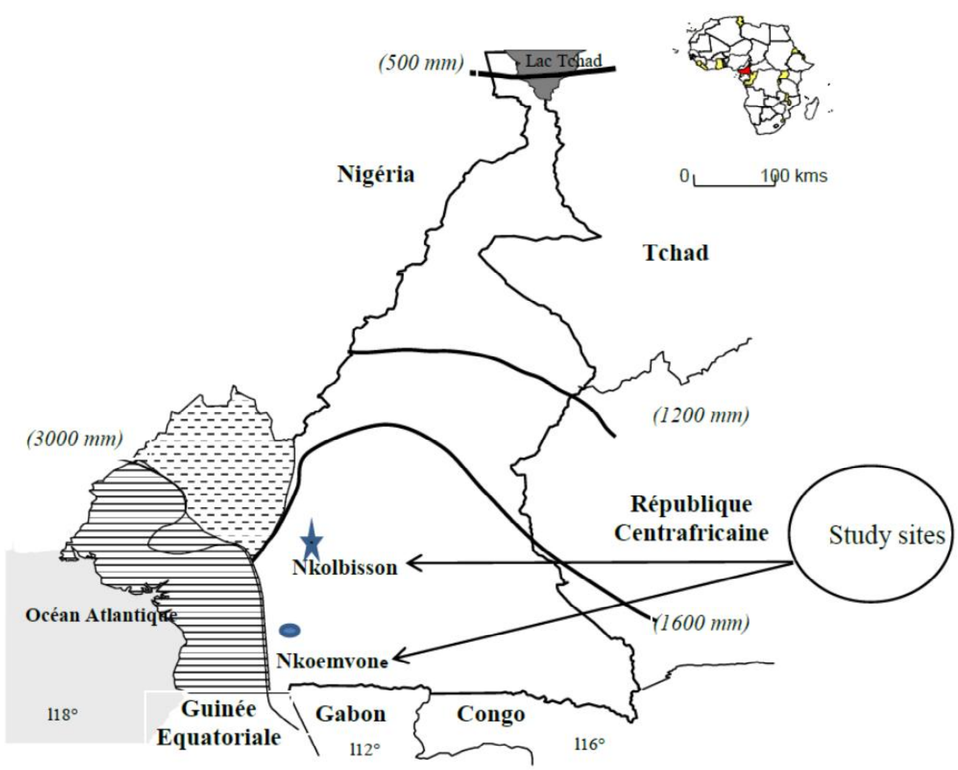

Fig. 1. Geographical location of study sites

At Ebolowa (2°40'N 12°24'E), the site was located at the heart of humid forest zone at 615 m altitude above sea level and with a semi-deciduous vegetation. Its climate is of the Guinean type with an average rain fall of 1875 mm/year and a mean temperature of 24°C. The soil has a clay texture with Aluminium toxicity (2,326 c mol (+) kg), a saturation rate of 32.74%, pH_{H20} of 4.33, an ECEC of 3.5 C mol (+) kg and a C/N ratio of 9.28 c mol (+) kg (Table 1).

2.2 Germplasm

The germplasm used was made up of 52 maize inbred lines genotypes consisted of 25 IRAD Cameroon lines, 3 IITA (Nigeria) lines and 24 lines from CIMMYT-Colombia. The characteristics of these maize inbred lines genotypes are presented in Table 2.

Table 1. Soil characteristics of the fields trials

Sites	pH H_20	H^+(cmol(+)kg)	C/N ratio (cmol(+) kg)	Al (cmol(+) kg)	Mn (ug/g)	SR (%)
Nkoemvone **(Al toxicity)**	4.33	$4.67.10^{-3}$	9.28	**2.32**	6.49	**32.74**
Nkolbisson **(Mn toxicity)**	5.12	$7,58.10^{-4}$	13.86	0.52	**90.6**	**39.02**

SR: saturation rate; C/N: Carbon is to nitrogen ratio

Table 2. Characteristics of 52 maize inbred lines genotypes

Entry	Genotypes	Genetic base	Origin	PTL	Color	Vegetative cycle (day)
Short life cycle genotypes						
1	ATP S5 20Y-2	ATP	IRAD	T	Yellow	115
2	ATP S5 26Y-2	ATP	IRAD	T	Yellow	115
3	ATP S5 31Y-2	ATP	IRAD	T	Yellow	115
4	ATP S6 20Y-1	ATP	IRAD	T	White	115
5	ATP S6 21Y-2	ATP	IRAD	T	Yellow	115
6	ATP S6 32Y-2	ATP	IRAD	T	White	115
7	ATP S6 33Y-1	ATP	IRAD	T	Yellow	115
8	ATP S6 31Y-BB	ATP	IRAD	T	Orange	115
9	ATP S8 26Y-2	ATP	IRAD	T	Orange	115
10	ATP S8 30Y-3	ATP	IRAD	T	Orange	115
11	ATP S9 17Y-4	ATP	IRAD	T	White	115
12	ATP S9 30Y-1	ATP	IRAD	T	Yellow	115
13	ATP S9 35Y-4	ATP	IRAD	T	Orange	115
14	ATP S9 36Y-BB	ATP	IRAD	T	Orange	115
15	ATP-49	ATP	IRAD	T	White	115
16	ATP-50	ATP	IRAD	T	Yellow	115
17	ATP-53	ATP	IRAD	T	Yellow	115
18	CML 304	/	CIMMYT	T	Orange	115
19	Clgp1-17	Suwanl-SR	IRAD	T	White	115
20	88069	/	IRAD	AT	Yellow	115
21	ATP 14	ATP	IRAD	T	Orange	115
22	ATP 43	ATP	IRAD	T	Yellow	115
23	ATP 46	ATP	IRAD	T	Yellow	115
24	ATP- Last	ATP	IRAD	T	Yellow	115
25	87036	Crossing between TMZ_{SR} and $Pop_{43.}$	IRAD	AT	White	115
26	Cam-Inb gp117(F)	Suwanl-SR	IRAD	T	Yellow	115

