Agro-morphological Characterization of Maize (*Zea mays* L.) Hybrids Under Acid Soils in Two Contrasting Environments

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Abstract

Acidic soils cover 75 to 80% of the arable soils in the humid forest areas of Cameroon, causing maize yield losses of around 69%. Sixty-four accessions of maize hybrids were developped from "Line × Tester" crosses between twenty tropical inbred lines with three testers (Cam inbgp117, 88069 and 9450) and between testers themselves, and one acid tolerant open pollinated variety (ATP-SR-Y). Those inbred breeding lines were collected from CIMMYT, IITA and IRAD and the derived single hybrids were characterized using agro-morphological maize's descriptors on a completely randomized block design in two contrasting environments (Nkoemvone and Nkolbisson). The data collected was subjected to multivariate analyses. The Principal Component Analysis showed the first two components being 73.60% and 78.99% of the total variation in Nkoemvone and Nkolbisson, respectively. Furthermore, grain yield showed a positive and highly significant correlation with the plant emergence rate in Nkoemvone (r = 0.61, *P* < 0.001) and Nkolbisson (r = 0.84, *P* < 0.001). Hierarchical Clustering Analysis indicated that these accessions forms four distinct groups, where each of the groups showed clear specific features for which the performance differs from that of the others in Nkoemvone and Nkolbisson. Characters such as plant emergence rate, prolificacy, ear appearance and grain yield have been found as important phenotypic markers for assessing agromorphological diversity of maize hybrids. These traits should necessarily be considered in maize breeding programs for varietal discrimination and formulation of cores collection of maize tolerant to aluminum and manganese toxicities in the soil.

Keywords: acidic soil, aluminum tolerance, humid forest zones, maize, manganese tolerance

1. Introduction

Maize is one of the most important cereal crops in the world, providing a staple food, and being used as source of income for many populations in developing countries (Tandzi et al., 2020). It is an essential source of carbohydrate for human diets and animal feed in developing countries (Undie et al., 2012). In Central Africa, it is a major staple crop and has the potential to mitigate the food insecurity in the sub region (Tandzi et al., 2015a). Corn is widely consumed in Central and West Africa (Thé et al., 2007). The way maize is processed and consumed greatly varies from one country to another, with maize flour and meal being the most popular products (USAID, 2002; Ranum et al., 2014). It is the most important food in South America, the Caribbean and Africa (Claudia, 2000; Mapiemfu, 2011). Corn bristles are used for their cholagogue, antidiuretic and antihemorrhagic properties (Lepengue et al., 2012).

The cultivation of maize covers all of the five agro-ecological zones of Cameroon (Ngonkeu, 2009) where yields are limited by several constraints such as soil acidity (Horst, 1997), diseases and pests (Adregbola, 1994), the non-use of suitable agricultural practices as well as the unavailability and ignorance of improved seeds. Maize yields were found to be reduced significantly because of aluminum and/or manganese toxicity, with deficiencies in Ca, Mg, P, and Mo (Aldrich et al., 1975; Borrero et al., 1995; Clark, 1997; Krstic et al., 2012) inhibiting root development and reducing water absorption in plant (Mossor-Pietraszewska, 2001; Velasquez et al., 2008). The humid forest areas of the country covers 21.7 million hectares with 75 to 100% of acidic soils (Bindzi-Tsala, 1987; Ambassa-Kiki, 2002). These acidic soils hamper maize production, causing yield losses of up to 69% (Tandzi et al., 2018).

For an acceptable agricultural production, Thé et al. (2006) showed that acidic soils improvement with lime (2 t·ha^{-1}) increased grain yield of tolerant and susceptible maize varieties. Furthermore, Ngonkeu (2009) showed that the use of improved maize varieties coupled with the biological soil fertility processes of certain species of arbuscular mycorrhizal fungi improved the tolerance of maize plants to soil with aluminum and manganese toxicities. The given solutions are costly for resource-poor farmers (Thé et al., 2003). Wood ash at 4 t·ha^{-1} has also been used and this has significantly increased the yield in acid soils (Mbahet al., 2010). Moreever, Tandzi et al. (2015a) stated that this method is not always sustainable because of the non-availability of ash. Therefore, the use of maize cultivars tolerant to soil acidity could provide less expensive and permanent solution, contributing to sustainable crop production on acid soils (Granados et al., 1993; Welcker et al., 2005). Therefore, two hybrids (ATP-SR-Y × 87036 and ATP S5 SYN-Y × 9450) were identified as being tolerant of soil acidity (Tandzi, 2005), but these varieties are not available to farmers. Moreover, the most acid-tolerant open-pollinated (OP) variety (ATP-SR-Y) so far released since 1999, suffers yield reduction due to soil acidity within the ranges of 57 to 60% (The et al., 2006; Tekeu, 2013), becoming thereby sensitive. Among the new hybrid varieties of highly productive maize, many have interesting traits that could be exploited by breeders in breeding programs. Tandzi et al. (2015b) characterized some of the selected inbred lines under acidic soil with aluminum toxicity whereas Petmi et al. (2016) screened inbred maize lines for adaptation on acid soils in the humid forest zone of Cameroon. However, no studies have been conducted to provide agro-morphological information such as emergence rate of plants, prolificacy, appearance of the ear and grain yield on the promising varieties of maize hybrids developed by Tekeu et al. (2015). This study was investigate to characterize the agro-morphological performances of maize hybrids varieties under acidic soils conditions with aluminum and manganese toxicities.

