Original Research Article

Screening of maize *(Zea mays* L.) genotypes for adaptation on contrasted acid soils in the humid forest zone of Cameroon

ABSTRACT

Soil acidity is a major limiting factor for maize productivity in the humid forest zone of Cameroon. A yield loss of 60% has been reported in acid tolerant population. The objectives of the study was todetermine the level of tolerance of some selected inbred lines under Aluminum and Manganese toxicities soils of a chosen experimental sitesand to classify them into specific pools. The experimental was laid 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 was then carried out in contrasted acidic soil with Al (Nkoemvone site) and Mn (Nkolbisson site) toxicities based on six agro-morphological parameters. Soil correction was made by the application of 2 t/ha of dolomite. Soil analysis reveals that, at Nkolbisson there wasMn toxicity of 90. 6 (ug/g), while at Nkoemvone we had Al toxicity with value of 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 negatives control. At Nkoemvone, 7.54 % of inbred lines expressed themselves as efficient, 3.77 % were tolerant, 75.47 % were susceptible, 13.20 % were negatives controls 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 after analysis showedthree groups maize genotypes at Nkolbisson and four groups at Nkoemvone. The best genotypes at Nkolbissonwere: 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 Nkoemvonewere: 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).

Keywords: Maize genotypes, screening, Aluminum toxicity, Manganese toxicity, acid soil, humid forest, Cameroon.

1. INTRODUCTION

Maize is the most consumed cereal crop world-wide and represents 40% of the global production followed by wheat (29%) and rice (19%) [1].In Cameroon, although the production of maize is estimated at 1 647 036 t in 2014 [2], several sources revealed that; there is a national production deficit that ranges from 300 000 to 500 000 tons and which keep on increasing every year. In order to curd down this deficit relative to the population increase estimated at 19 558 000 inhabitants [3], Cameroon government invested several billions for importation. In that respect, 10 748.05 tons of maize were imported in 2013 corresponding to a worth of 4.3 $ billion [2].

The world’s arable land is 30% acidic out of which 50 % of this value cames from Africa, while Cameroon’s humid forest zone covers about 75 to 100 % [4, 5, 6, 7]. In sub-Saharan countries, acid soil is a major limiting factor for the production of maize and can cause yield losses drastically of about 80 %[8, 9]and approximately 54-80 % yield losses have been reported in Cameroon [10]. Moreover, 61 % of seeds had lost their genetic potential because of a complete absence of genetic resource banks and in addition, hazards caused by climatic change have come to worsen the plaque of constrains faced by maize farmer [11]. A soil is said to be acidic when the level of free H^+ ions is greater than that of alkaline

or alkaline earth cations. This acidity is not only due to the presence of H^+ ions, but also due to a higher level of Al^{3+}, Mn^{2+} or Fe^{3+} ions in the soil [11, 12, 13]. Acid soils are generally characterized by a low pH (pH< 5.5), a low cation exchange capacity (CEC), deficiencies in phosphorus, calcium, magnesium and molybdenum, [13, 14, 16] low quantities of organic matter as well as a strong erosion capacity,[17]excessive root growth reduction and a decrease in the absorption of the essential nutrients by plants[18]. Indeed, the perception of Al toxicity by the plant in the soil triggers the emission of Al-signal (Si-Al) which plays the role of inducing callose formation and the release of roots exudate. A better resistance by the root apex to Aluminium toxicity results in a very low quantities of callose formation induced by signal Al[15]. In addition, research carried out by [19]revealed that, organic acid exudates (citrate) in response to Al and Mn toxicity have been observed in the apical regions of roots where the first symtoms have been identified in resistant genotypes.