Entry	Genotypes	Genetic base	Origin	PTL	Color	Vegetative cycle (day)
Intermediate life cycle genotypes						
27	4001	/	IITA	AT	Yellow	105
28	9450	B73	IITA	AT	Yellow	105
29	D 506-2	/	CIMMYT	AT	White	105
30	CML 358	Pop SA3	CIMMYT	T	Yellow	105
31	CLA 154	/	CIMMYT	S	Orange	105
32	CLA 106	/	CIMMYT	S	Yellow	105
33	CLA 18	/	CIMMYT	T	Yellow	105
34	D 506-3	/	CIMMYT	AT	Yellow	105
35	D 504-4	/	CIMMYT	AT	Orange	105
36	Ku 1414	/	IITA	AT	Yellow	105
Premature variety						
37	CML 357	/	CIMMYT	T	Orange	90
38	CML 435	/	CIMMYT	T	Yellow	90
39	CML 436	/	CIMMYT	T	Orange	90
40	CML 437	/	CIMMYT	T	Yellow	90
41	CML 438	/	CIMMYT	T	Orange	90
42	CML 439	/	CIMMYT	T	Orange	90
43	CML 533	/	CIMMYT	T	Orange	90
44	CML 534	/	CIMMYT	T	Orange	90
45	CML 535	/	CIMMYT	T	Orange	90
46	CML 322	/	CIMMYT	T	White	90
47	CML 332	/	CIMMYT	T	White	90
48	CML 486	/	CIMMYT	T	Yellow	90
49	CML 479	/	CIMMYT	T	Yellow	90
50	CLA 183	/	CIMMYT	AT	White	90
51	CML 434	/	CIMMYT	T	Orange	90
52	D 300-17	/	CIMMYT	AT	White	90

Reference sources: [23] and [21]

T: Tolerant, AT: Averagely Tolérant, S: Susceptible, PTL: Presumed Tolerance Level, CML: CIMMYT Maize Line, CLA: CIMMYT Line Acid, ATP: Acid Tolerant Population, ATP SR Y: Acid Tolerant Population Streak Resistant Yellow; Pop : Population ; Suwanl-SR: Thaïland Research Station; CIMMYT : Centro Internacional de Mejoramiento de Maíze y Trigo (Centre international pour l'amélioration du maïs et du blé) ; IRAD : Institute of Agricultural Research for Development; IITA : International Institute of Tropical Agriculture.

2.3 Seed Sowing and Fertilizer Application

On each experimental site, land was ploughed and divided into two major parts with an alley of 2m. On one part of the field, the acidity of the soil was corrected with the incorporation of 2t/ha of dolomite. As soon as the rain started during the first rainy season, maize inbred lines were sown on rows of 4 m long with 9 hills. The distance between two consecutive rows was 75 cm and 50 cm between two consecutive hills in a row. Two maize seeds were planted per hill with no thinning. Plant density at planting was approximately 53,333 plants/ha. Weeds and insects were chemically controlled.

Mineral fertilizers were applied twice [22]: the basal application was done 15 days after sowing and was composed of a bag of 100 kg NPK 14-24-14 + 5(S) + 3.5 (MgO) with a bag of 50 kg/ha of urea. The second application was done 32 days later, at a dose of 50 kg/ha of urea.

2.4 Experimental Design

The trials were carried out in each experimental site on an area of 1326.8 m². The experiment setup was a split plot; where the main plot was the soil type made of the native acid soil with Aluminum or Manganese toxicity known as treatment "O" and the corrected acid soil known as treatment 'T'. The subplots were made of genotypes. The genotypes were arranged into a complete randomized block design with three replications.

2.5 Data Collection

The following phenotypic parameters were measured: plant height (HP) and ear insertion height (HIE), the ears weight (WE) and grain moisture content (MC) measured in the field during harvest. Grain yield (Y in kg/ha) of the genotypes were obtained using the formula below:

$$Y\left(\frac{t}{ha}\right) = \frac{EFW\ x\ SP\ (100 - MC)x10000}{DMP} \qquad [13]$$

Y: Grain yield in tons/ha.
EFW: Ear field weight in kg
SP: Shelling percentage estimated at 0.83
MC: Moisture content
DMP: Dry mass percentage estimated at 85% when the relative moisture content is 15%

- Percentage yield loss PYL due to the acidity of the soil was calculated following the formula:

$$PYL(\%) = \frac{YC - YA}{YC} \times 100 \qquad [13]$$

PYL: Percentage yield loss
YC: Grain yield in corrected soil
YA: Grain yield in acidic soil

2.6 Data Analysis

Data were subjected to the analysis of variance using the SAS 9.0 software package. The SPSS 16.0 software package was used for the construction of a dendrogram for each site. The Student Newmann Keul's test enabled the comparison of means at 1% and 5% probability levels. The mathematical model used was:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij}$$

Y_{ij}: Performance of the individual
μ: Population mean
α_i: Random effect of the ith repetition (i = 1, 2,3)
β_j: Fixed effect of the genotype (j = 1,2,…, 54)
$(\alpha\beta)_{ij}$: Random effect of the repetition x genotype interaction.

3. RESULTS AND DISCUSSION

3.1 Results

<u>3.1.1 Genotypes identification adapted in acidic soil with Al and Mn toxicity</u>

At Nkolbisson, grain yield of inbred lines on acidic soil varied from 0.11 t/ha (CLA 154) to 4.11 t/ha (CLA 183), making a deviation of about 4 t/ha between the most productive and the least productive. 17 genotypes produced a yield greater than 2t/ha and were grouped into three classes [2-3[, [3-5[and [5-6[(Fig. 2). Genotypes CLA 183 (4.11 t/ha), ATP-14 (4.08 t/ha), 9450 (4.07 t/ha) and CML 535 (4.07 t/ha) were revealed as the best varieties on the acidic soil at Nkolbisson.

