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Maize Grain Yield Response to Changes in Acid Soil Characteristics with Yearly Leguminous Crop Rotation, Fallow, Slash, Burn and Liming Practices

C. The[1], S. S. Meka[1*], E. L. M. Ngonkeu[1], J. M. Bell[2], H. A. Mafouasson[1], A. Menkir[3], H. Calba[4], C. Zonkeng[1], M. Atemkeng[1] and W. J. Horst[5]

[1]Institute of Agricultural Research for Development (IRAD), P.O. Box 2067, Yaoundé Cameroon.
[2]University of Yaoundé I, Po Box 812 Yaoundé Cameroon.
[3]International Institute for Tropical Agriculture, Ibadan, Nigeria (IITA).
[4]CIRAD-CA 8 TA70/01, 34398, Montpellier, Herault, France.
[5]Institute for Plant Nutrition, University of Hannover, Germany.

Authors' contributions

This work was carried out in collaboration between all authors. Author CT was the chief investigator. He designed the project, wrote the protocol, received funds and the genetic materials as well and wrote the first draft. Author SSM was involved in field trials. She collected useful data and used some for her D.E.A obtained from the University of Yaounde I, helped to finalize and submit the manuscript. Authors ELMN and MA also participated in field trials and provided the literature cited. Author JMB critically reviewed the manuscript and the experimental design. Authors CZ and HAM participated in field experiments and data analysis. Author AM provided genetic materials and advice for field experimentation. Author HC conducted soil analysis at CIRAD laboratory and helped in results interpretation. Author WJH reviewed the protocol and the manuscript, secured the grant from E.U. All authors read and approved the final manuscript

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ABSTRACT

An experiment was conducted for 4 years to assess the effectiveness of fallow, slash and burn farming systems on maize grain yield and soil chemical characteristics. It was also meant to measure the response to yearly rotation of maize and leguminous crops

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

(cowpea and mucuna), as options for managing the acidity of the soil of the study site. The maize tolerant cultivar (cvr) out yielded the sensitive cvr and the farmers' variety by 43% and 16% respectively. On the maize/grain legume rotation plots, the tolerant and sensitive cvr yielded 5% and 7% respectively more than their corresponding yields on plots with fallow, slash and burn rotation. Maize/grain legume rotation demonstrated one of the least soil acidifications, exhibiting the least increase in exchangeable Al (23%), H (24%), and Al saturation (5%) resulting in improved soil fertility through increase in available Ca (2%), Mg (85%), P (75%), and CEC (14%). The fallow, slash and burn rotation, associated with the tolerant cvr showed similar grain yield with grain legume rotation, but contributed more to soil acidification. Maize/leafy legume rotation gave a similar yield to the above mentioned practices. The yearly application of 250 kg ha^{-1} of dolomitic lime for four consecutive years did not result in significant changes in soil characteristics and grain yield especially for the Al tolerant cvr. However, application of 2250 kg ha^{-1} of lime neutralized the Al toxicity, regardless of the rotation scheme. The study concluded that the four years maize cultivation through fallow/ slash and burn rotation extensively used in the humid forest zone is not the best option on acid soil.

Keywords: Acid soil; leguminous crops; lime; maize; rotation; slash and burn.

1. INTRODUCTION

Higher yields of maize in the humid forest zone will require the reduction of soil acidity, which is considered a major constraint to crop production [1, 2]. Soil acidity is generally characterized by low pH, toxic levels of Al or Mn, and or deficiencies of Ca, Mg, and P [3]. Soil acidity is an important cause of low fertility of tropical soils [4]. Food security in the tropics would depend on the development of strategies for efficient and sustainable use of resources to manage humid forest zone acid soils. This includes the development and utilization of germplasm tolerant to acid soils as well as the decrease of soil acidity through lime application, rotation with leguminous crops, and soil amendments with organic manure such as poultry manure or *Senna spectabilis* leaves [5]. Lime, although known as the most effective means for correcting soil acidity, has some short falls such as determining the quantity required per hectare, the extra labor and the cost of its application.

These are out of reach of most tropical forest resource poor farmers who practice shifting cultivation and fallow slash and burn rotation [5]. Grain yield reduction of 67% due to increase in soil acidity through continuous maize cultivation has been reported in Cameroon [1]. They reported a decrease in pH (0.23 units), available Ca (31%), and Mg (36%), and an increase of exchangeable Al (20%). However, the acid soil tolerant cvr, ATP-SR-Y, recorded 61% yield more than the susceptible cultivar, Tuxpeño sequia. Significant genotypic responses and genotype x lime interaction effects were reported on acid soil [1].