Several studies have been carried out in the laboratory and in the field in order to correct the acidity of the soil. These studies were focused on calcic and organic soil amendments and mineral fertilization [23]. In fact, soil liming was confirmed as the most effective means to correct the acidity of the soil [20, 21]. For the correction of one ha of an acidic soil, 4 to 10 tons of calcium carbonate (0-2 MM) will be required and should be applied 2-3 years for better plant growth[13]. The price of one bag of 50 Kg dolomite is 4.1 $ making a total of 16.36 $ to 40.9 $/ha. The combination of organic and inorganic manures had helped to obtain maize yield of 1,5 to 2 times higher than those obtained on acidic soil with a moderate soil pH. The use of organic manures as the livestock wastes, more precisely the droppings of hens, brings to the plant Ca^{2+} and Mg^{2+} and P, nutrients essential for its development[14]. However, these methods are too costly and sometimes not affordable to farmers in developing countries. To increase and sustain maize grain yield in acidic soil, there is need to developproductivity improvement programs, nutritional value and disease resistance geared to the identification of maize genotypestolerant for acidic soil with Al and Mn toxicity. In this respect, the aim of this study was todetermine the level of tolerance of some selected inbred lines under Aluminum and Manganese toxicities soils of a chosen experimental siteand to classify them into specific pools.

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 (Yaoundé) and the second at Nkoemvone (Ebolowa). Both sites are separated by a distance of about 180 km (Fig. 1.).

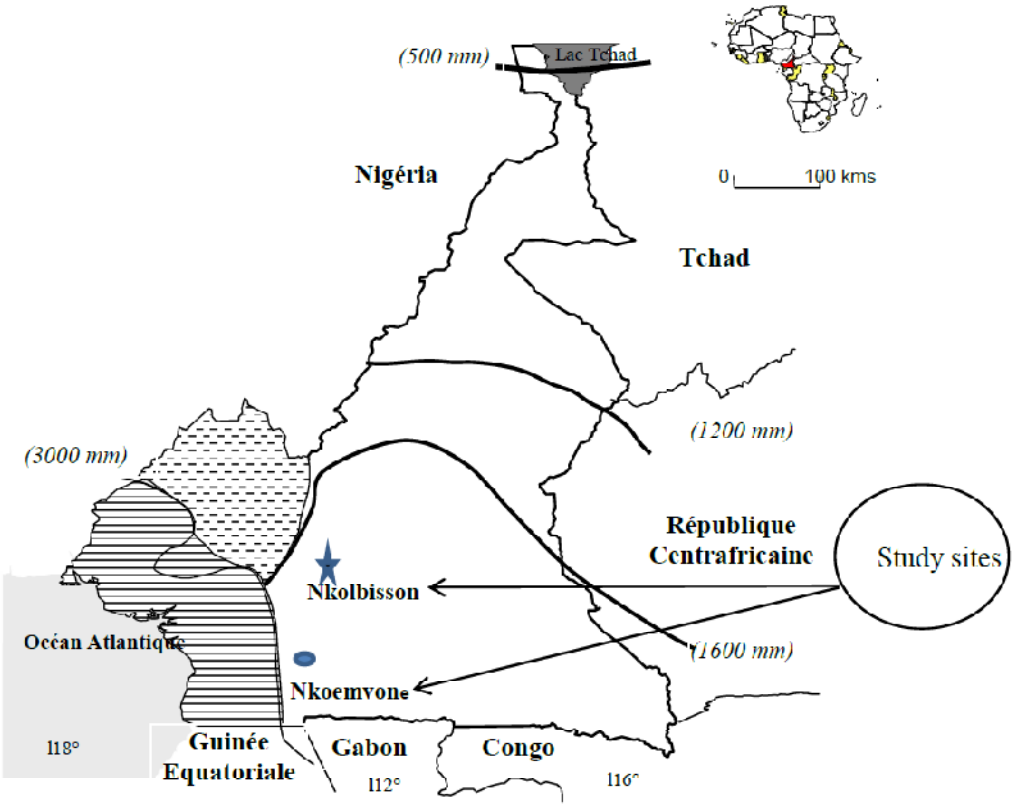

Fig.1. Geographical location of study sites

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 water 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. This site was in a low land with, regular flooding by nearby river.

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 water of 4.33, an ECEC of 3.5 C mol (+) kg and a C/N ratio of 9.28 c mol (+) kg (Table I).

Table I: Physico-chemical characteristics of studied soil

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

77 **2.2. Germplasm**

78 The germplasm used was made up of 52 maize inbred lines genotypes from IRAD (Cameroon),
79 IITA (Nigeria) and CYMMYT (Colombia) (Table II).
80
81 Table II. Genetic characteristics of different genotypes.
82

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	CIgp1-17	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	Camlnbgp117(F)	Suwanl-SR	IRAD	T	Yellow	115
		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: Thé et *al*., 2012, Ngonkeu, 2009, Cameroon Inco Annual report year 1999.
T: Tolerant, AT: Averagely Tolérant, S: Susceptible, PTL: Presumed Toleraance 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 raining 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. Three grains were introduced in each hill at a depth of 3 cm giving a density of 53333 plants/ha.