Grain yield on corrected acid soil (control) varied from 0.37 t/ha (ATP S5 20Y-2) to 5.57 t/ha (CML 358), making a difference of about 5.2 t/ha. In the control, 22 genotypes produced a yield greater than 2 t/ha and are grouped into three classes [2-3[, [3-5[and [5-6[(Fig. 2). Genotypes CML 358 (5.57 t/ha), ATP-14 (5.00 t/ha) and ATP-46 (4.42 t/ha) were revealed as the best varieties.

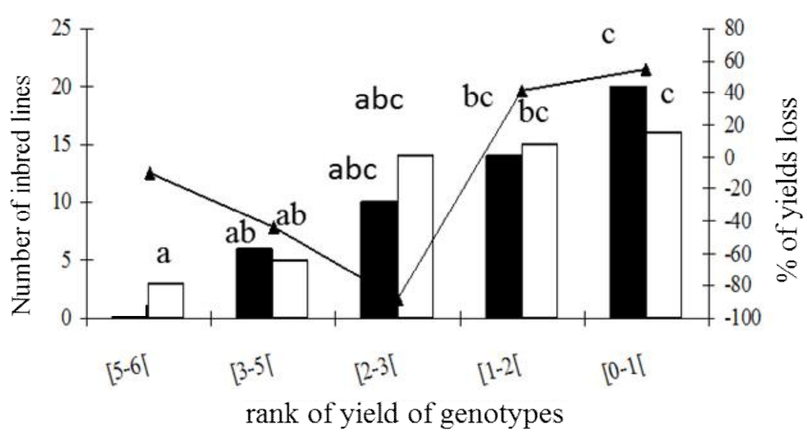

Fig. 2. Yield and yield loss of the best inbred lines on acidic and corrected soil at Nkolbisson
Same letters indicates: non-significant, different letters indicates: significant

Acid soil   Corrected acid soil   % Yield loss

Inbred lines responding well on acid and corrected acid soil presenting regressive losses less than -50% were: CML 535 (4.07 t/ha), CML 437 (3.28 t/ha), CML 486 (2.17 t/ha). These inbred lines were said to be efficient on acid soils with Manganese toxicity. For 17 genotypes that produced yields greater than 2 t/ha, five of them showed less than 54% yield loss and were considered as tolerant strains to acidic soils with Manganese toxicity. These were ATP-14 (18.40 %), ATP S5 31Y-2 (34.11%), ATP S9 30Y-1(29.79%), ATP-43 (29.39%) and CamInbgp1 17 (F) (45.80%). 37 parents (69.81%) had low yields (less than 1 t/ha) and yield losses greater than 50%. They were grouped as susceptible genotypes while 8 genotypes (15.09%) showed very regressive losses beyond -50% and high yields on acid soil; they were considered as negative control genotypes at Nkolbisson (Table 3).

At Nkoemvone, grain yield of lines on acidic soil vary from 0.22 t/ha (ATP S6 33Y-1) to 3.9 t/ha (Clgp1 17), making a yield deviation of about 3.68 t/ha between the most productive and the less productive lines. On the same acidic soil, only 5 genotypes gave in a yield greater than 2 t/ha and were grouped into two classes [3-4[and [2-3[while 10 genotypes were in the less class [1-2[and had yield greater than 1 t/ha (Fig. 3.). Clgp1 17 (3.9 t/ha), CML 322 (2.24 t/ha), CML 479 (2.24 t/ha) and CML 533 (2.05 t/ha) were the best under acid soils at Nkoemvone.

Table 3. Grouping of screened progeny on acidic soil at Nkolbisson

Efficient genotypes	Tolerant genotypes	Susceptible genotypes	Negative control genotypes
CML 535	ATP-14	ATP S6 20Y-1	CLA 183
CML 486	ATP-43	CML 357	9450
CML 437	ATP S9 30Y-1	CML 439	88069
	ATP S5 31Y-2	CML 436	ATP S9 35Y-4
	CamInbg1 17 (F)	ATP S9 36Y-BB	CML 479
		CML 322	CML 438
		Clbg1 17	CML 534
		CLA 18	CML 332
		ATP-53	
		CML 358	
		ATP S8 26Y-2	
		D 300-17	
		ATP-32	
		ATP S8 30Y-3	
		ATP-46	
		CML 304	
		ATP-50	
		Ku 1414	
		CML 435	
		D 506-3	
		CLA 135	
		ATP S6 31Y-BB	
		87036	
		9848	
		ATP S5 20Y-2	
		D 506-2	
		D 506-4	
		ATP S5 20Y-3	
		CLA 106	
		CLA 154	
		ATP S6 21 Y-2	
		ATP 49	
		CML 486	
		4001	

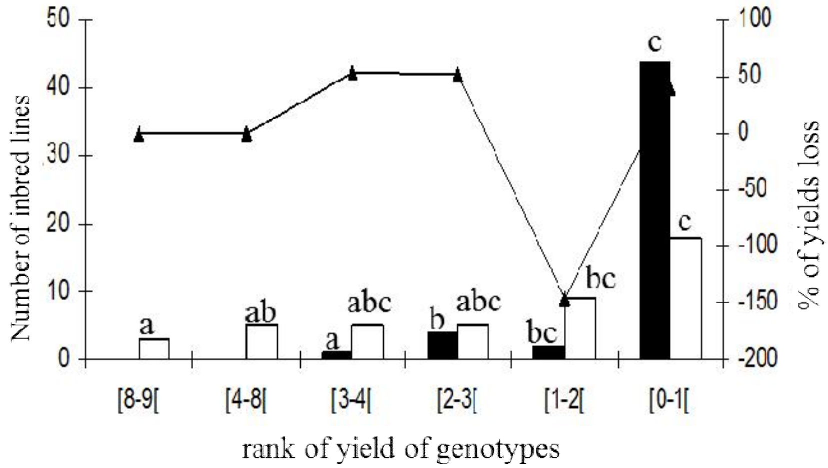

Fig. 3. Yield and yield loss of the best inbred lines on acidic and corrected soil at Nkoemvone Same letters indicates: non-significant, different letters indicates: significant

