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Liming and Mineral Fertilization of Acid Soils in Maize Crop within the Savannah of Southwestern of Democratic Republic of Congo

Jean Pierre Kabongo Tshiabukole[1,2*], Gertrude Pongi Khonde[1], André Matondo Phongo[1], Nlandu Ngoma[1], Roger Kizungu Vumilia[1,3], Amand Mbuya Kankolongo[1,2]

[1]Institut National pour l'Etude et la Recherche Agronomiques/Mvuazi, Mvuazi, Democratic Republic of the Congo
[2]Université Pédagogique Nationale, Kinshasa, Democratic Republic of the Congo
[3]Université de Kinshasa, Kinshasa, Democratic Republic of the Congo
Email: *jpkabon2005@gmail.com

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Abstract

This paper mainly investigated the interactive effects between liming and mineral fertilization in the acid soils in maize crop of the south-west of the DRC, two factors including liming as main factor, at two levels (with and without) and three levels of mineral fertilizers (controls without fertilizer, NPK 12-24-12, NPK12-24-12 + Urea 46%) as secondary factor, were used in a split-plot design with three replications. The results showed that the soils neither limed nor fertilized considerably reduced ($p < 0.05$) the agronomic performance of maize. However the interactions between liming and mineral fertilizers have significantly influenced ($p < 0.05$) and positively the growth parameters (height of the insertion) and flowering (day at 50% male flowering and female flowering), and therefore a significant difference ($p < 0.05$) for grain yield, harvest rate and appearance of the ears. Liming combined to mineral fertilization, in the proportions required for maize cultivation, improved around 50% of the production per unit area of maize gain in the acidic soils of Mvuazi.

Subject Areas

Agricultural Science

Keywords

Liming, Mineral Fertilizer, Acidic Soil, *Zea mays*, INERA

1. Introduction

In Africa under the tropics, maize is grown on 94 million hectares whose acid soils occupy 29% of the arable lands [1]. On these lands, maize yields are reduced due to Aluminum (Al) or Manganese (Mn) toxicity, or Calcium (Ca), Magnesium (Mg), Phosphorus (P), and Molybdenum (Mo) deficiencies [2] [3] [4], low basal saturation, altered biological activity, and other acidity induced soil fertility and plant nutrition problems [5]. These soils generally have a low pH, so-called acidic. The characteristics mentioned above inhibit root development, leading to low absorption of water and nutrients and consequently to low yields. These problems are particularly acute in humid tropical regions where soils have been greatly weathered by the elements [6]. As the soil becomes more and more acidic, particularly when the Hydrogen potential (pH) drops below 4.5, it becomes increasingly difficult to produce food crops [6] because the supply of most plant nutrients decreases while aluminum and some micronutrients become soluble and toxic to plants [7].

Soil acidity affects about 50% of potentially arable land worldwide, particularly in the humid tropics [8]. However, the level of this acidity, as well as its associated impact on soil fertility and crop productivity, should intensify in a changing climate [9] [10] [11].

The ideal soil pH for many crops is slightly acidic, between 6.0 and 7.0 [12] because all nutrients are in well-balanced proportions in this range [13].

Agricultural lime ($Ca(OH)_2$) is the main way to improve soil acidity [14] because it has strong acid-neutralizing ability, which can effectively remove the existing acid. Liming increases nutrient uptake, stimulates biological activity and reduces heavy metal toxicity.

The use of lime as well as integrated nutrient management is therefore recommended to increase the phytoactivity of essential nutrients and improve other fertility constraints induced by acidity [5] [15] [16]. Favorable crop responses to liming appear to be primarily caused by aluminum deactivation [6].

The South western of the Democratic Republic of Congo (DRC) is a very important agricultural area, with a typically high level of soil acidity and very high rainfall. Acidity-induced soil fertility problems associated with traditionally minimal use of mineral fertilizers are often blamed for low levels of crop productivity [17].

Since lime makes minerals available to plants, liming without fertilizer application leads to a decline in soil fertility which could lead to serious production problems [6]. Therefore, the application of fertilizers to correct the nutritional constraints caused by acidity would be necessary to improve agricultural productivity.

The objective of this work is to evaluate the interactive effect of liming and mineral fertilization on the performance of growth and yield of maize in acid soils of southwestern DRC.

2. Materials and Method

The trial was conducted on acid soil at the INERA Mvuazi research center during cropping season A 2019-2020. Mvuazi is located at 14˚54' East longitude and 5˚21' South latitude, at an altitude of 470 m. The soil of Mvuazi belongs to the Sudano-Guinean climatic zone of type AW4 following the Köppen classification. This soil is characterized by low organic matter content and low water retention capacity, resulting in low nitrogen availability [18] [19] and Orthic ferral soil type (**Table 1**). According to the soil acidity scale of [20], with a pH of 5.76, the soils of Mvuazi are classified as acidic.