2. Material and Methods

2.1 Plant Material

The plant material consisted of 64 single hybrids derived from "Line × Tester" crosses between 20 tropical inbred lines with three testers (Cam inbgp117, 88069 and 9450) and between testers themselves, and one acid tolerant open pollinated variety (ATP-SR-Y) used as control. These lines were crossed in order to get hybrids with broad genetic bases, coming from parents presenting different levels of tolerance to soil acidity, their geographical origin diversity (IRAD, IITA, CIMMYT Cali and CIMMYT Colombia) and their varied colors, responding to users' choices (Table 1).

Table 1. Origins and characteristics of the lines, testers and maize composite tested

No.	Varieties	Origins	Genetic basis	Presumed level of tolerance to toxicity: aluminum-manganese	Grain colors
1	ATP S6 33Y-1	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
2	ATP S6 32Y-1	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
3	ATP-Last	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
4	ATP-46	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
5	ATP-43	IRAD	ATP-SR	Tolerant-Tolerant	Yellow
6	D 506-3	CIMMYT	n.d.	n.d.	Yellow
7	D 506-4	CIMMYT	n.d.	n.d.	Yellow
8	Ku 1414	IITA	n.d.	Tolerant-Tolerant	Yellow
9	87036	IRAD	TMZsr × pop32	Tolerant -Tolerant	White
10	CLA 154	CIMMYT	n.d.	n.d.	Yellow
11	CLA 106	CIMMYT	n.d.	Tolerant-Tolerant	Yellow
12	ATP-14	IRAD	n.d.	n.d.	Yellow
13	CLA 18	CIMMYT	n.d.	Intermediate-Tolerant	Yellow
14	Cml 322	CIMMYT	n.d.	n.d.	White
15	Cml 358	CIMMYT	Pop SA3	Tolerant-Tolerant	Yellow
16	9450	IITA	B73	Intermediate-Tolerant	Yellow
17	88069	IRAD	n.d.	n.d.	Yellow
18	Cam Inb gp1 17	IRAD	Suwan I-SR	Sensitive-Tolerant	Yellow
19	C4RR SA3	CIMMYT	n.d.	n.d.	Yellow
20	C4RR SA4	CIMMYT	n.d.	n.d.	Yellow
21	C4SRR SA6	CIMMYT	n.d.	n.d.	Yellow
22	C4 SRR A7	CIMMYT	n.d.	n.d.	Yellow
23	CIgp1 17 (F)	IRAD	Suwan I-SR	Tolerant-Tolerant	Yellow
24	ATP-SR-Y	IRAD	ATP-SR	Tolerant-Tolerant	Yellow

Note. n.d.: not determined; CIMMYT: International Maize and Wheat Improvement Center; IRAD: Agricultural Research Institute for Development. IITA: International Institute of Tropical Agriculture; Pop: population; ATP: Acid Tolerant Population.

Source: Cameroon Inco Annual Repport Year 1999; The et al. (2006b).

2.2 Experimental Sites and Chemical Propreties of Soils

The first experimental site is located in the Central region (Nkolbisson, Yaoundé) and the second is located in the South region (Nkoemvone, Ebolowa), (Figure 1). In Nkolbisson (3°44′N; 11°36′E), the site is located 650 m above sea level. The annual average temperature was 23.5 °C, the rainfall is bimodal and the annual average is 1560 mm. Classification show a soil with a clay-silty texture with a strong tendency to hydromorphy and manganese toxicity and is of the Kandiudox type. In Ebolowa, the experimental site, Nkoemvone (2°40′N; 12°24′E) is located 25 km from the city, at 615 m above sea level. The average annual temperature is 24 °C with a Guinean-type climate and a bimodal annual average rainfall of 1875 mm. The soil had a clay texture and aluminum toxicity, classified in the Kandiudox type and belonging to oxisols (Welcker et al., 2005; Thé et al., 2005). Nkolbisson was characterized by acidic soil with manganese toxicity while in Nkoemvone, its acidity was linked to aluminum toxicity (Tekeu et al., 2015).
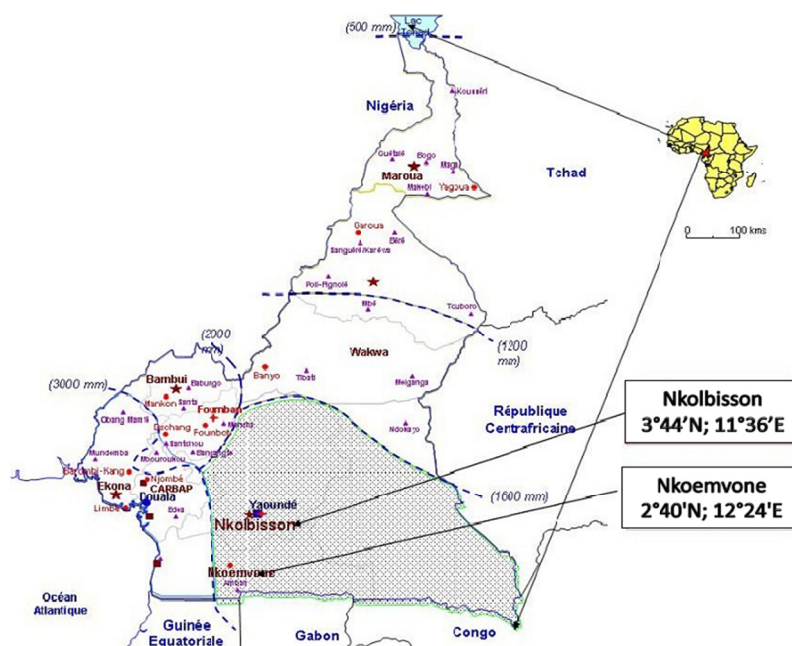
Figure 1. Position of the experimental sites in Cameroon (Ngonkeu, 2009)