The yield of inbred lines on corrected acid soil varied from 0.21 t/ha (D 300-17, ATP S8 26Y-2, CML 438, 87036, CLA 135) to 8.20 t/ha (ATP S6 32Y-2), making a deviation of about 7.99 t/ha. On corrected soil, 17 genotypes realized a yield greater than 2 t/ha ([8-9[, [4-8[, [3-4[, [2-3[) while 10 genotypes ([1-2[) had yield greater than 1 t/ha (Fig. 3). Equally, Clgp1 17 were the best strain followed by ATP S6 32Y-2, 88069, ATP S6 21Y-2, ATP-53 and ATP S6 33Y-1.

At Nkoemvone, four lines responding on both acidic and corrected acid soils gave yield losses between -14.70% and 0%. These lines were grouped as efficient and tolerant genotypes. They are Clgp1 17 (3.9 t/ha), CML 479 (2.24 t/ha), CML 533 (2.05 t/ha) and ATP S9 30Y-1 (1.04 t/ha). The yield and yield loss percentages obtained from the evaluated parents showed that 2 genotypes out of the 43 left were retained as tolerant on acid soil of Aluminum toxicity (CML 535 (31.84%) and CML 439 (16.79%)). 6 lines presented very regressive losses between -600% and -163.45% and quite considerable yields on control treatments: they were characterized as negative control genotypes on acid soils at Nkoemvone. They are: CML 322 (-600%), ATP S8 26Y-2 (-400%), D 300-17 (-438.09%), CML 358 (-255.81%), ATP-49 (-251.16%) and CML 437(-163.43%). Besides, 40 parents which expressed yield less than 1 t/ha and percentage yield losses greater than 50 % were said to be susceptible genotypes to the soil type at Nkoemvone (Table 4).

A comparative study of screened genotypes on the two sites revealed that ATP S5 30Y-1 and CML 535 were the best among all, both at Nkoemvone and at Nkolbisson. Hence they are considered as ubiquitous strains, while 15 genotypes perfectly expressed themselves as susceptible on both experimental sites and were equally most susceptible of all tested genotypes. They are: ATP S6 21Y-1, ATP 53, CLA 106, CLA 154, ATP-32, Ku 1414, D 506-4, 87036, ATP S6 31Y-BB, ATP-46, CLA 135, ATP-50, ATP S8 30Y-3, D 506-3 and CML 304.

3.1.2 Classification of genotypes into specific pools

The dendrogram obtained after analysis by grouping genotypes based on yield at Nkolbisson (Fig. 4.) showed that, it was made up of three large groups. Group I consisted of 31 averagely tolerant genotypes, group II had 3 tolerant genotypes and group III had 18 susceptible genotypes. The distance between group I and II and that between group II and III was 77.42 and 86.66 respectively. Each group encloses parents which look alike phenotypically.

Group I contains varieties that were efficient (CML 535, CML 486, CML 437) and tolerant (ATP-14, ATP-43, ATP S9 30Y-1, ATP S5 31Y-2, Camlnbg1 17 (F). Observations within studied parameters in each group revealed that group II appears to be the best with good ears, Y (4.33 t/ha), HP (1.59 m), HIE (0.73 m) and GR (64.81%) higher than group I and III.

Table 4. Grouping of screened progeny on acid soil at Nkoemvone

Efficient genotypes	Tolerant genotypes	Susceptible genotypes	Negative control genotypes
Clgp1 17	CML 535	ATP S6 21Y-1	CML 322
CML 479	CML 435	ATP 53	ATP S8 26Y-2
CML 533		CLA 183	D 300-17
ATP S9 30Y-1		ATP-43	ATP SR Y
		CML 436	CML 358
		CLA 18	ATP-49
		88069	CML 437
		CML 438	
		CLA 106	
		CLA 154	
		ATP S5 26Y-2	
		CML 486	
		ATP-32	
		Ku 1414	
		D 506-4	
		9450	
		CML 534	
		ATP S6 20Y-1	
		87036	
		ATP S6 32Y-2	
		CML 434	
		ATP-14	
		ATP S6 31Y-BB	
		4001	
		CML 332	
		ATP-46	
		Camlnbgp1 17(F)	
		CLA 135	
		ATP S9 36Y-BB	
		ATP-Last	
		CML 439	
		ATP-50	
		ATP S8 30Y-3	
		ATP S9 35Y-4	
		ATP S5 31Y-2	
		D 506-3	
		CML 357	
		ATP S6 33Y-1	
		ATP S9 17Y-4	
		CML 304	

The dendrogram obtained after analysis by grouping genotypes based on yield at Nkoemvone showed that, it was made up of four large groups (Fig. 5.). Group I was made up of 17 averagely tolerant genotypes; group II had 8 tolerant genotypes. Group III had five averagely susceptible parents and group IV had 21 susceptible genotypes. The distance between groups I and II was 20.19, that between groups II and III is 23.60 and that between groups III and IV is 40.38. Hence, each group encloses parents that look alike phenotypically.

In group I, some efficient varieties (CML 479, ATP S9 30Y-1) and tolerant (CML 435) were obtained after screening, Group II was the best with good ears (1.6), Y (1.68 t/ha), HP (1.28 m), HIE (0.57 m), GR (40.27%) and these data were higher than those in groups I, III and IV.