Lime application generally increased the grain yield of the susceptible genotype (208%) compared to 82% of the tolerant genotype, and usually was associated with significant reduction in exchangeable Al [4]. With acid soils in Rwanda, acceptable crop yields were obtained only when lime was mixed with NPK fertilizer [4]. Al toxicities and soil P fixing capacity were alleviated or reduced through liming [6]. This neutralizes exchangeable Al, increases P availability from fixed P fraction and provides Ca and some Mg to crops [7]. An increase in CEC due to liming in acid soil with a high exchangeable Al has been reported [8]. Significant increase in pH (more than 28%) and available P (more than 90%) was obtained

[9] when studying the effects of different lime doses on some chemical soil properties of an acid soil. Exchangeable Al was completely eliminated when most of the soil samples had pH above 5.0.

In the tropical forest zone, shifting cultivation with its associated slash and burn practices has been widely used by resource-poor farmers in marginal areas, where maize as sole crop, is cultivated during the first growing season (March to July), followed by leguminous crops such as groundnut or cowpea in the second season. Otherwise, the land is left to fallow, slash and burn at the beginning of the following growing season. Slash and burn practices have been used to clear land in the forest for agriculture. Ashes from burning provide the amount of nutrients needed for a minimum harvest on infertile soils [10]. Burning also has direct effects as a source of NPK fertilizer and as a liming material [11]. This is made possible through the transformation of non-plant-available P and N in the soil into mineral forms readily available to plants. The dose of nutrient loss through slash and burn has been reported to be among the highest [10], and sustaining soil fertility depends on understanding the details of the nutrient fluxes and losses that accompany such fires [12]. The effect of leguminous crops on tropical acid soils has not received much attention. Legumes are known to improve the N status of the soil, with subsequent beneficial effects on succeeding cereal crops. The use of leguminous crops can improve soil fertility through nutrient cycling and symbiotic fixation of N [13].

This paper reports the findings of a study conducted from 2001 to 2004 in Ebolowa, Cameroon. The objectives were to assess the effectiveness of fallow, slash and burn farming systems on maize grain yield and chemical properties of acid soils widely used in the humid forest zone. And then, to measure the response of yearly rotation of maize and some leguminous crops, as options for managing soil acidity and the effects of liming. The knowledge gained from the interaction of the above practices with different lime doses and chemical properties in the acid soil of the study site would help to identify efficient and economical practices for tropical farmers.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted from 2001 to 2004 at Nkoemvone, Ebolowa (2º90’ N latitude, 11º20’ E longitude and 560 m above sea level), in the humid forest zone of Cameroon. The average annual rainfall is 1800 mm with bimodal distribution; the soil is a typical Kandiudox (USDA 1992 classification), with low pH of 4.10, low nutrient status and high exchangeable Al [14].

2.2 Soil Sampling and Analysis

Soil sampling was done at the beginning of the experimentation in 2001 and 2003, as baseline information to measure the changes in soil characteristics due to the application of treatments. Five soil samples were collected per plot from the uppermost 20 cm in 2001 and 2003. These samples were bulked per plot and a representative sub-sample was taken, and analyzed at CIRAD (International Centre of Agricultural Research for Development) Montpellier, France. Exchangeable elements were determined by the Cobaltihexammine method [15], and the soil-water ratio for pH determination was 1:2.5.

2.3 Experimental Design

The experiment consisted of a 3x3x2 factorial. The factors were:

- dolomitic lime application: 0, 250 and 2250 kg ha^{-1},
- rotation schemes: Fallow/ slash and burn, grain legume and leafy legume,
- maize cultivars: the acid soil tolerant cvr (ATP-SR-Y), the acid soil sensitive cvr (Tuxpeño sequia) and the farmers' variety (CMS 8501).

