

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 of the 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 to improve maize productivity and emphasis was laid more to identify efficient, tolerant and susceptible genotypes on Al and Mn toxicities, in order to classify them into specific heterotic pools. The experimental design was a Split-plot in completely randomized blocks design with three replications. An assessment of 53 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 0.2 t/ha of dolomite. Soil analyses reveal that, at Nkolbisson there is Mn toxicity of 90.6 (ug/g), while at Nkoemvone we have Al toxicity with value of 2.32 (cmol (+) kg). At Nkolbisson, 5.76 % of 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 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-ecology. The dendrogram obtained after analysis show three groups of endogamous maize genotypes at Nkolbisson and four groups at Nkoemvone. The best genotypes at Nkolbisson are: ATP-14 (4.08 t/ha), CamInb1 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 are: 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%) (Conseil international des céréales, 2016). In Cameroon, although the production of maize is estimated at 1 647 036 t in 2014 (INS, 2016), 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 (MINEPAT, 2010), 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 2 358.65 billion FCFA (INS, 2016).

The world's arable land is 30-40 % acidic of which 50 % is in Africa, covering about 75 to 100 % in Cameroon's humid forest zone (Bindzi Tsala, 1987; Von Uexkull et Mutert., 1995; Ambassa Kiki., 2002, Tekeu et al., 2015). 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 % (Welcker et al., 2005; Kochian., 2012) and approximately 54-80 % yield losses have been reported in Cameroon (Tandzi et al., 2015). Moreover, 61 % of seeds had lost their genetic potential because of a complete absent of genetic resource banks and

in addition, hazards caused by climatic change have come to worsen the plaque of constraints face by maize farmer (Ngonkeu et al., 2009). 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 (The et al., 2006; Mapienfou et al., 2011, Ngonkeu et al., 2009). 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 (Granados et al., 1993; Horst et al., 2007, Pandey et al., 2013; Gusti et al., 2014), low quantities of organic matter as well as a strong erosion capacity (Tri et al., 2014), excessive root growth reduction and a decrease in the absorption of the essential nutrient by plants (Kochian et al., 2012, Krstic et al., 2012). 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 (Horst et al., 2001). In addition, researched carry out by Keltjens (1988) on Al^{3+} tolerance mechanism in maize revealed that, resistant genotypes to Al have citrate level in the roots than the sensitive genotypes. Problems resolution linked to acidity of the soil is carried out by the application of lime, Phosphorus, organic matter, bio fertilizers and tolerant variety (Ngonkeu et al., 2009). Several studies have been carried out in the laboratory and in the field in order to support the importance of these practices. These studies were focused on calcic and organic soil amendments and mineral fertilization (Thé et al., 2012). In fact, soil liming was confirmed as the most effective means to correct the acidity of the soil (Thé et al., 1999, Roy and Bhadra, 2014). 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 (The et al., 2006). The price of one bag of 50 Kg dolomite is 22.500F CFA, making a total of 90.000 to 225.000F CFA/ha. The combination of organic and inorganic manures had help 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 (Granados and al., 1993). 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 develop breeding programs geared to identify maize genotypes tolerant for acidic soil with Al and Mn toxicity. In this respect, the aim of this study was to improve maize productivity via the identification of efficient, tolerant and susceptible genotypes in acidic soil with Al and Mn toxicity, in order to classify them into specific heterotic pools.

2. MATERIALS AND METHODS

2.1. Site presentation, physical and chemical characteristics of studied soil

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.).