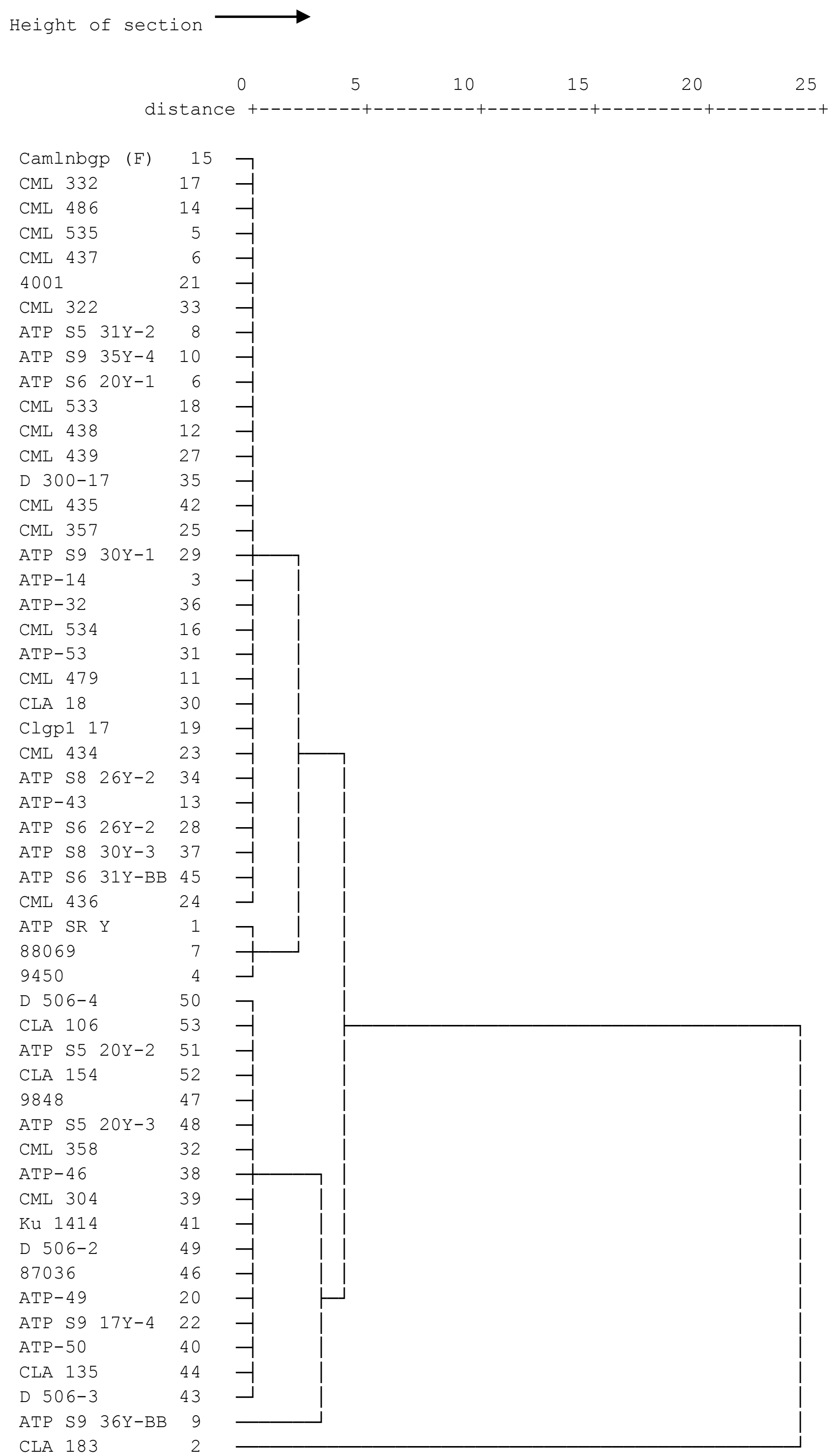

Fig. 4. Dendrogram obtained by linkage between groups and by the non-hierarchical classification process of endogamous genotypes at Nkolbisson