Using a split-plot device with three replications involving two factors, the main factor of which was the liming at two levels (Liming and without = Nill) and the secondary factor was the application of mineral fertilizers at three levels (controls without fertilizer, NPK12-24-12 and NPK12-24-12 + Urea (46%). The NPK was applied at the sowing by a method called microdosing at 100kg/ha. The microdosing consisted of a localized application of NPK fertilizer (3 g/hill) *i.e.* 160 kg/ha and Urea (1.125 g/hill) *i.e.* 60 kg/ha [21] Urea was applied in two halves respectively on the 15th day and on the 30th day after sowing. 800 kg/ha was applied according to the Arvalis protocol [22] for ploughing.

The SAMARU maize variety (obtained by INERA and sensitive to low soil nitrogen levels) serving as a test plant was sown at spacings of 0.75 m × 0.50 m at the rate of 2 grains per hill in individual plots of 2.5 m × 5 Mr.

The cultural care consisted of weeding and cleaning the paths and the surroundings of the experimental field. **Figure 1** presents the experimental device used in the test.

Lime treatments (limed): T0 = Control without mineral fertilizer
T1 = NPK
T2 = NPK + Urea

Nill treatments (not limed): T3 = Control without mineral fertilizer
T4 = NPK
T5 = NPK + Urea

The data was collected on the basis of observations made on the growth variables, namely: days at 50% male flowering (Poll), days at 50% female flowering (Silk), interval between male flowering and female flowering (ASI), plant height (Plant height), height of upper ear insertion (Ear height), percentage of root

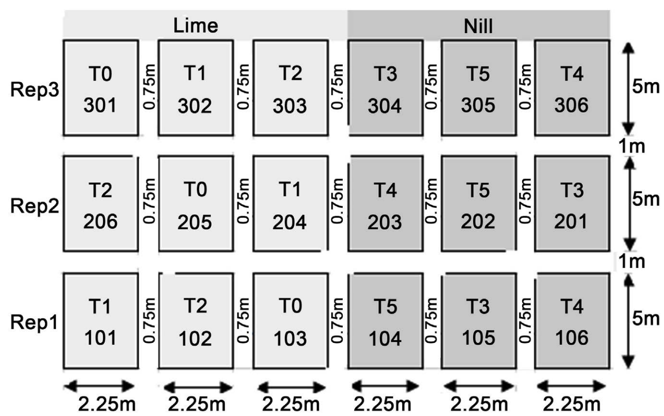

Figure 1. Experimental device.

Table 1. General physico-chemical properties of Mvuazi soil.

Parameters (unit)	Sol pH	P1 (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Mn (ppm)	S (ppm)	Cu (ppm)	B (ppm)
Results	**5.76**	14	105	1505	229	55	23	12.30	0.21
Bottom guide	6.00	30	268	1651	165	100	20	2.00	1.00
Top guide	7.00	100	537	2064	264	250	200	10.00	2.00
Paramètres (unité)	**Zn (ppm)**	**Na (ppm)**	**Fe (ppm)**	**CEC (meq/100g)**	**OC (meq/100g)**	**Silt (%)**	**Sand (%)**	**Clay (%)**	**N (%)**
Résultats	7.98	47	194	13.76	4.07	13	49	39	0.21
Guide Bas	4.00	0	150	15.00		30	30	20	0.20
Guide Haut	20.00	158	350	30.00		50	55	55	0.50

lodging (Root lodg), percentage of stem lodging (stem lodg) and productivity variables as percentage of plants harvested (Plant harv), plant aspect (plant aspct), ear aspect (Ear aspect), grain yield (Yield), ear rot percentage (Ear rot).

Aspects of seedlings and ears were rated on a rating scale of 1 to 5 where 1 = excellent, 2 = good, 3 = fairly good, 4 = not good and 5 = bad [23].

3. Statistical Analyzes

The data collected were subjected to analysis of variance using the agricolae package of the R statistical software following the general linear model (aov(y~fact1*fact1+rep)) to determine the difference between the means of the treatments. The means of the treatments which presented significant differences were separated by the post-hoc test of the least significant difference (LSD) at the threshold of 5%. A principal component analysis (PCA) using the R package FactoMineR was carried out to establish the correlations between the studied variables.

4. Results and Discussion

After processing and analyzing the data collected during and at the end of the trial, two groups of results were identified according to the development phases of the maize plants.