2.3 Phenotyping, Data Collection and Statistical Analysis

Field trials were conducted in a completely randomized block design with three replicates on an area of 780 m². Crosses and evaluations were made in 2010-2011 and 2011-2012, respectively. The planting was done at a density of 53,333 plants·ha⁻¹. The experimental unit was 4 m row lenght, with inter-row of 0.75 m and intra-row of 0.5 m. The experiment received a basal dose of fertilizer of 37 N, 24 P_2O_5 and 14 K_2O kg·ha⁻¹ applied 10 days after planting and 46 N kg·ha⁻¹, applied 30 days after planting (The et al., 2006).

The variables measured were: seedling emergence rate; appearance of the maize's ears in the field (the rating index varies from 1 to 5, where the indices between 1 and 1.9; 2 and 2.9; 3 and 5 were respectively assigned to the best, average and bad aspects of the ears) was assessed at the physiological maturity stage of plants; plant prolificacy (the number of ears on a plant) as described by Welcker et al. (2005); the plant stand at harvest and the number of ears at harvest were also recorded. At harvest, all ears from each plot were counted and the number of ears per plant (EPP) was calculated using the formula: EPP = EC/PC, Where EC and PC = number of ears and number of plants per row, respectively (Tandzi et al., 2015). Yield was adjusted to 15% moisture using the formula: GY (t·ha⁻¹) = [Grain Weight (kg·plot⁻¹) × 10 × (100 − MC)/(100 − 15)/(Plot Area)], where, MC = Grain Moisture Content (CIMMYT, 1985).

The analysis of the classification of the accessions was made through a multivariate analysis using the software SPSS version 16.0, based on the agro-morphological variables and the Pearson correlation was carried out by SAS 9.0 to establish interrelations between descriptors. Principal component analysis (PCA) was done using Spad version 5.0.

3. Results

3.1 Chemical Composition of Soils

In both sites, the results of the analysis showed soil pH below 5.5. In Nkolbisson, the pH was 5.12 while in Nkoemvone, it hardly exceeds 4.3 (Table 2). The soils also had low assimilable phosphorus values, between 4.65 ug·g⁻¹ (Nkolbisson) and 7.55 ug·g⁻¹ (Nkoemvone) compared to the normal value for acid soils which was between 18 and 20 ug·g⁻¹. In Nkolbisson and Nkoemvone, the saturation rates were 39.3% and 32.8% ($10 \leq Ts \leq 50\%$), respectively. Hence the acidity of Nkolbisson was characterized by manganese toxicity with a toxicity rate 96.1% (Tt (Mn) > 60%) whereas in Nkoemvone, it was characterized by aluminum toxicity with a toxicity rate of 67.2% (Tt > 60%).

Table 2. Chemical characteristics of Nkolbisson and Nkoemvone soils

Chemical composition	Nkolbisson	Nkoemvone
	0-20 cm	0-20 cm
Ca (cmol(+)/kg)	2.68	0.68
Mg (cmol(+)/kg)	0.72	0.2
K (cmol(+)/kg)	0.24	0.24
Na (cmol(+)/kg)	0.05	0.013
Al (cmol(+)/kg)	0.52	2.32
CEC (cmol(+)/kg)	9.4	3.45
Zn (ppm ou ug/g)	4.73	0.533
Cu (ppm ou ug/g)	3.08	1.75
Mn (ppm ou ug/g)	90.6	6.49
Fe (ppm ou ug/g)	414.67	113.35
P (ppm ou ug/g)	4.65	7.55
N total (%)	0.13	0.121
C total (%)	1.81	1.13
C/N	13.86	9.28
PHeau	5.12	4.33
Ts (%)	39.25	32.84
Tt (Al/Mn) (%)	96.13	67.18
Conclusion	manganese toxicity	aluminum toxicity

Note. Ts: saturation rate; Tt (Al/Mn): rate of aluminum/manganese toxicity.

3.2 Agromorphological Characteristics of Accessions

The Analysis of variance showed highly significant differences between different sites for the emergence rate, prolificacy and grain yield, and was not significant for the appearance of ears while between accessions, highly significant differences were observed for all traits (Table 3).

Table 3. Mean squares resulting from the Analysis of Variance

Source of variations	df	TL	PR	AE	GYD
Environment	1	4645.70***	1.51***	0.39 ns	3.18 ns
Accessions	63	522.21***	0.15***	0.76***	11.28***
Error	702	200.81	0.05	0.31	4.75

Note. df: degree of freedom; GYD: grain yield; TL: emergence rate; PR: prolificacy; AE: appearance of the ear.