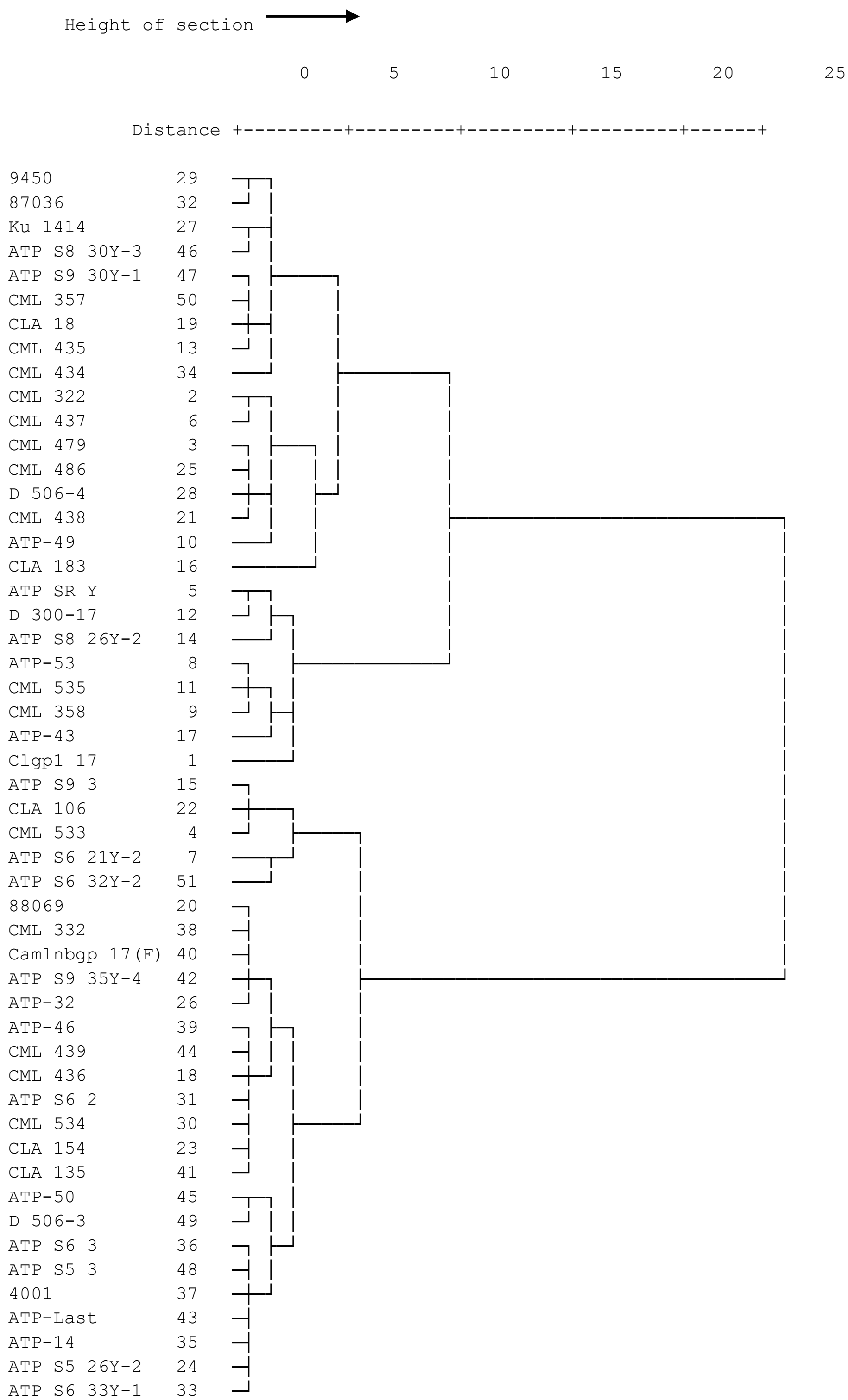

Fig. 5. Dendrogram obtained by linkage between groups and by the non-hierarchical classification process of endogamous genotypes at Nkoemvone

3.2 Discussion

3.2.1 Genotypes identification adapted in acidic soil with Al and Mn toxicity

At Nkolbisson; the following genotypes CML 535, CML 437, CML 486 representing a proportion of 5.76% revealed efficient and tolerant genotypes on acid soil more than on corrected soil. Also, four inbred lines (ATP S5 31Y-2, ATP S9 30Y-1, ATP-43, and Cam Inb gp1 17 (F)) presumed as tolerant from origin, confirmed their level of tolerance on acid soil especially under Manganese toxicity at Nkolbisson. This result was a proof that these genotypes could possess major tolerance genes as compared to other susceptible genotypes and this result are in line with those obtained by previous authors [24,25,23,26] who identified four inbred lines (ATP-46, 87036, and Cam Inb gp117, C4SRRA7) with high general combining ability (GCA) and were retained as good progenitors. Both the GCA and SCA (specific combination ability) 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. The serious regressive yield losses obtained within negative control genotypes were a consequence of environmental effects such as flooding which washed soil elements from upstream, to the benefit of the lines downstream. Similar results were obtained by [27] in the course of evaluating hazards caused by flooding in Tandjile, mayo kebbi East, Mayo kebbi West, which proved that the impact of flooding on harvest were very significant and losses predicted with regards to a normal year move up to 91% for maize.

Besides that, in Aluminum toxicity at Nkoemvone, Clgp1 17, CML 479, CML 533, and ATP S9 30Y-1 were more performant on acid soil than on control soil and were ranged as efficient genotypes (7.54%). Among these lines, Clgp1 17 which was specified from the origin as tolerant actually revealed to be the best. This result is in agreement with that of [13], who identified specific groups for maize (*Zea mays* L) tolerance to acid soils in the tropics. Only two genotypes: CML 535 and CML 439 out of the 49 remaining revealed themselves as tolerant. This result suggests that, the environment favors a better expression of their genes as compared to susceptible genotypes. Moreover, the low yields and yield losses obtained among varieties CLA 18 (0.87 t/ha), D 506-4 (0.65t/ha), Ku 1414 (0.65 t/ha) and D 506-3 (0.22 t/ha) were mainly due to floral abnormalities. This phenomenon, observed within varieties for which the male and female inflorescence are found on the same stalk gives reason to affirm that acid soils have a considerable impact on the entire maize plant. Actually, this floral abnormality named 'mantled' with reference to the 'mantled' appearance of the mentle fruit had been observed in regenerated oil palm plants (*Elaeis guineensis* Jacq.) (6%) which is a monoecious plant like maize, by [28].

On corrected acid soil at Nkolbisson, quick lime had a significant effect on genotypes from germination to maturity. This result is similar to the one with the results obtained by [29] for where Calcium improvement compensates the acidification produced by biological activity, increasing the lowering of the soil pH and therefore favoring the assimilation of soil nutrients.

On corrected acid soil at Nkoemvone, dolomitic lime equally had a significant effect on the evaluated genotypes in the course of maturity comparatively to the results of [23]. In addition, low yield and high yield losses obtained in this corrected plot are due to repercussions of stems borer and hedgehog.These results confirm those conducted by [30]. This author had proved on cereals pathology study in Cameroon that yields losses due to these crops pests vary from 15 to 50% compared to total annual production.