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. Weeding was done manually.

2.4. Experimental design

The trials were carried out in each experimental site on an area of 1326.8 m². The experimental setup was a split plot; where the main plot was the soil type made of the native acid soil with Aluminium 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:

$$\boldsymbol{Y\left(\frac{t}{ha}\right) = \frac{EFW\ x\ SP\ (100 - MC) x 10000}{DMP}} \quad [13]$$

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:

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

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 exploited for the construction of a dendrogram for each site. The Student NewmannKeul's test enabled the comparison of means at 1 % and 5 % probability levels. The mathematical model used was as follow:

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

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

3.1.1. Genotypes identification adapted in acidic soil with Al and Mn toxicity

At Nkolbisson, grain yield of inbred lines on acidic soil vary 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 are grouped into three classes [2-3[, [3-5[and [5-6[(Fig.2). Parents like 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 best varieties on the acidic soil at Nkolbisson.

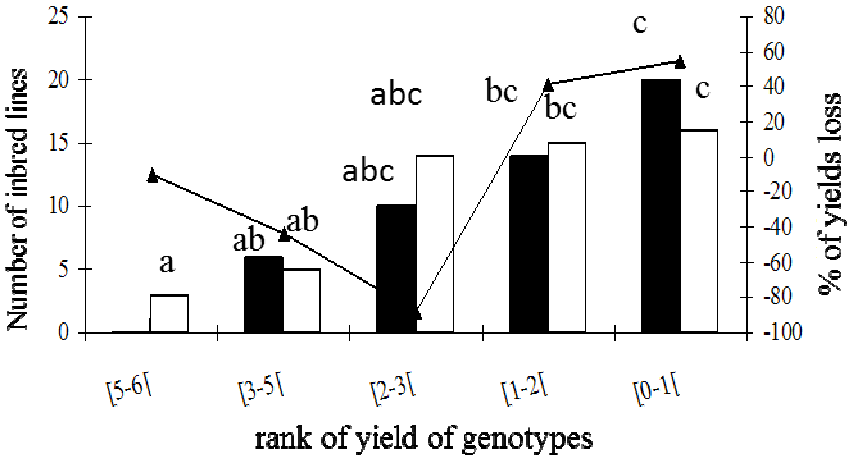

Fig. 2.Yield and yield losses of the best inbred lines on acidic and corrected soil at Nkolbisson.

Column diagram followed by a different letter indicate significant differences at $P < 0.05$.

Acid soil Corrected acid soil % Yield loss

Grain yieldon 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 g ɔed 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) d ATP-46 (4.42 t/ha) were revealed best varieties.

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 shown 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 Camlnbgp1 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 III).

Table III. Grouping of screened progeny on acidic soil atNkolbisson.

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
	Camlnbg1 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	

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.

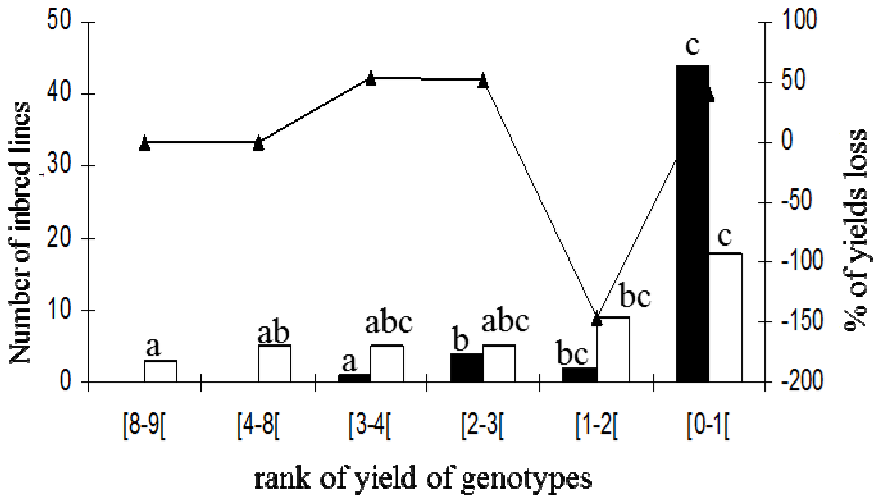

Fig. 3.Yield and yield losses of the best inbred lines on acidic and corrected soil at Nkoemvone. Column diagram followed by a different letter indicate significant differences at $P < 0.05$.