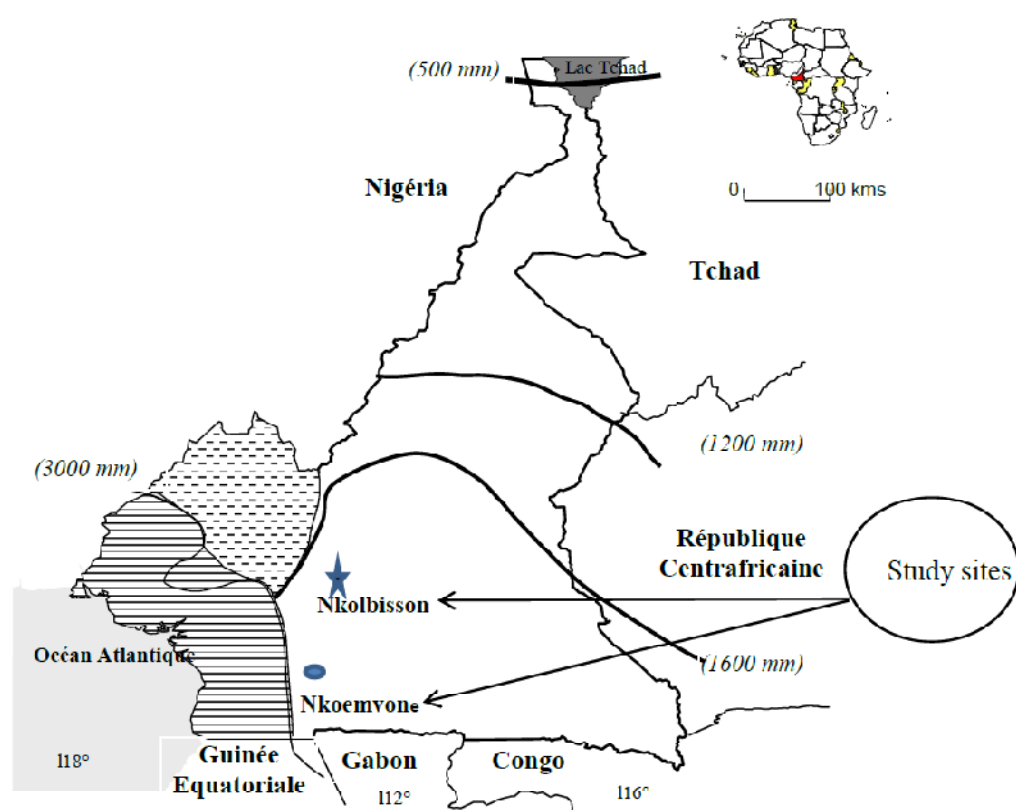


Fig.1. Geographical location of study sites

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 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 ₂ O	H ⁺ (cmol(+)/kg)	Report/ratio C/N(cmol(+)/kg)	Al (cmol(+)/kg)	Mn (ug/g)	T S (%)
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

2.2. Maize genotypes characterization

Biological material used was made up of 52 maize inbred lines genotypes from IRAD (Cameroon), IITA (Nigeria) and CYMMYT (Colombia) (Table II).

Table II. Genetic characteristics of different genotypes.