A similar study of screened genotypes on the two sites showed that ATP S5 30Y-1 and CML 535 manifested as the best in terms of yield. These genotypes tolerance ability, retained on contrasting soil are considered as ubiquitous lines. The following genotypes: ATP S6 21Y-1, ATP 53, CLA 106, CLA 154, ATP-32, Ku 1414, D 506-4, 87036, ATP S6 31Y-BB, ATP-46, CLA 135, ATP-50, ATP S8 30Y-3, D 506-3 and CML 304 revealed to be susceptible on acid soils in both sites. These genotypes are very sensitive to acid soil. On the contrary, CML 304 showed itself as the most susceptible variety among all with relatively very low germination rate and poor yield. The inferiority of the number of tolerant and efficient genotypes obtained at Nkoemvone as compared to those obtained at Nkolbisson was one of the demonstrative proofs that Aluminum toxicity had more significant impact on maize development than Manganese toxicity. This observation was explained by the fact that Aluminum is more polynuclear than Manganese, thus provoking a more drastic phytotoxicity)

[23,31]. In addition, the number of susceptible parents (75.47%) obtained on acid soil at Nkoemvone was higher than that obtained on acid soil at Nkolbisson (69.81%). Therefore, the toxicity due to Aluminum was the greatest limitation to the growth and development of plant under acidic soils [26,32].

3.2.2 Classification of genotypes into specific pools

At Nkolbisson, three groups of strains were obtained (group I, II and III). Genotypes ATP 14, ATP 43, ATP S9 30Y-1, ATP S5 31Y-2 and Camlng1 17 (F) of group I initially defined as tolerant from origin confirmed to actually be tolerant. [33] Identified Clgp1 17 and CML 357 as tolerant to acid soils and similarly the genotypes Clgp1 17 and CLA 18 were found to be as tolerant by [33]. Furthermore, 9450 which had been detected as tolerant by [33,23] figures in group II.

At Nkoemvone, four groups of inbred lines were obtained (group I, II, III and IV). These results showed that group I was made up of 17 averagely tolerant endogamous varieties. Group III distinguished itself with 5 averagely susceptible genotypes while group IV presented 21 very susceptible lines. Group II proved to be the best. The averagely tolerant variety CML 357 (group I) and the tolerant varieties Clgp1 17 (group II) were shown to be tolerant by [22]. Averagely tolerant varieties CLA 18 and 9450 (group I) were shown to be tolerant by [33]. These results were similar to those of [34] and [14], who showed that, maize cultivars present a great variability of soil acidity tolerant genes, meaning that; tolerance of maize in acidic soil is controlled by major genes [21].

4. CONCLUSION

The evaluation of 52 inbred lines under Aluminum and Manganese toxicities soils showed a great variability on the level of tolerance of genotypes to the different types of soil acidity studied. Some numbers of efficient, tolerant and susceptible lines were identified. Also, common groups of progeny for acidity tolerance were known: 3 groups at Nkolbisson and 4 groups at Nkoemvone. The best progeny of Nkolbisson were: ATP-14 (4.08 t/ha), Camlnb1 17 F (3.93 t/ha), ATP S9 30Y-1 (3.86 t/ha), CML 437 (2.72 t/ha) and CML 535 (2.54 t/ha). The best genotypes at Nkoemvone were: Clgp1 17 (3.9 t/ha), CML 322 (2.24 t/ha), CML 479 (2.24 t/ha) and CML 533 (2.05 t/ha). The results of this study showed that maize cultivation on acid soils could lead to grain yield reduction of 60% or more in tropical environments. Grain yield loss due to soil acidity could be minimized by the development of hybrids from crosses between locally adapted inbred lines and those introduced from CIMMYT Colombia and soil program. Farmers of Center, South and East regions of Cameroon would benefit if they adopt hybrids developed with these inbred lines identified to be efficient and tolerant genotypes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Von Uexkull HR, Mutert E. Global extent, development and economic impact of acid-soils. Pp 5–19 In Data RA, et al. (eds.) Plant-soil interaction at low pH: Principles and management. Kluver Academic Publishers, Dardrecht, The Netherlands Maize. Crop Sci. 1995;34:1511–14.
2. Salazar FS, Pandey S, Namo L, Perez JC, Ceballos H, Parentoni SN, Bahia Filho AFC. Diallele analysis of acid-soil tolerant and intolerant tropical maize populations. Crop Sci. 1997;37:1462-73.
3. Granados G, Pandey S, Ceballos H. Response to selection for tolerance to acid soils in a tropical maize population. Crops Sci. 1993;33:936-40.
4. Duque-Vargas JS, Pandey G, Granados H, Ceballos, Knapp E. Inheritance of tolerance to soil acidity in tropical maize. Crop Sci. 1994;34:50-54.
5. ACDIC. The maize crisis and the misfortunes of cameroon's agriculture, Citizens Association for the Defence of collective interests. 2010;46.
6. FAOSTAT. Statistical database of the food and agriculture of the United Nations. FAO Statistics Division; 2011. Available: http://www.fao.org
7. Nguimgo KAB, Balasubramanian V, Kaho F, Zeukeng P. Maize-legume rotation and association for intensive maize production in the humid forest zone of Cameroon. Maize revolution in West and Central Africa. Proceedings of a regional maize workshop IITA-Cotonou, Benin Republic; 2003.
8. Hauser S, Bengono B, Bitomo OE. Maize yield response to *Mucuna pruriens* and