4.1. Effects of Lime and Mineral Fertilizers on Maize Growth and Flowering Stage

Table 2 below presents the performance results of maize during the growth phase under the conditions of liming, mineral fertilization and their combination. The analyzes of variance carried out on the data from the growth and flowering stage of maize showed very significant effects ($p < 0.01$) of mineral fertilizers at 50% male flowering and significant effects ($p < 0.05$) for 50% of female flowering. However, the effects of liming and fertilizer were less significant ($p = 0.0929$) for the flowering interval. The number of days at 50% male flowering varied between 52 and 57 days respectively for T2 and T3. While the number of

Table 2. Effects of liming and mineral fertilizers on maize growth under Mvuazi conditions.

Liming	Fertilizers	Poll	Silk	ASI	Plant eight (cm)	Ear eught (cm)	Root lodg. (%)
Lime	Control	55.66 ± 2.08ab	56.33 ± 2.08a	0.66 ± 1.15b	185.58 ± 2.09a	97.41 ± 7.96b	26.37 ± 12.12a
	NPK	54.66 ± 0.57ab	56.66 ± 1.52b	2.00 ± 1.73ab	187.31 ± 17.41a	**104.25 ± 10.53ab**	28.32 ± 9.27a
	NKP + Urea	52.00 ± 1.00c	53.33 ± 1.52b	1.33 ± 0.57ab	198.08 ± 8.30a	**119.33 ± 11.76a**	22.18 ± 13.79a
Nill	Control	57.00 ± 1.73a	60.33 ± 2.88b	3.33 ± 1.15a	180.25 ± 21.68a	97.75 ± 10.39b	39.62 ± 11.99a
	NPK	54.33 ± 1.15bc	56.33 ± 1.15b	2.00 ± 2.00ab	187.50 ± 4.75a	**109.33 ± 5.44ab**	41.45 ± 14.54a
	NKP + Urea	53.66 ± 1.15bc	54.33 ± 1.15b	0.66 ± 1.15b	188.50 ± 15.59a	**109.00 ± 8.52ab**	40.62 ± 20.15a
Lime Effect		0.20857	0.1031	0.2839	0.479	0.7229	0.0248*
Fertilizer effect		0.00917**	0.0112*	0.2259	0.618	0.0481*	0.9316
Lime*fertilizer effect		0.552	0.0683.	0.0929.	0.743	0.675	0.9931
CV (%)		2.5873	3.3	75.31	7.55	9	36.85
LSD (p < 0.05)		2.53	3.33	2.25	25.52	17.17	21.919

Signif. codes: 0 "***" 0.001 "**" 0.01 "*" 0.05 "." 0.1 " " 1.

days at 50% female flowering varied between 53.3 and 60.3 days corresponding to the T2 and T3 treatments. The interval between male and female flowering varied between 0.6 and 3.3 days respectively for T0, T5 and T3. No significant difference ($p > 0.05$) was observed between the averages of the plants height, while a significant difference ($p < 0.05$) was observed for the height of insertion of the upper ear with positive fertilizers effects for both levels of liming. The height of the insertion of the upper ear varied between 119.3 cm for T2 and 97.4 cm for T0. Lime application had significantly influenced ($p < 0.05$) root lodging. The smallest root lodging rate (22.18) was recorded in T2, while the highest rate (41.45) was recorded in T4.

4.2. Effects of Liming and Mineral Fertilizers on Maize Yield Parameters

Analysis of variance on yield data (Table 3) showed a significant difference ($p < 0.05$) between treatments on stem lodging. The application of mineral fertilizers had a significant effect ($p = 0.03152$) on stem lodging. The highest stem lodging rate was recorded in Q5 (22.09) and the lowest rate was recorded in Q3. From the point of view of plant appearance, significant effects of liming and NPK + Urea fertilizers were observed. The best aspect of the plant (1 = excellent) was recorded at T2 and the worst at T3 (control without fertilizer). In general, the application of NPK + Urea fertilizers influenced significantly ($p = 0.0045$) the yield. The average yield varied between 0.14 kg/m^2 and 0.33 kg/m^2 respectively for T3 and T5. It appears from these analyzes that lime and fertilizers did not significantly influence ($p > 0.05$) the appearance of the ear, ear rot, or the rate of harvested plants.

Table 3. Effects of liming and mineral fertilizers on maize productivity under mvuazi conditions.