***: significant at $P < 0.0001$; ns: not significant at $P > 0.05$.

The result of the principal component analysis (PCA) explained the genetic diversity in our maize collection in Nkoemvone (Figure 2) and Nkolbisson (Figure 3). The "eigenvalues" measure the importance and the contribution of the component in the total variance, while each eigenvector coefficient indicates the degree of contribution of each original variable with which the main component is associated. The largest of the coefficients, whatever its sign (positive or negative), is the most efficient at discriminating accessions. There is no standard test to prove the significance of eigenvalues and coefficients. In this study, the PCA grouped the nine (9) variables (Table 4): Number of plants stand (Pst), emergence rate (TL), number of plants at harvest (PH), number of ears at harvest (PE), prolificacy of plants (PR), appearance of the ear (AE), weight of ears (EW), moisture content of seeds (% M) and grain yield (GYD). Indeed, the first two components report 79% of the variation in Nkolbisson and 73.6% in Nkoemvone. Table 1 and Figure 2 show that in Nkolbisson, the main component 1 (PC1) is associated with Pst, TL, PH, EH and EW accounting for 67.0% of the total variation while PC2 is associated mainly with PR , EA,% M and GYD accounting for 12% of the total change. In Nkoemvone, PC1 is associated with Pst, TL, PH, EH, EW and GYD with 60.3% of the total variation while PC2 is coupled with PR, EA, and% M with 13.3% of the total variance.

Table 4. Coefficients of the eigenvalues and vectors associated with the main component of the different agro morphological descriptors

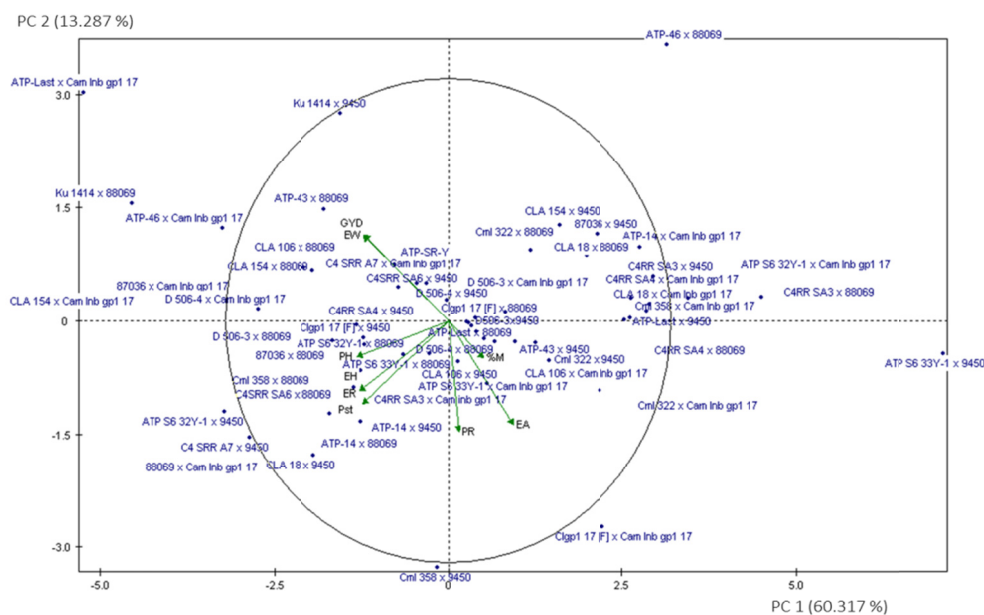| | Eigenvectors | | | |
| | Nkolbisson | | Nkoemvone | |
	PC_1	PC_2	PC_1	PC_2
Eigenvalues	6.033	1.075	5.428	1.195
Total variance (%)	67.044	11.951	60.317	13.287
Cumulative (%)	67.044	78.999	60.317	73.604
Cumulative eigen values	6.033	7.1	5.428	6.624
	Eigenvalues			
Pst	0.963	0.119	0.886	0.329
TL	0.963	0.119	0.886	0.329
PH	0.969	0.144	0.942	0.126
EH	0.941	-0.093	0.905	0.349
PR	-0.353	-0.668	-0.105	0.627
EA	-0.655	0.273	-0.699	0.438
EW	0.945	-0.121	0.882	-0.337
%M	-0.104	0.673	-0.299	0.144
GYD	0.944	-0.164	0.883	-0.345
Var. Exp	6.033	1.075	5.428	1.195
Prp. Tot	0.67	0.11	0.603	0.132

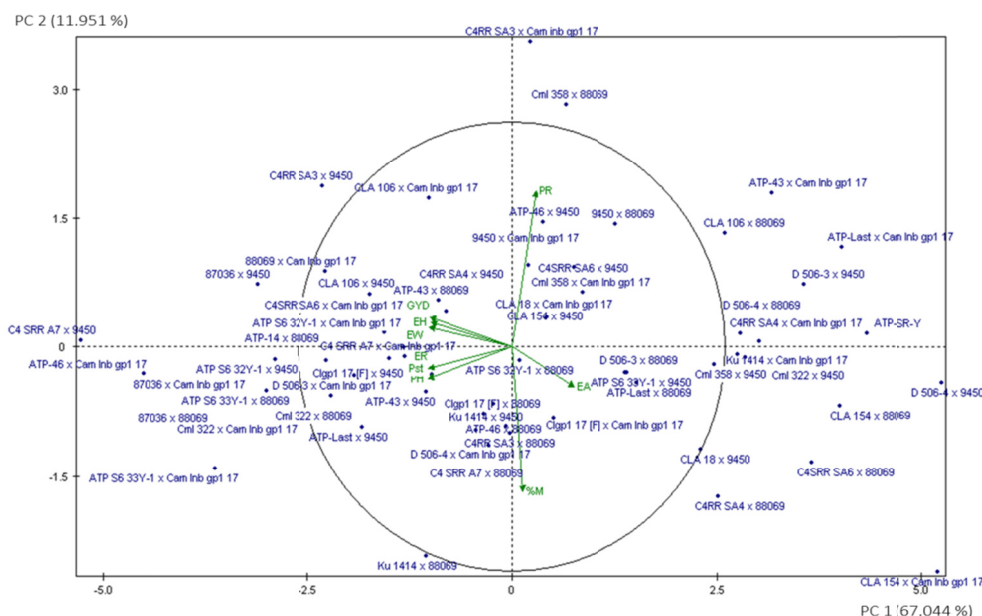Figure 2. Principal Component Analysis of descriptors in maize cultivars at the Nkoemvone site