Acid soil Corrected acid soil % Yield loss

The yield of inbred lines on corrected acid soil varies 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, fourlines respondingon both acidic and on corrected acid soils gave yield losses comprised 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 Aluminium toxicity (CML 535 (31.84 %) and CML 439 (16.79 %)). 6 lines presented very regressive losses comprised between - 600 % and -163.45 % and quite considerable yields on control treatments: they werecharacterized 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 atNkoemvone (Table IV).

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

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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	

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 expressed themselves perfectly as susceptible on both experimental sites. 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 which proved to be the most susceptible of all tested genotypes.

3.1.2. Classification of genotypes into specific pools

The dendrogram obtained after analysis by grouping genotyped based on yield at Nkolbisson (Fig. 4.) showed that, it was made up of three large groups. Group I consists of 31 averagely tolerant genotypes, group II has 3 tolerant genotypes and group III had 18 susceptible genotypes. The distance between group I and II and that between group II and III was77.42 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.

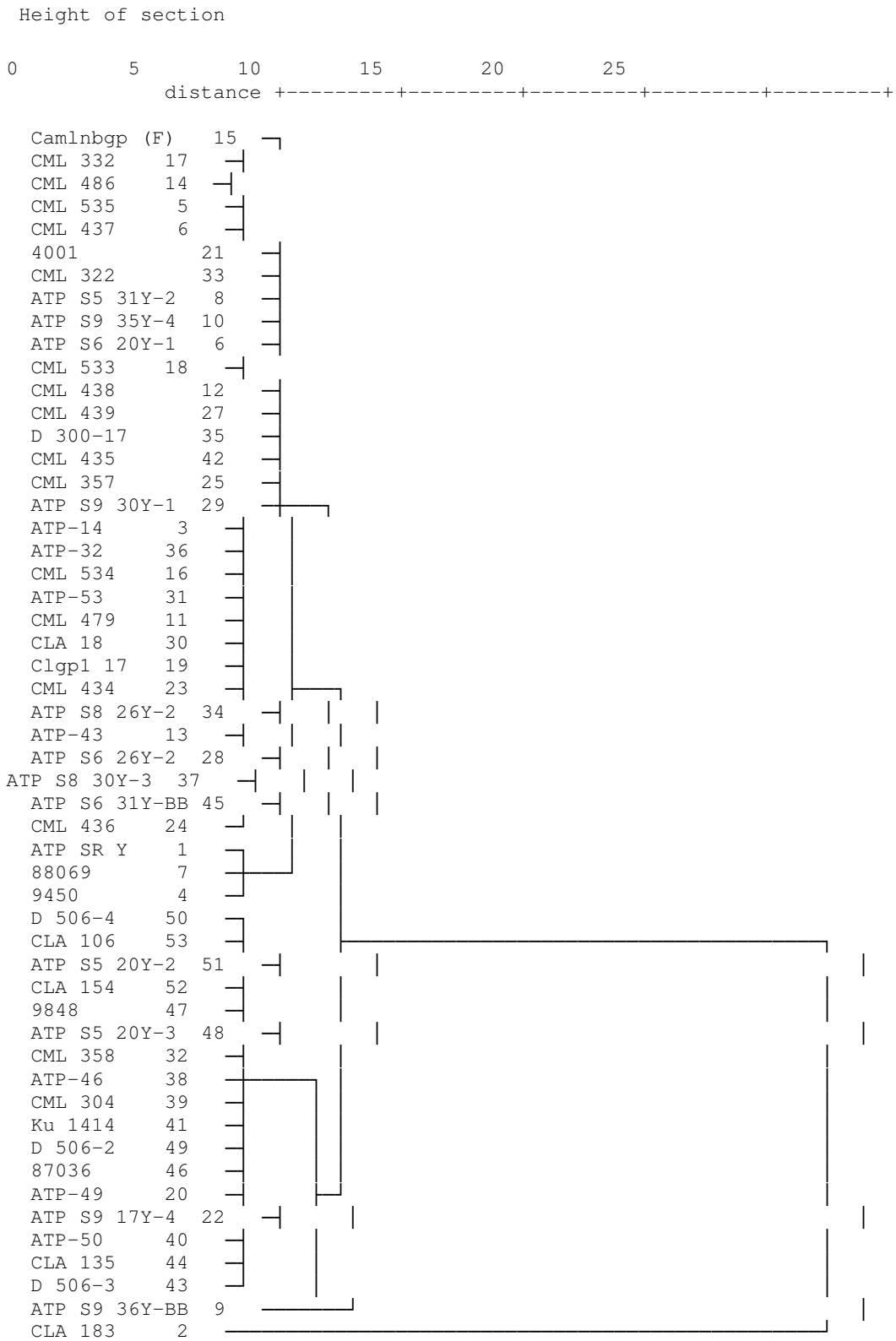

Fig.4. Dendrogramgenotypes of acid soil at Nkolbisson obtained by mean linkage between groups and by thenon-hierarchical classification process of endogamous genotypes

The dendrogram obtained after analysis by groupinggenotyped based on yieldatNkoemvone(Fig. 5.). It wasshowed that, it was made up of four large groups. Group I is made up of 17 averagely tolerant genotypes, group II had 7 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 varieties that were efficient (CML 479, ATP S9 30Y-1) and tolerant (CML 435) obtained after screening, except CML 535 (tolerant) and Camlnbg1 17 (F) which figures in group II. Group II was the best with good ears (1.6), Y (1.68 t/ha), HP (1.28 m), HIE (0.57 m) and GR (40.27 %) and were higher than groups I, III and IV.