ATP-SR-Y was developed by recombining acid soil tolerant varieties from Colombia, Brazil, Nigeria (IITA), and Cameroon. Tuxpeño sequia came from CIMMYT, Mexico and was drought tolerant and phosphorus efficient. CMS 8501 used as farmers' check variety was derived from a cross between Pop 49 (Tuxpeño) of CIMMYT and TZB from IITA Nigeria. Each of the four replications was made of 18 treatments and a local maize check cvr, CMS 8501 was also included. Plot size was 8 m x 6.75 m, consisting of 9 rows of maize per plot (5 ATP-SR-Y and 4 Tuxpeño sequia rows). The spacing between rows was 0.75 m, while the spacing within rows was 0.50 m. Two seeds were planted per stand with no thinning. Fertilizer was applied according to local recommendations as follows: 100 kg ha^{-1} of N, 24 kg ha^{-1} of P_2O_5 and 14 kg ha^{-1} of K_2O. The total amount of P_2O_5, K_2O and 40 kg of N was applied 10 days after planting (DAP). The remaining 60 kg ha^{-1} of N was applied at 35 DAP. The seasonal rotation consisted of maize/fallow, slash and burn, maize/leguminous crop rotations. The two contrasting maize cultivars were evaluated during the first rainy season (March 15 to July 15) and the land was fallowed or planted with leguminous crops: grain legume (cowpea) and leafy legume (Mucuna) during the second season (August 15 to November 15). Agronomic data collected consisted mainly of cob weight per plot, from which grain yields were calculated, assuming a shelling percentage of 80%, and was expressed at 15% moisture content. The amount of rainfall and its distribution were adequate throughout the cropping seasons except for the year 2004 in which drought period was severe.

2.4 Statistical Analysis

Analysis of variance was performed on yearly basis throughout the experiment using the GLM procedure of the SAS software [16]. Treatment effects were considered fixed and years were allocated at random. The effects of each practice on grain yield were estimated each year using orthogonal contrasts. Changes in soil characteristics due to the various rotation schemes and lime doses were estimated by comparing the initial soil characteristics obtained at the onset of the experiment in 2001, with soil characteristics after three consecutive years of maize cultivation and rotation.

3. RESULTS AND DISCUSSION

The analysis of variance for grain yield, revealed no significant cultivar x year x rotation scheme x lime dose interaction. This indicated that the tolerant cvr gave better yields compared to the sensitive cvr year in year out, regardless of the lime dose and the rotation scheme used. A significant difference was observed in the interaction of factors: cultivar x rotation scheme x lime dose. In addition, the effect of the different lime doses and the different rotation schemes were significantly different. No significant differences were found when comparing the effect of burning versus grain legumes (Table 1).

Table 1. Mean square from the orthogonal contrast of treatments by year on grain yield

Treatments	2001	2002	2003	2004	Means
Lime *vs* No lime	110062^{ns}	10265504***	551784^{ns}	9784889***	11367447**
Grain legume *vs* burn	867025^{ns}	5903^{ns}	284898^{ns}	150286^{ns}	125393^{ns}
Leafy legume *vs* burn	320563^{ns}	6349882***	9178405***	6858^{ns}	6003697*
Grain legume *vs* Leafy legume	133194^{ns}	5968565***	6229164**	92936^{ns}	7864398*
(Grain legume x Leafy legume) *vs* burn	747328^{ns}	2247668**	4232481***	73784^{ns}	1464594^{ns}

^{vs} Versus; ^{ns} Not significant; **Highly significant; ***Very highly significant

3.1 General Performance of Maize Cultivars During the Four Years of Experimentation

The general performance of the tested maize cultivars and the control during the four years of experimentation shows that ATP-SR-Y consistently and significantly out yielded Tuxpeño sequia. The highest grain yields were obtained from the two cultivars after the application of 2250 kg ha^{-1} of lime, on plots with maize/grain legume rotation (3834 kg ha^{-1}**),** followed by plots with maize/fallow, slash and burn rotation (3700 kg ha^{-1}). The lowest grain yields were obtained with Tuxpeño sequia on plots under maize/leafy legume rotation. With the yearly application of 250 kg ha^{-1} of dolomitic lime, ATP-SR-Y yielded 3363 kg ha^{-1}, which was not significantly different from the 3352 kg ha^{-1} obtained on acid soil, and therefore this cvr did not respond to this lime dose. Tuxpeño sequia yielded 2720 kg ha^{-1} exhibiting a 13.6% grain yield increase in response to 250 kg ha^{-1} of lime application. With 2250 kg ha^{-1} application of lime for four consecutive years, ATP-SR-Y yielded 3969 kg ha^{-1} and Tuxpeño sequia gave 3164 kg ha^{-1} which corresponded to 18.4% and 32% respective grain yield increases over their respective performances on acid soils (Fig. 1).