Figure 3. Principal Component Analysis of descriptors in maize cultivars at the Nkolbisson site

3.3 Grouping and Agro-morphological Characterization

In order to characterize the accessions of maize cultivated on acid soils in humid forest zone, an Hierarchical Clustering Analysis was carried out, based on the agro-morphological characters presented by each accessions. Indeed, the cross-section of the dendrogram at the points of dissimilarity at 12.0% and 4.5% respectively in Nkoemvone and Nkolbisson reveals that the 64 varieties evaluated on acid soil formed 4 distinct groups in each study site (Figures 4 and 5). Each of the groups showed clear specific features for which the performance differs from that of the others (Table 5).

Table 5. Average values of the variables by group of accessions on acid soil at the two sites

Variables	Group 1		Group 2		Group 3		Group 4	
	Nkoemvone	Nkolbisson	Nkoemvone	Nkolbisson	Nkoemvone	Nkolbisson	Nkoemvone	Nkolbisson
TL	57.24	**46.96**	35.76	25.58	35.18	29.01	**64.81**	20.78
PR	0.96	1.14	**1**	1.50	0.76	**2.02**	0.75	0.90
AE	1.86	**2.04**	2.31	2.48	2	2.17	**1.5**	2.64
GYD	5.28	**5.98**	3.2	3.27	2.62	4.28	**11.67**	2.61

Note. TL: emergence rate; PR: prolificacy; AE: appearance of the ear; GYD: grain yield. The bold numbers indicate the high values observed for each variable at each site.

3.3.1 Nkoemvone Site

In Nkoemvone, group 1 is made up of 45 accessions (Figure 4). These are varieties characterized mainly by average emergence rates (57.6%), indicating that about 50% of plants emerge at the stage of 14 days after planting. They have a low prolificacy (0.96). In addition, at maturity, their ears have good appearance (1.86) and they produce average yields of 5.28 t·ha⁻¹ on acid soil. For these reasons, this group of accessions can be qualified as tolerant varieties. Group 2 contains 16 maize accessions. In view of the results, these are accessions characterized by low emergence rates (35.75%), indicating the difficulty experienced by the plants to emerge at the stage of 14 days after planting. Their prolificacy is high (1), indicating that they generally produce one ear per plant on acid soil, and whose interval between male and female flowerings is short. At maturity, their ears look bad (2.31) compared to the other groups and they produce yields of around 3.20 t·ha⁻¹ on acid soil. They can therefore be classified as sensitive cultivars. In addition, the 2 accessions belonging to group 3 show relatively low emergence rates (35.18%), indicating that most plants do not emerge at the stage of 14 days after planting. Their prolificacy is low (0.75), showing that they produce at most one ear per plant. They also produce spikes of poor appearance (2), compared to the other groups, and give yields of around 2.62 t·ha⁻¹. For these reasons, they

can be considered as varieties very sensitive to acidic soils under aluminum toxicity. Group 4 is essentially made up of a single hybrid. It is characterized by early emergence (64.81%) at the stage of 14 days after planting and producing at most one ear per plant (0.76). In addition, it has better looking ears (1.5) and is highly productive with a yield of 11.67 t·ha⁻¹. In view of these results, this group consisting of a single hybrid can be selected as a variety very tolerant of acidic soils under aluminum toxicity.

3.3.2 Nkolbisson Site

In Nkolbisson, group 1 is made up of 36 varieties (Figure 5). Compared to the other groups on the site, they have the best emergence rates (47%) and at maturity, their ears have good aspects (2.04). They have a high prolificacy (1.13), that is to say that they produce on average at least one spike per plant, indicating the approximation between the dates of male and female flowering. In other words, they have a strong potential for adaptation in acidic soil under manganic toxicity conditions. Also, their ears show better aspects (2.0) and they produce the highest yields (6 t·ha⁻¹). For this, they can be considered as very tolerant accessions to acid soils under manganese toxicity.

As for group 2, it consists of 16 accessions, characterized by low lift rates (25.6%). They have high prolificities (1.44), showing that they produce on average at least one ear by plant. Their ears do not show good aspects (2.48) and also, they produce low yields (3.3 t·ha⁻¹). Thus, they can be considered as susceptible varieties.

Regarding the group 3, it has 3 accessions. These accessions are very affected by soil acidity during the first 14 days after planting because their emergence rates are very low (29.0%) but, they have the highest potential for ear production on acid soil with prolificities of the order of 2.0. They produce on average at least two ears of maize per plant. These results suggest that the interval between male and female flowering is very short, favoring timely fertilization. Compared to other groups, its ears have moderately good appearance (2.2) and produce average yields of 4.3 t·ha⁻¹. For these reasons, this group of accessions can be qualified as tolerant varieties.