Entry	Genotypes	Genetic base	Origin	PTL	Color	Vegetative cycle
short life cycle genotypes						
1	ATP S5 20Y-2	ATP	IRAD	T	Yellow	115 jrs
2	ATP S5 26Y-2	ATP	IRAD	T	Yellow	115 jrs
3	ATP S5 31Y-2	ATP	IRAD	T	Yellow	115 jrs
4	ATP S6 20Y-1	ATP	IRAD	T	White	115 jrs
5	ATP S6 21Y-2	ATP	IRAD	T	Yellow	115 jrs
6	ATP S6 32Y-2	ATP	IRAD	T	White	115 jrs
7	ATP S6 33Y-1	ATP	IRAD	T	Yellow	115 jrs
8	ATP S6 31Y-BB	ATP	IRAD	T	Orange	115 jrs
9	ATP S8 26Y-2	ATP	IRAD	T	Orange	115 jrs
10	ATP S8 30Y-3	ATP	IRAD	T	Orange	115 jrs
11	ATP S9 17Y-4	ATP	IRAD	T	White	115 jrs
12	ATP S9 30Y-1	ATP	IRAD	T	Yellow	115 jrs
13	ATP S9 35Y-4	ATP	IRAD	T	Orange	115 jrs
14	ATP S9 36Y-BB	ATP	IRAD	T	Orange	115 jrs
15	ATP-49	ATP	IRAD	T	White	115 jrs
16	ATP-50	ATP	IRAD	T	Yellow	115 jrs
17	ATP-53	ATP	IRAD	T	Yellow	115 jrs
18	CML 304	/	CIMMYT	T	Orange	115 jrs
19	Clgp1-17	Suwanl-SR	IRAD	T	White	115 jrs
20	88069	/	IRAD	AT	Yellow	115 jrs
21	ATP 14	ATP	IRAD	T	Orange	115 jrs
22	ATP 43	ATP	IRAD	T	Yellow	115 jrs
23	ATP 46	ATP	IRAD	T	Yellow	115 jrs
24	ATP- Last	ATP	IRAD	T	Yellow	115 jrs
25	87036	Crossing between TMZ _{SR} and Pop ₄₃ .	IRAD	AT	White	115 jrs
26	Camlnbpgp117(F)	Suwanl-SR	IRAD	T	Yellow	115 jrs
Intermediate life cycle genotypes						
27	4001	/	IITA	AT	Yellow	105 Jrs
28	9450	B73	IITA	AT	Yellow	105 Jrs
29	D 506-2	/	CIMMYT	AT	White	105 Jrs
30	CML 358	Pop SA3	CIMMYT	T	Yellow	105 Jrs
31	CLA 154	/	CIMMYT	S	Orange	105 Jrs
32	CLA 106	/	CIMMYT	S	Yellow	105 Jrs
33	CLA 18	/	CIMMYT	T	Yellow	105 Jrs
34	D 506-3	/	CIMMYT	AT	Yellow	105 Jrs
35	D 504-4	/	CIMMYT	AT	Orange	105 Jrs

36	Ku 1414	/	IITA	AT	Yellow	105 Jrs
Premature variety						
37	CML 357	/	CIMMYT	T	Orange	90 jrs
38	CML 435	/	CIMMYT	T	Yellow	90 jrs
39	CML 436	/	CIMMYT	T	Orange	90 jrs
40	CML 437	/	CIMMYT	T	Yellow	90 jrs
41	CML 438	/	CIMMYT	T	Orange	90 jrs
42	CML 439	/	CIMMYT	T	Orange	90 jrs
43	CML 533	/	CIMMYT	T	Orange	90 jrs
44	CML 534	/	CIMMYT	T	Orange	90 jrs
45	CML 535	/	CIMMYT	T	Orange	90 jrs
46	CML 322	/	CIMMYT	T	White	90 jrs
47	CML 332	/	CIMMYT	T	White	90 jrs
48	CML 486	/	CIMMYT	T	Yellow	90 jrs
49	CML 479	/	CIMMYT	T	Yellow	90 jrs
50	CLA 183	/	CIMMYT	AT	White	90 jrs
51	CML 434	/	CIMMYT	T	Orange	90 jrs
52	D 300-17	/	CIMMYT	AT	White	90 jrs

Reference sources: Thé et *al.*, 2012, Ngonkeu, 2009, Cameroon Inco Annual report year 1999.

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: Thailand Research Station; CIMMYT : Centro Internacional de Mejoramiento de Maíz 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. Experimental design

The trials were carried out in each experimental site on an area of 1131.8 m² with a 2 m alley separating each block. The experimental setup was a split plot; where the primary variable was the soil type: treatment "O" for acidic soil of Aluminium or Manganese toxicity and treatment 'T' corresponding to corrected acidic soil. The secondary variable was made of genotypes, arranged into completely randomized blocks with three replications. The correction of the acidity consisted in the spreading of 0.2 t/ha of dolomite applied on a surface of 496 m².

2.4. Seed sowing and fertilizer application

After the first rainy season (15 March-15 April), maize lines were sown on rows that measured 4 m each with up to 9 hills. The distance between two consecutive rows was 75 cm and 50 cm between two consecutive hills. Three grains were introduced in each hill at a depth of 3 cm corresponding to a density of 53333 plants/ha.

Mineral fertilizers were applied in two splits (Thé et *al.*, 2005): 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 split was applied 32 DAS, before flowering at a dose of 50 kg/ha of urea. Necessary agronomic practice were done including weeding that was done manually.