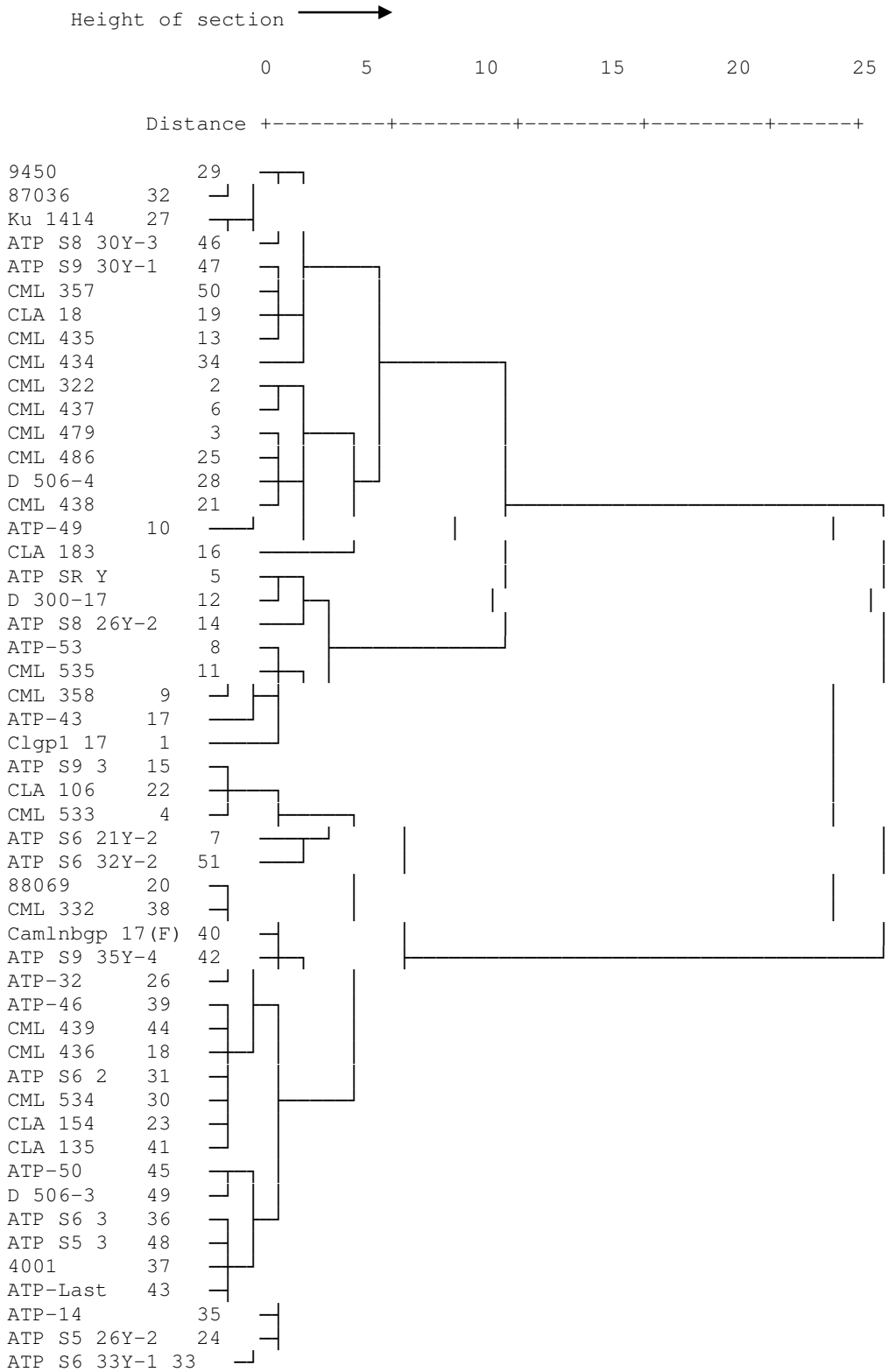

Fig.5.Dendrogram genotypes of acid soil at Nkoemvone obtained by mean linkage between groups and by thenon-hierarchical classification process of endogamous genotypes.

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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 Camlnbgp1 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 goes hand in hand with those obtained by previous authors [717, 23, 24] 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 [25] 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 Aluminium 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 congruent with that of The et *al.* (2006)[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 allowed for 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 (0.65t/ha) and D 506-3 (0.22t/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 (*Elaeisguineensis*Jacq.) (6 %) which is a monoecious plant like maize, by [26].

On corrected acid soil, quick lime had a significant effect on genotypes from germination to maturity. This result is similar to the onewith the results obtained by [27] for whereCalcium 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 [28]. This author had provedoncereals pathology study inCameroon 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 the 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 Nkolbissonwas one of the demonstrative proofs that Aluminium toxicity had more significant impact on maize development than Manganese toxicity. This observation was explained by the fact that Aluminium is more polynuclear than