In addition, group 4 includes 9 accessions, characterized by a low capacity to adapt under acidic soil conditions. They have shown that they are very affected in acidic environments through low values obtained for each agro-physiological characteristic measured. Under these conditions, the emergence of the plants is very slow and they are unable to carry a large amount of ears because their emergence rates and prolificities are 20.78% and 0.9 respectively. In addition, their ears have moderately good appearance (2.64) and they produce very low yields (2.61 t·ha⁻¹). Thus, they can be classified as a very susceptible variety under the conditions of acid soils under manganese toxicity (Figure 3).

In order to determine the selection criteria for maize varietal under uncorrected acid soil conditions, a phenotypic correlation analysis was made between the emergence rate (TL), prolificacy (PR), ear appearance (AE) and grain yield (GYD) at the Nkoemvone and Nkolbisson sites (Table 6). Indeed, the correlation coefficients (r) vary highly depending on the trait. Under acidic soil conditions, the yield shows a positive and highly significant correlation with TL in Nkoemvone (r = 0.61) and Nkolbisson (r = 0.84), which indicates that the acceleration of the emergence of seedlings leads to high yield.

Also, negative and highly significant correlations were observed between TL and AE in Nkoemvone (r = -0.41) and Nkolbisson (r = -0.49). Between PR and TL, a negative and highly significant correlation was observed in Nkolbisson (r = -0.38) while in Nkoemvone, it was not significant. In addition, the Pearson's correlations observed between the PR and the AE was not significant whereas between the PR and the GYD, they are significant in Nkoemvone (r = -0.14) and in Nkolbisson (r = -0.21). Also, positive and highly significant correlations were found between the GYD and AE in Nkoemvone (r = 0.73) and in Nkolbisson (r = 0.68). Thus, these correlations observed indicate the direct link between the yield and the agronomic traits (TL, PR and AE).

Table 6. Phenotypic correlation (Pearson coefficient) between the variables evaluated on uncorrected acidic soil in the two study sites

| | TL | | PR | | AE | | GYD | |
	Nkoemvone	Nkolbisson	Nkoemvone	Nkolbisson	Nkoemvone	Nkolbisson	Nkoemvone	Nkolbisson
TL	1		-0.08 ns	-0.38 ***	-0.41 ***	-0.49 ***	0.61 ***	0.84 ***
TP			1		0.10 ns	0.13 ns	-0.14 *	-0.21 *
AE					1		0.73 ***	0.68 ***