Liming	Fertilizers	Stem lodg. (%)	Plant asp. (1-5)	Yield (kg/m²)	Ear rot (1-5)	Ear asp. (1-5)	Plant harv. (%)
Lime	Control	16.42 ± 17.59ab	1.66 ± 0.57b	0.20 ± 0.020bc	1.66 ± 2.08a	1.66 ± 0.57a	76.84 ± 20.21a
	NPK	10.47 ± 6.99bd	1.33 ± 0.57b	0.20 ± 0.08bc	1.66 ± 0.57a	1.33 ± 0.57a	64.09 ± 5.25a
	NKP + Urea	8.60 ± 4.55bc	1.00 ± 0.00b	**0.29 ± 0.038a**	1.33 ± 1.52a	1.33 ± 0.57a	67.24 ± 3.92a
Nill	Control	3.17 ± 2.74c	2.66 ± 0.57a	0.14 ± 0.095c	1.00 ± 1.00a	1.66 ± 1.15a	55.77 ± 17.88a
	NPK	**11.15 ± 6.33abc**	1.66 ± 0.57b	0.266 ± 0.055ab	1.33 ± 1.52a	1.66 ± 1.15a	69.99 ± 7.43a
	NKP + Urea	**22.09 ± 11.19a**	1.33 ± 0.57b	**0.33 ± 0.058a**	1.33 ± 1.52a	1.33 ± 0.57a	79.26 ± 13.62a
Lime Effect		0.91857	0.0454*	0.61663	0.49894	0.768	0.873
Fertilizer Effect		0.03152*	0.0392*	0.00452**	0.94783	0.895	0.424
Lime*Fertilizer effect		0.07844.	0.2925	0.07893.	0.7806	0.718	0.113
CV (%)		51.9	32.41	20.94	72.81	51.89	19.696
LSD ($p < 0.05$)		11.181	0.938	0.0911	1.817	1.399	24.377

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5. Principal Component Analysis

The PCA was carried out on 12 active variables characterizing the variables on the basis of the data of the combination of the factors. More than 58% of the variability is represented on the plane formed by two axes Dim1 and Dim2. Only four dimensions had an eigenvalue greater than 1. The factorial map of the variables (**Figure 2**) shows that the two dimensions are characterized by strong correlations between the variables.

Dim1 benefits strong contributions from growth and yield-related variables, including male and female flowering and flowering interval, plant height, height of ear insertion, and plant appearance. This indicates that the yield is greater when the intervals between male and female flowering are short (ASI < 3) and the harvest rate is high. Otherwise an excellent aspect induces a good production. As for fertilization, we observe that the combination of lime, NPK and Urea promotes good productivity (**Figure 3**). Correlations are negative between flowering interval and yield, as are days at 50% male and female flowering.

Dim2 is characterized by the rate of root lodging, stem lodging, ear rot rate and ear appearance. Strong positive correlations between root lodging and rot have been observed, however these parameters are negatively correlated with stem lodging (**Figure 2**). The individual factorial map shows that a significant dispersion of the treatments (with lime and without lime) was observed around two axes. The Lime + NPK + Urea combinations remain favorable for a higher yield (**Figure 3**).

At the end of the verification of the hypothesis according to which liming without fertilizer application leads to a drop in soil fertility which could lead to serious production problems, it emerges from the results of this work that treatments without lime presented the values of variables lower than those of lime treatments. Like the conclusions of research made by Harter [6], it should be said that the results of this work corroborate with those of Anetor and Ezekiel [14].

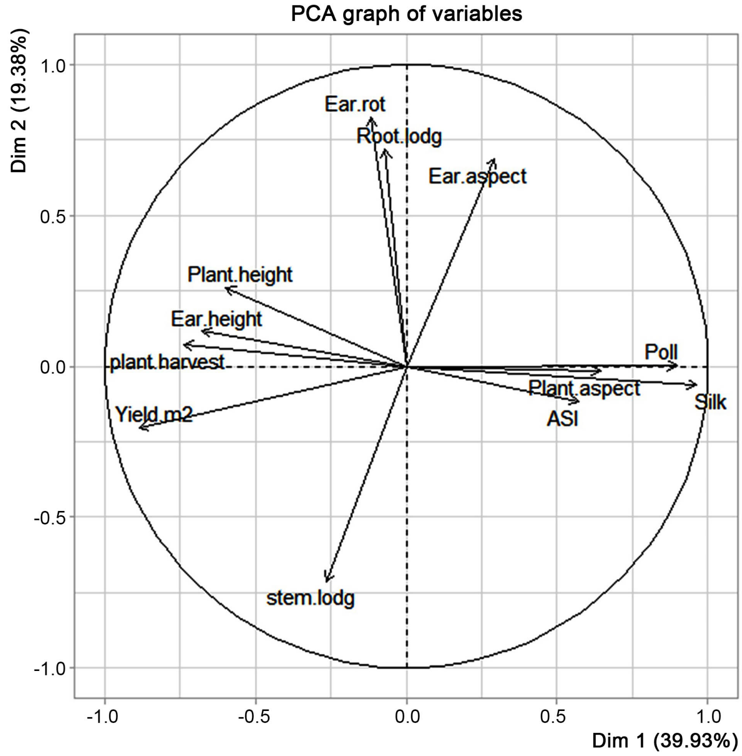

Figure 2. Factorial map of the variables studied.