2.5. Data collected

The following phenotypic parameters were measured one week before flowering: plant height (HP) and ear insertion height (HIE), the ears weight (WE) and grain moisture content (MC) measured in the field during harvest. Dendrogram was constructed with the parameters above including the grain yield and the germination rate (GR) evaluated 2 WAS. Grain yield (Y in kg/ha) of the genotypes were obtained using the formula below:

$$Y\left(\frac{t}{ha}\right) = \frac{EFW \times SP (100 - MC) \times 10000}{DMP} \quad (Thé et al., 2006)$$

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:

$$PYL(\%) = \frac{YC - YA}{YC} \times 100 \quad (Thé et al., 2006)$$

PYL: Percentage yield loss

YC: Grain yield in corrected soil

YA: Grain yield in acidic soil

2.6. Data analysis

Data were subjected to an analysis of variance using the SAS 9.0 software package with the General Linear Model (GLM). The SPSS 16.0 software package was exploited 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 as follow:

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

Y_{ij} : Performance of the individual

μ : Population mean

α_i : Random effect of the i th repetition ($i = 1, 2, 3$)

β_j : Fixed effect of the genotype ($j = 1, 2, \dots, 54$)

$(\alpha\beta)_{ij}$: 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.

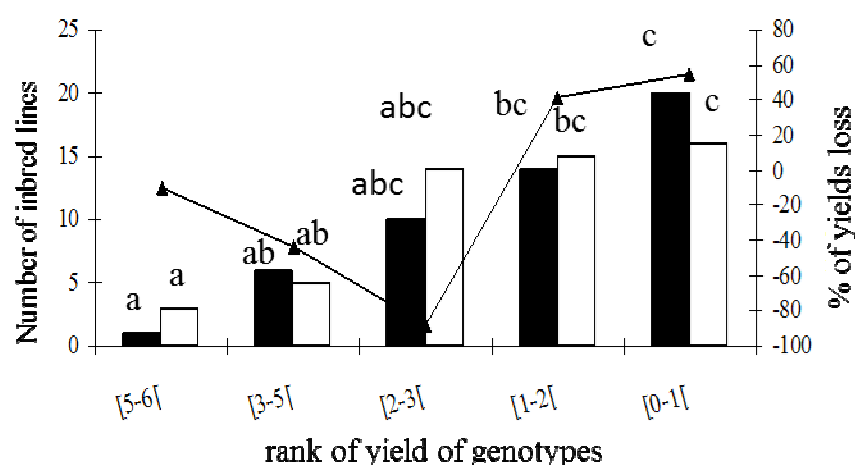


Fig. 2. Yield and yield losses of the best inbred lines on acidic and corrected soil at Nkolbisson.

Same letters indicates: non-significant, different letters indicates: significant.

■ Acid soil □ Corrected acid soil ▲ % Yield loss

Parent grain on corrected acid soil (control) vary 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] representing a yield interval in which each genotype is found (Fig. 1). Genotypes CML 358 (5.57 t/ha), ATP-14 (5.00 t/ha) and ATP-46 (4.42 t/ha) revealed themselves as the best varieties.

Inbred lines responding well on acidic and corrected soil observed 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 lines are said to be efficient on acid soils with Manganese toxicity. For 17 genotypes that produced yields greater than 2 t/ha, five varieties presented less than 54 % yield loss and were retained as tolerant strains to acidic soils with Manganese toxicity. These are 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 characterized as susceptible genotypes while 8 genotypes (15.09 %) showed very regressive losses of beyond -50 % and high yields on acid soil; they are considered as negative control genotypes at Nkolbisson acid soils (Table III).

Table III. 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
	Camlnbgp1 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 least productive lines. On the same acidic soil, only 5 genotypes procured a yield greater than 2 t/ha and were grouped into two classes [3-4] and [2-3] while 10 genotypes were in the 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 on acidic soils at Nkoemvone.