Note. ***: significant at P < 0.0001; *: significant at P < 0.05; ns: not significant at P > 0.05. TL: seed emergence rate; PR: prolificity; AE: appearance of the ear; GYD: grain yield.
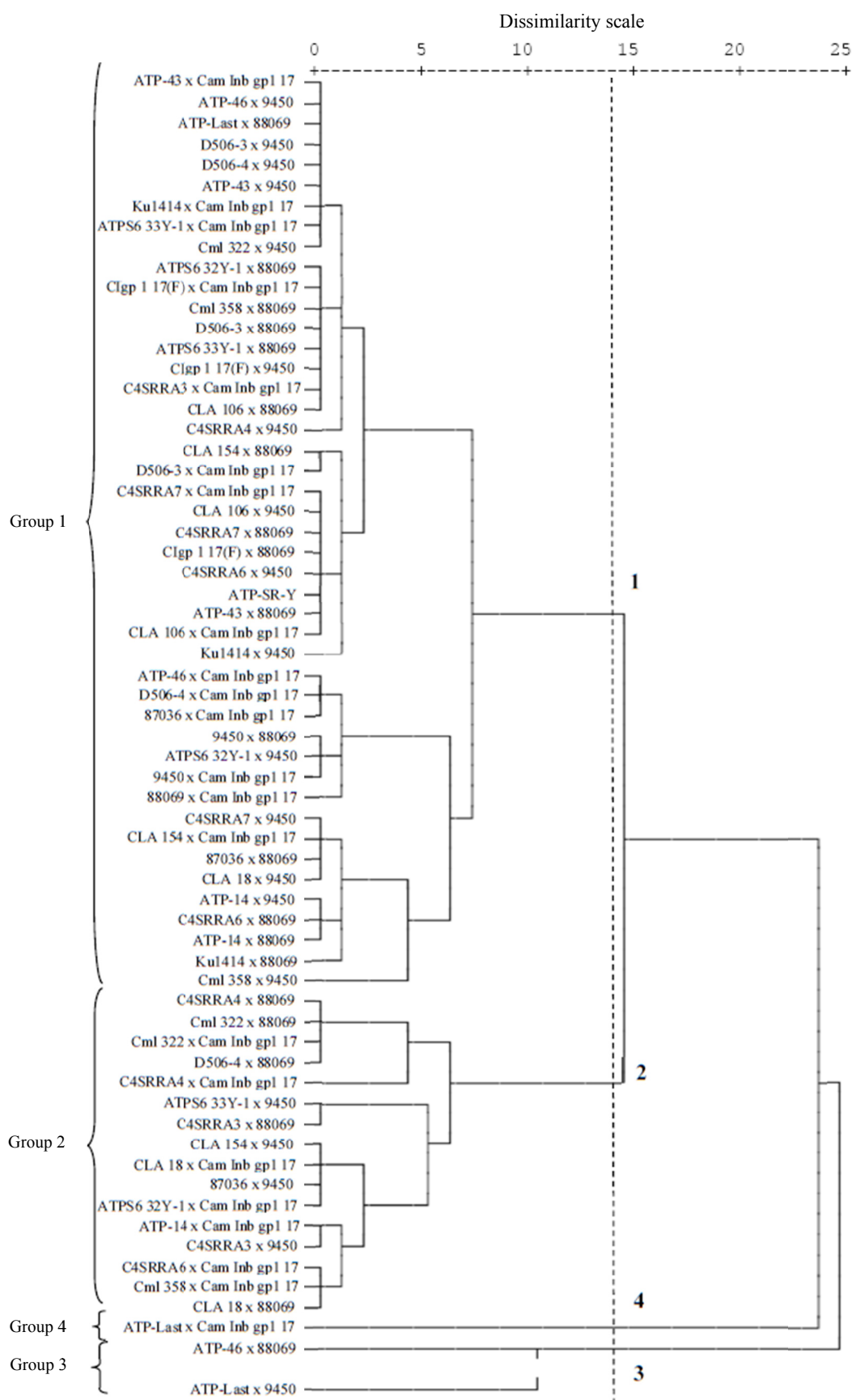
Figure 4. Dendrogram of the classification of 64 hybrid maize accessions evaluated on acid soil of Nkoemvone. The vertical dotted line represents the reference points for the delimitation of groups 1, 2, 3 and 4
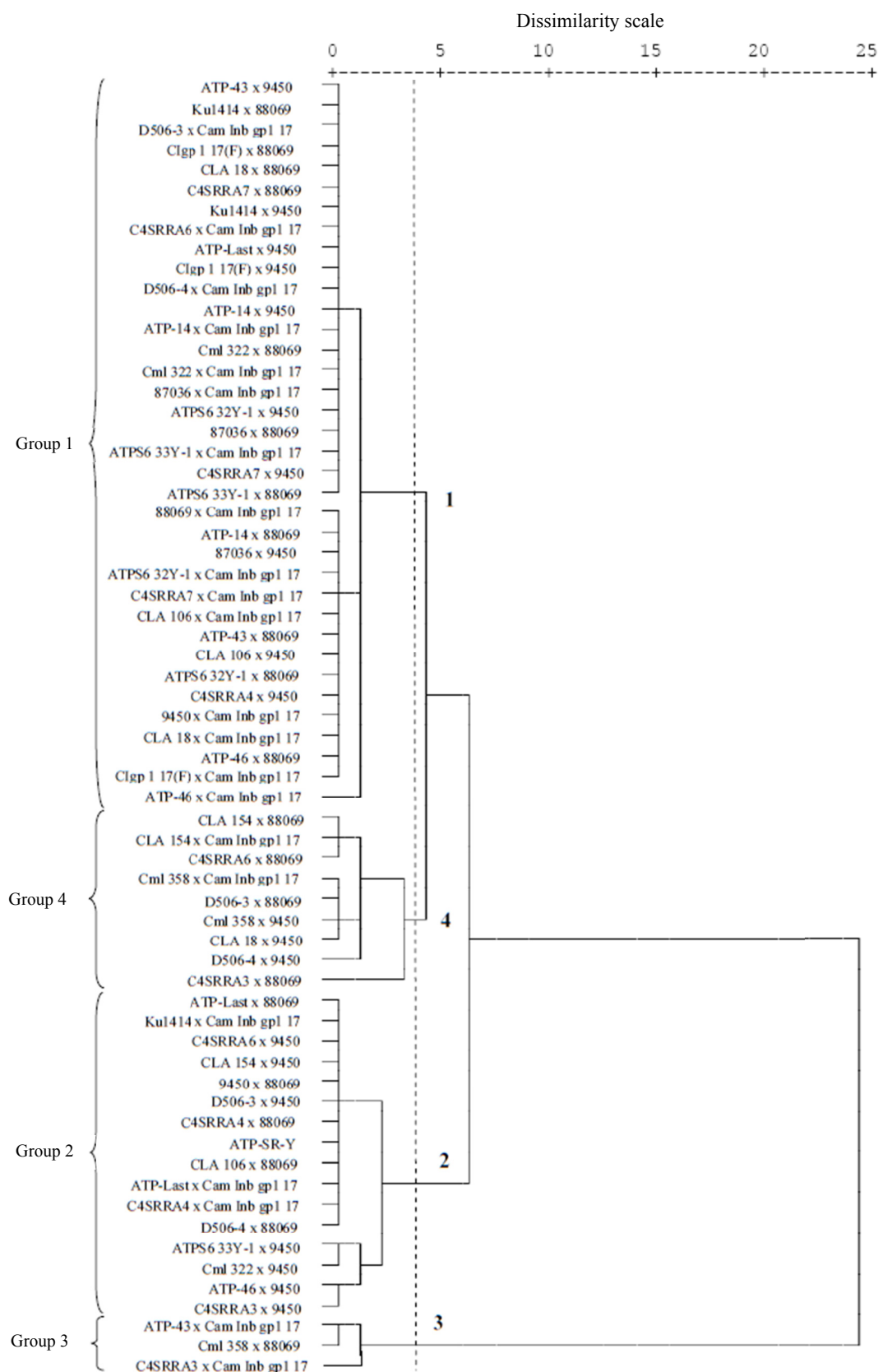
Dissimilarity scale