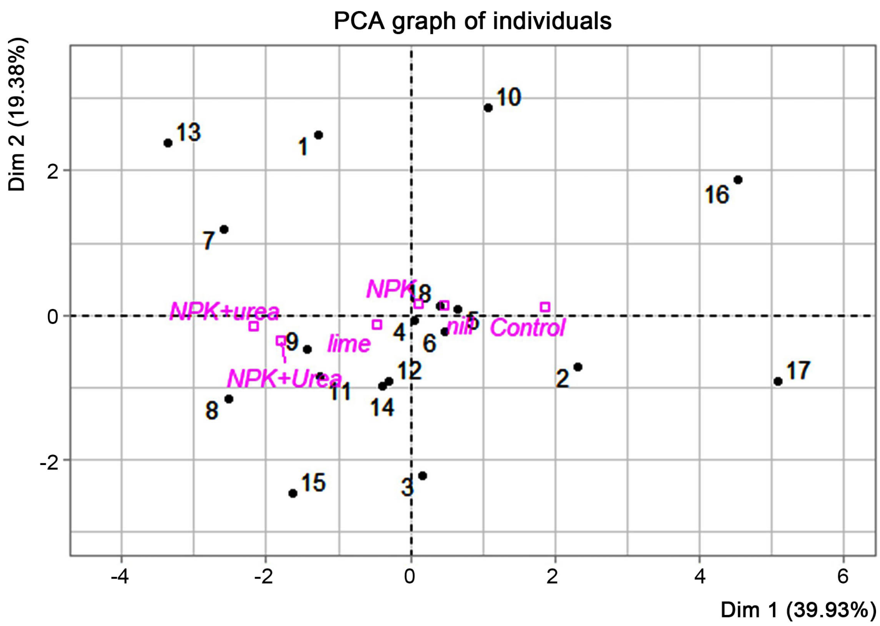

Figure 3. Factorial map of observed individuals.

This situation can be explained by the fact that in general, the increase in calcium content and soil pH stimulates microbial growth, which affects the availability of nitrogen, as noted, as well as on that of some other nutrients. Conversely, increased microbial growth can lead to faster loss of organic matter in the soil, which is generally considered negative.

The low productivity observed in treatments without lime or fertilizers is dependent on the presence of soluble aluminum in the soil, which leads to toxicity responsible for a drop in yield. As a result, a pH above 5.5 will be sought in most situations, especially for barley, corn and beet crops [24].

Based on the results of maize growth analysis, many laboratory studies have determined that the first visible damage caused by aluminum is the inhibition of root elongation [25] [26] [27] [28] [29]. Plant height should therefore be reduced in maize plants sown without; such is therefore the case of T3 in this work.

Tshiabukole *et al.* [23] showed that intervals between male and female flowering greater than 3 days indicated the susceptibility of maize to stress. However, it was found in this work that the control plants (T3) had average ASI values greater than 3 days. Thus this treatment favored a reduction in grain yield of nearly 50%.

Regarding the grain yield, it was observed in this work that the treatments combining lime and fertilizers had significantly improved the yield of the fertilizer treatment. Thus the results of this test confirm the hypotheses put forward by Harter [6]. But the variations were greater, around 50%, when no fertilizer was applied. Thé *et al.* [30] have shown that in maize, soil acidity can lead to yield reductions of around 67%, however Welker *et al.* [31] asserted that the negative effect of the aluminum toxicity of soils on grain yield is between 46 and 73% depending on the locality.

6. Conclusion

The purpose of this work was to evaluate the interactive effect of liming and mineral fertilization on the growth and yield performance of maize. Indeed it results from this work some relevant observations such as the soils of Mvuazi being acidic are characterized by a weak growth and production of the corn. Lime amendments alone in these soils are not sufficient to improve the agronomic performance of maize. A combined application of lime and mineral fertilizers (NPK and Urea) in the proportions corresponding to the needs of the plant is necessary to restore the soil in one growing season and improve maize production by almost 50%.

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Conflicts of Interest

The authors declare no conflicts of interest.

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