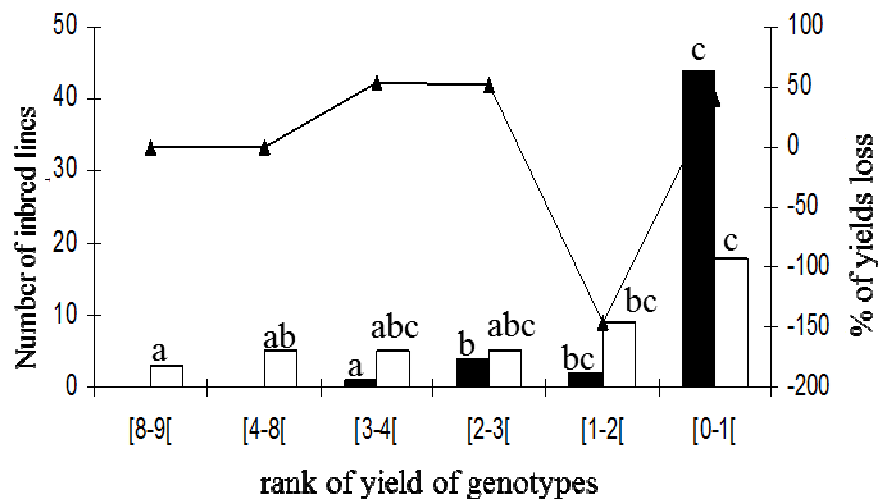


Fig. 3. Yield and yield losses of the best inbred lines on acidic and corrected soil at Nkoemvone.

Same letters indicates: non-significant, different letters indicates: significant.

■ Acid soil □ Corrected acid soil ▲ % Yield loss

The yield of parents on corrected 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, four lines responding on both acidic and on corrected soils with yield losses comprised between -14.70 % and 0 %. These lines were grouped as efficient, 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 %)). 7 lines presented very regressive losses comprised between - 600 % and -163.45 % and quite considerable yields on control treatments: they are 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 %), ATP SR Y (-365.11 %), 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 % are said to be susceptible genotypes to the soil type at Nkoemvone (Table IV).

Table IV. 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	
		CamInbgp1 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 heterotic pools

The dendrogram obtained after analysis by grouping different variables at Nkolbisson (Fig. 4.) showed that, it is 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 is 77.42 and 86.66 respectively. Each group encloses parents which look alike phenotypically.

Group I contains varieties that are efficient (CML 535, CML 486, CML 437) and tolerant (ATP-14, ATP-43, ATP S9 30Y-1, ATP S5 31Y-2, Camlnbg1 17 (F) obtained after screening. 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.