Figure 5. Dendrogram of the classification of 64 hybrid maize accessions evaluated on acid soil of Nkolbisson. The vertical dotted line represents the reference points for the delimitation of groups 1, 2, 3 and 4

4. Discussion

4.1 Chemical and Ecological Aspect of Soils

Chemical analyzes of the soils have shown that the pH values are below 5.5, indicating that these soils are very acidic as previously demonstrated by Robain (1993). These results confirm the statements of certain authors (Ambassa-Kiki et al., 2002; Bindzi Tsala, 1987) who showed that 75 to 100% of the land in the forest area of Cameroon is acidic. In addition, these results are similar to the data reported in the Centre's Cameroon region by certain authors (Thé et al., 2006b; Ngonkeu, 2009) who found that the soils of the humid forest zone with bimodal rainfall are very acidic ($4.52 \leq pH \leq 5.12$).

Indeed, acid rain also contributes to soil acidification. This is because tropical soils are high in sesquioxides and are already very acidic, so the contribution of acidic precipitation has little effect on pH (Harter, 2007).

The soils studied have low assimilable phosphorus values, compared to the normal value (Mémento de l'Agronome, 2006). These results could be explained by the fact that under acidic conditions, phosphorus is present in the form of poorly soluble compounds such as iron phosphate, aluminum phosphate and occluded phosphorus (Dabin, 1963). To maintain a stock of phosphate in assimilable form, sufficient for the needs of plants, a supply of fertilizer or dolomitic lime is necessary.

Regarding the site effect, highly significant differences were observed between the two study sites, for the traits emergence rate and prolificity, where the highest values were obtained in Nkolbisson, suggesting that acidic soils under aluminum toxicity delay the growth of plants in the juvenile state and reduces the production of the number of ears. These results are consistent with data reported in hydroponic solution by some authors (Sierra et al., 2003; Krill et al., 2010; Krstic et al., 2012) who showed that aluminum delays the growth of the primary root and inhibits the formation of lateral roots, limiting the yield by reducing the absorption of water and nutrients in the soil.

4.2 Characterization of Accessions and Correlations Between Variables

Analyzes based on the classification of maize accessions have shown that the sixty-four accessions can form four discriminating groups. Each group has its own characters which could be used to describe the group. Indeed, in Nkolbisson, the cultivars of group 1 are tolerant because of their good performance on acid soil. Among the thirty-six hybrids in this group, fourteen have parents from IRAD, one comes from a cross between two parents from IITA and twenty-one have parents of various origins. They have presumed levels of acid tolerance and different genetic bases. Furthermore, the cultivars of groups 2 and 3 are varieties with low emergence rates, good prolificities and spikes of good appearance. The varieties of group 4 had low yields because of their susceptibility on acid soil with manganese toxicity. Of the nine varieties in this group, six come from crosses between CIMMYT and IRAD cultivars and three are from the crosses between CIMMYT and IITA varieties. In Nkoemvone, the cultivars of group 2 and 3 presented bad-looking ears. Indeed, all the energy expended in the emergence stage led to the low grain yields produced by these accessions in this study. These results are similar to the data obtained by Sobda et al. (2013), who indicated that cowpea varieties which take longer in the juvenile stage produce less yield in the Sudano-Sahelian zone of Cameroon. Group 1 accessions exhibited poor prolificacy. They had difficulty completing their development cycle properly because of the long interval between male and female flowering. This result is not consistent with the data reported by Summerfield et al. (1985) who pointed out that seeds that produce good yields are generally varieties with short flowering periods. In addition, early maturity is recognized as a relatively important agronomic feature in the plant breeding program (Rachie, 1985). The better yields obtained by the group 4 hybrid result from its potential. Indeed, it has a large genetic base (ATP-SR and Swan I-SR) and its parents (ATP-Last and Cam Inb gp1 17) are recognized by IRAD as tolerant varieties to acid soils (The et al., 2006).

On the basis of the relationships between the descriptors, highly significant correlations observed between the agro-morphological characteristics (emergence rate, prolificity and appearance of the ear) and the grain yield confirm the statements of Ouedraogo et al. (2008) who showed that the Vigna subterranea L. plants which take longer in the vegetative stage produce less yield under the conditions of semi-arid soil in Burkina Faso.

Agro-morphological traits such as plant emergence rate, prolificacy, ear appearance and grain yield have been found as important phenotypic markers for assessing the genetic diversity of germplasm. These descriptors should be considered by maize varietal improvement programs in Cameroon. Multivariate analyzes have made it possible to describe the variability between the varieties used. However, molecular characterization of the cultivars in each group could provide additional information on the genetic basis of these accessions.

5. Conclusion

The characterization of the sixty-four accessions provided phenotypic information to users of these new varieties of maize hybrids. Despite their diversity and varied origins, these hybrid's varieties of maize evaluated on acidic soils can be classified into four main groups, based on the agro-morphological characteristics presented by each variety in Nkoemvone and Nkolbisson. Morphological characters such as plant emergence rate, prolificacy, ear appearance and grain yield have been found as important phenotypic markers for assessing genetic diversity and germplasm. These descriptors should necessarily be considered by breeding programs, varietal discrimination and formulation of maize cores for tolerance to acidic soils with aluminum and manganese toxicities. The multivariate technique, PCA, used in this study effectively described the variability for descriptors in varieties of those maize accessions. However, molecular characterization of the cultivars in each group could provide additional information on the genetic basis of these accessions.

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