Pueraria phaseoloides cover crop fallow and biomass burning versus mulching in farmer managed on-farm experiments. Conference on International Agricultural Research for Development, University of Bonn, October. 2006;11-13.
9. Etoundi SMN, Dia KB. Determinants of the adoption of improved varieties of maize in Cameroon: Case of cms 8704. African Economic Conference. 2008;397-413.
10. USDA World corn production 2014/2015, United States Department of Agriculture (USDA);2014. Available:http://www.worldcornproduction.com/?gclid=CjwKEAjw68ufBRDt0Zmrn4W_8AwSJADcjp1cixR5TfsZrSG-HgGaZbnrzN0Pd3thp6qdVP4Cpph9BoCmUfw_wcB
11. FAOSTAT. Food and agriculture organization of united nation, Statistics division;2013. Available:http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor
12. Thé C, Tandzi NL, Zonkeng C, Ngonkeu ELM, Meka S, Leon C, Horst WJ. Contribution of introduced inbred lines to maize varietal improvement for acid soil tolerance. *IN* Badu-Apraku B, Fakorede MAB, Lum AF, Menkir A, Ouedraogo M. (Eds.) Demand-driven technologies for sustainable maize production in west and central Africa. IITA-Cotonou, Bénin, International Institute of Tropical Agriculture (IITA); 2005.
13. Thé C, Calba H, Zonkeng C, Ngonkeu ELM, Adetimirin OV, Mafousson HA, Meka SS, Horst WJ. Response of maize grain yield to changes in acid soil characteristics after soil amendments. Plant and Soil. 2006;284 (1):45-57.
14. Filho MLT, Furlani PRLEC, Sawazaki E. Genetics of environmental resistance and super-genes: Latent aluminium tolerance. Maize Genetic. Coop. Newslet. 1984; 58:45–46.
15. Borrero JC, Pandey S, Caballos H, Magnavaca R, Bahia Filho AFC. Genetic variances for tolerance to soil acidity in a tropical maize population. Maydica. 1995; 40:283-288.
16. Eticha DC, Thé C, Welcker L, Narro Stab A, Horst W. Aluminium induced callose formation in root apices: Inheritance and delection of trait for adaptation of tropical maize to acid soils. Field Crop Res. 2005; 15:43-55.
17. Ceballos HS, Pandey L, Narro, Perez-Valazquez JC. Additive, dominant and epistatic effects for maize grain yield in acid and non-acid soils. Theor Appl Genet. 1998;96:662-668.
18. Okiyo T, Gudu S, Kiplagia O, Owuoche J. Combining drought and aluminum toxicitytolerance to improve sorghum productivity. Afr. Crop Sci. J. 2010; 18:147–154.
19. Thé C, Horst WJ, Calba C, Welcker C, Zonkeng C. Identification and development of maize genotypes adapted to acid soil of the tropics. In Bau- Apraku B, Fakorede MAB, Ouedraogo, Carsky RJ. (eds). Impact, challenges and prospects of maize research and development in West Central Africa. 1999;107-127.
20. The C. Fitting maize into cropping systems on acid soils of the tropics: IRAD Cameroon, Final progress report 01/01/1996 - 30/09/2000, INCO II. 2000; 21.
21. Ngonkeu MEL. Tolerance of some varieties of maize on soil at aluminic and manganic toxicity of Cameroun and molecular and functional diversity of mycorhizes with arbuscules. Thesis of Doctorate PhD University of Yaounde I. 2009;65.
22. Welcker C, The´C, Andre´au B, De Leon C, Parentoni SN, Bernal J, Félicite´ J, Zonkeng C, Salazar F, Narro L, Charcosset A, Horst WJ. Heterosis and combining ability for maize adaptation to tropical acid soils. Implications for Future Breeding Strategies. 2005;53-63.
23. Thé C, Meka SS, Ngonkeu ELM, Bell JM, Mafouasson HA, Menkir A, Calba H, Zonkeng C, Atemkeng M, Horst WJ. Maize grain yield response to changes in acid soil characteristics with yearly leguminous crop rotation, fallow, slash, burn and liming practices. International Journal of Plant & Soil Science. 2012;1(1):1-15.
24. Tekeu H, Ngonkeu MEL, Tandzi NL, Djocgoue PF, Bell JM, Mafouasson AH, Boyomo O, Petmi CL, Fokom R. Evaluation of maize (*Zea mays* L.) accessions using line x tester analysis for aluminum and manganese tolerance. Int. J. Biol. Chem. Sci. 2015;9(4):2161-73.
25. Tri L, Didy S, Trikoesoemaningtyas, Sintho WA. Screening of several sorghum genotypes on acid soil tolerance. International Journal of Agronomy and

Agricultural Research. 2014;5:170-176. Available: http://www.innspub.net
26. Tandzi LN, Ngonkeu EL. Molecular characterization of selected maize *(Zea mays* L.) inbred lines maize. Genomics and Genetics. 2015;6(2):1-5.
27. Nodjimadji N, Foudoussia IAet, Djondimadji F. Dans l'évaluation des besoins dus aux inondations dans la Tandjile, Mayo Kebbi Est, Mayo Kebbi Ouest. Rapport de la FAO sur l'inondation dans le Sud Tchad. 2012;1-73.
28. Beulé T. Search for early molecular markers of anomaly mantled of palm tree with oil *(Elaeis guineensis* jacq.*)* by analysis of transcriptome. Memory of diploma of EPHE (Earth and Life science). 2006;1-21.
29. Harter RD. Les sols acides des tropiques. Echo note technique. Hoopen MET et Maïga A, 2012. Production and transformation of maize. Pro-Agro. 2007;1-13.
30. Nankam C. Cereal pathology. NCRE annual report of activities. In Cameroon. 1990;19.
31. Horst WJ, Fitting maize into sustainable cropping systems on acid soils of the tropics. IAEA – TECDOC 2000;1159:47-59.
32. Bell LC, Edward DG. The role of aluminium in acid soil infertility. In Lathan, M. (ed) Soil Management under Humid conditions in Asia (ASIALAND). Bangkok.Thialand IBS RAM. 1987;103.
33. Mapiemfou LD, Thé C, Tsoata E, Zonkeng C, Mfopou MYC. Inhibition of growth and maize yield *(Zea mays* L.*)* in very acid soil in Cameroon, and identification of early criteria of tolerance to toxicity. Tropicultura. 2011;29(2):94-100.
34. Rhue RD, Grogan CO, Stockmeyer EW, Everett HC. Genetic control of aluminium tolerance in corn. Crop Sci. 1978; 18:1063–67.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/17157