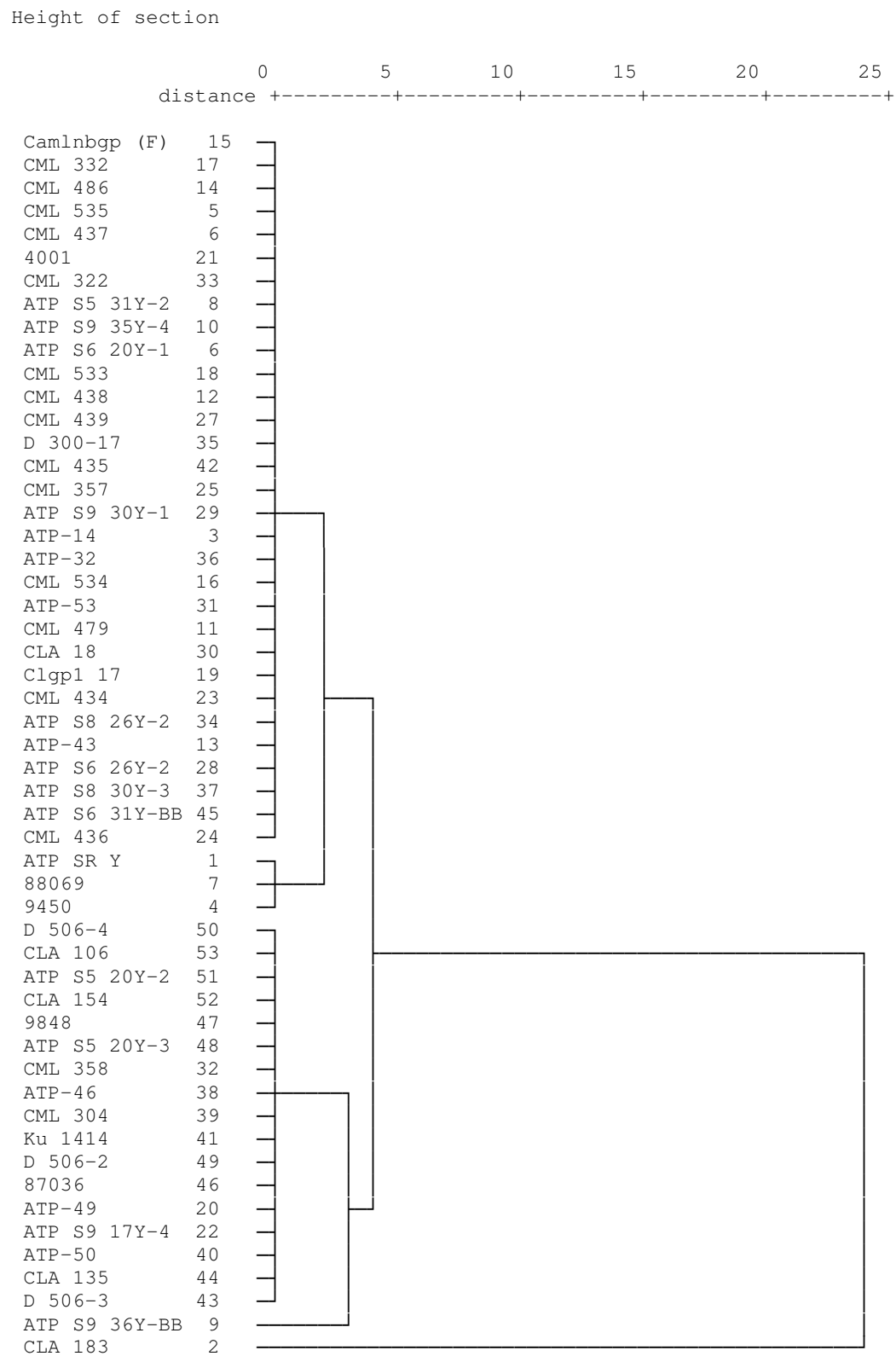


Fig.4. Dendrogram of genotypes of acid soil at Nkolbisson obtained by mean linkage between groups and by the non-hierarchical classification process of endogamous genotypes

The dendrogram obtained (Fig. 5.) after analysis by groups of different variables at Nkoemvone it is showed that, it is made up of four large groups mentioned in (Fig.5.). Group I demarcates with 17 averagely tolerant genotypes, group II with 7 tolerant genotypes. Group III had five averagely susceptible parents and group IV had 21 susceptible genotypes. The distance between groups I and II is 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 are efficient (CML 479, ATP S9 30Y-1) and tolerant (CML 435) obtained after screening are present, except CML 535 (tolerant) and CamInbg1 17 (F) which figures in group II. Group II is 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 are higher than groups I, III and IV.