Manganese, thus provoking a more drastic phytotoxicity)[23, 29]. In addition, the number of susceptible parents (75.47 %) obtained on acid soil at Nkoemvonewas higher than that obtained on acid soil at Nkolbisson (69.81 %). Therefore, the toxicity due to Aluminiumwas the greatest limitation to the growth and development of plant under acidic soils [24, 30].

3.2.2. Classification of genotypes into specific pools

AtNkolbisson, 3 groups of strains were obtained (group I, II and III) (Fig 4). 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.[12]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 [12]. Furthermore, 9450 which had been detected as tolerant by [12] and [23] figures in group II.

At Nkoemvone, four groups of inbred lines were obtained (Fig. 5). These results showed that group I was made up of 17 averagely tolerant endogamous strains. 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 [12].These results were similar to those of [31] and [32], who showed that, maize cultivars present a great variability of soil acidity tolerant genes, meaning that; tolerance of maize inacidic soil is controlled by major genes.

4. CONCLUSION

The evaluation of 52 inbred lines under Aluminium 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). 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.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors: 'Authors NELM, TNL, AZ and BO' designed the study. Author NW and author NELM reviewed the experimental design and enabled the practical realization of this work, physical and chemical soil analysis. Authors BJM, TH and MD performed the statistical analysis, Authors PCL, TNL, MH and NELM wrote the protocol, and wrote the first draft of the manuscript. 'Author PCL' and 'Author TNL' managed the analyses of the study. 'Author PCL' and Author NW managed the literature searches. All authors read and approved the final manuscript."

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