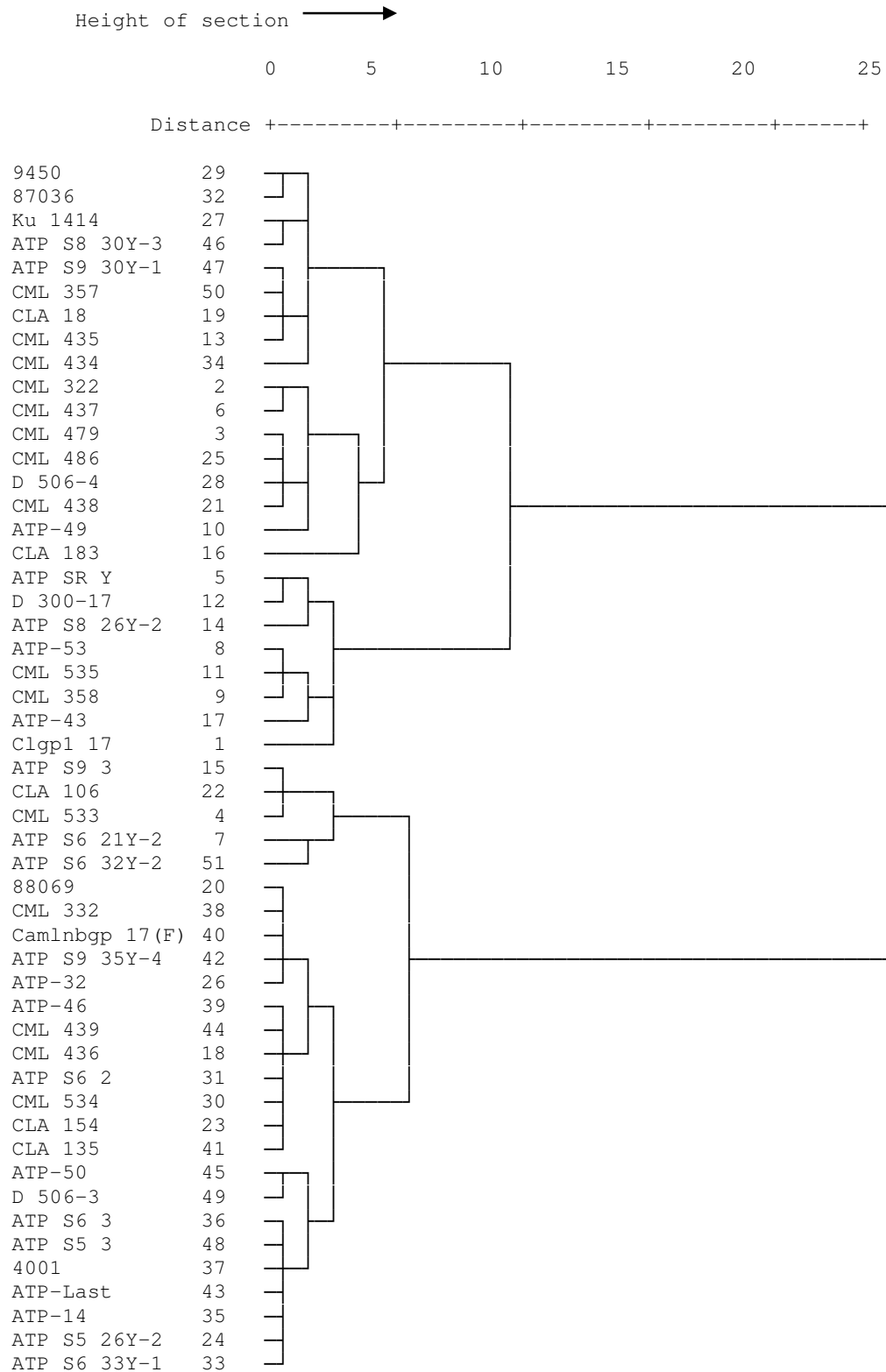


Fig.5. Dendrogram of genotypes of acid soil at Nkoemvone obtained by mean linkage between groups and by the non-hierarchical classification process of endogamous genotypes.

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 themselves as efficient and tolerant genotypes on acidic soil more than on corrected soil. Also, four inbred lines (ATP S5 31Y-2, ATP S9 30Y-1, ATP-43, and Camlnbpg1 17 (F)) presumed as tolerant from origin, confirmed their level of tolerance on acid soil especially under Manganese toxicity at Nkolbisson. This result is a proof that these genotypes could possess major tolerance genes as compared to other susceptible genotypes and this result agrees with those obtained by previous authors (Thé et al., 2007; Thé et al., 2012; Tri et al., 2014; Tandzi et Ngonkeu ., 2015, Tekeu et al., 2015). The serious regressive yield losses obtained within negative control genotypes are 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 Nodjimadji et al. (2012) 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 confirmed itself to be the best. This result concurred with that of Thé et al. (2006), who identified specific heterotic 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 is substantial proof that the environment allowed for a better expression of their genes as compared to susceptible genotypes (Thé et al., 2012; Tri et al., 2014). 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 described by Corley in 1986 and 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 Beulé (2006).

On corrected acid soil, quick lime had a significant effect on genotypes from germination to maturity. This goes hand in hand with the results obtained by Harter (2007) for which Calcium improvement compensates the acidification produced by biological activity, increasing the lowering of the soil pH and therefore favoring the assimilation of soil nutrients could be attributed to crop parasites such as: coal maize ear (*Ustilago maydis*), greenfly, larvae of the butterfly called *Hydraecia micacea* (Esper) and birds of the *Carduelis spinus* genus. This observation gives reason to confirm the assertion of (Nankam et al., 1990) for whom yield losses caused by crop destroyers vary from 15 to 50 % with regards to the total annual production.

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 Thé et al. (2012). In addition, low yield and high yield losses obtained in this corrected plot are due to repercussions of stems borer and hérissons (Nankam et al., 1990).

A similar study of screened genotypes on the two sites showed that ATP S5 30Y-1 and CML 535 manifested themselves as the best in terms of yield. These genotypes retained by virtue of their tolerance on contrasted 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 themselves as susceptible on the 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 Nkolbisson is one of the demonstrative proofs that acid soils of Aluminium toxicity have a more significant impact on the development of maize farming than acid soils of Manganese toxicity. This affirmation is explained by the fact that Aluminium is more polynuclear than Manganese, thus provoking a more drastic

phytotoxicity (Horst et al., 2001; Thé et al., 2012). In addition, the number of susceptible parents (75.47 %) obtained on acid soil at Nkoemvone is higher than that obtained on acid soil at Nkolbisson (69.81 %). Therefore, the toxicity due to Aluminium is the greatest limitation to the growth and development of plant on acidic soils (Bell and Edwards, 1987; Tandzi and Ngonkeu., 2015).

3.2.2. Classification of genotypes into specific heterotic pools

At Nkolbisson, 3 groups of strains were obtained (group I, II and III). Genotypes ATP 14, ATP 43, ATP S9 30Y-1, ATP S5 31Y-2 and Camlmg1 17 (F) of group I specified as tolerant from origin proved to actually be tolerant in the course of the screening. Thé et al (2006) identified Clgp1 17 and CML 357 as tolerant to acid soils and the genotypes Clgp1 17 and CLA 18 were demarcated as tolerant by (Mapienfou et al., 2011). Furthermore, 9450 which had been detected as tolerant by Mapienfou et al (2011) and The et al (2012) figures in group II. Acid tolerant populations (ATP) indicated as tolerant from origin proved to be susceptible in the course of the experiment because of the impact of climatic change on environment such as floods. These results are not in agreement with those obtained on the same site by other authors (The et al., 2006; Ngonkeu., 2009; Tandzi et al., 2015; Tandzi and Ngonkeu., 2015; Tekeu et al., 2015), who showed that ATP varieties had been revealed as tolerant on acid soil with Al, Mn or Fe toxicities.

At Nkoemvone, four groups of inbred lines were obtained. These results showed that group I was made up of 17 averagely tolerant endogamous strains. Group III distinguished itself with 5 averagely susceptible strains 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 Thé et al. (2007). Averagely tolerant varieties CLA 18 and 9450 (group I) were shown to be tolerant by Mapienfou et al. (2011). These results are similar to those of Rhue et al. (1978) and Miranda et al. (1984), 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.

4. CONCLUSION

The evaluation of 53 inbred lines on two types of acidic soil showed a great variability of lines tolerance to the different types of soil acidity studied. Yield, germination rate and plant height, ear insertion height, the ears weight and grain moisture content parameters were identified as the more effective criteria for the selection of genotypes for tolerance to acid soils of Aluminium and Manganese toxicity. At the end of this study, 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 are: ATP-14 (4.08 t/ha), Camlmb1 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 are: 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 studied inbred lines identified to be efficient and tolerant parental genotypes.

CONSENT

No manuscripts will be peer-reviewed if a statement of patient consent is not presented during submission.

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