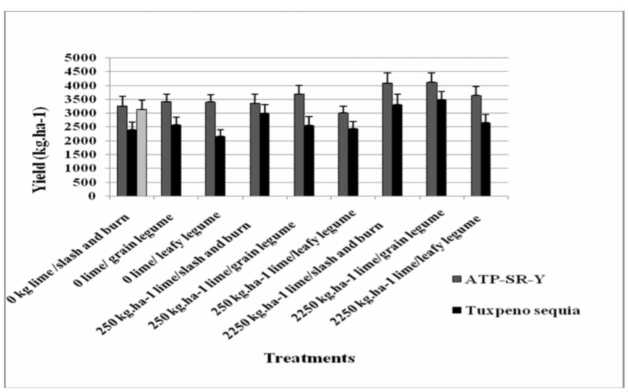

Fig. 1. General performance of the two maize cvs and the control during the four years of experimentation

Except for the first year of cultivation, the grain yield superiority of ATP-SR-Y over the susceptible cvr increased with years of cultivation up to 27% in the second year, 33% in the third year and 53% in the fourth year (Table 2). Tuxpeño Sequia responded better (23%) to lime application than ATP-SR-Y (9%). Rotation of ATP-SR-Y with grain legume yielded 3724 kg ha^{-1}, which represented 41% grain yield superiority over Tuxpeño Sequia (2647 kg ha^{-1}), and 14% more than the corresponding acid soil control.

Table 2. Maize grain yield as affected by lime doses and rotation scheme of two contrasting maize cultivars (ATP-SR-Y and Tuxpeño sequia) grown on an Al toxic soil from the years 2001 to 2004

Lime	Rotation	2001		2002		2003		2004	
Doses	**Scheme**	**ATP-SR-Y**	**Tuxpeño**	**ATP-SR-Y**	**Tuxpeño**	**ATP-SR-Y**	**Tuxpeño**	**ATP-SR-Y**	**Tuxpeño**
0	Fallow/burn	1417	972	4127	3314	4664	3483	2834	2006
	Grain legume	2135	1310	3819	3012	4295	3731	3311	2241
	Leafy legume	2508	1266	3608	2764	4241	2732	3259	1898
	Local check (CMS 8501)	1081	1081	3462	3462	4185	4185	2448	2448
250	Fallow/burn	1579	1159	4037	4090	4780	3933	3009	2797
	Grain legume	2278	1069	5066	3575	4435	3354	3115	2589
	Leafy legume	1732	1008	3777	3668	3668	2763	2877	2634
2250	Fallow/burn	1906	1068	5250	4529	4905	4181	4280	3480
	Grain legume	1991	1689	5263	4479	4953	4254	4487	3555
	Leafy legume	1746	989	4109	3292	4338	2957	4396	3496
Means Without Local		1921	1170	4339	3610	4476	3487	3483	2743
Coefficient of Variation (%)		29.12	29.12	13.45	13.45	14.60	14.60	20.94	20.94
Least Significant Difference (0 .05)		622	622	759	759	828	828	925	925

3.1.1 Maize grain yield of the two maize cultivars as affected by rotation schemes on the tested soil without lime application

On the fallow, slash and burn plots, ATP-SR-Y yielded 3261 kg ha^{-1} giving a significant grain yield advantage of 33% over Tuxpeño sequia that yielded 2444 kg ha^{-1}. The farmers' cultivar CMS 8501 had 16.7% less grain yield than ATP-SR-Y, but also 14.3% higher than Tuxpeño sequia. With the seasonal rotation of maize with grain legume (cowpea), ATP-SR-Y (3390 kg ha^{-1}) out-yielded Tuxpeño sequia (2574 kg ha^{-1}) by 32%. Compared to their corresponding controls under fallow, slash and burn rotation, Tuxpeño sequia responded slightly better (5.3%) than ATP-SR-Y (4%). Maize/grain legume rotation yielded 2982 kg ha^{-1}, which was 5% and 7% higher than grain yields of maize/fallow, slash and burn and maize/leafy legume rotations respectively.

The rotation of maize with the leafy legume (mucuna), showed an increase in grain yield of 4.4% with ATP-SR-Y, but 11% reduction with Tuxpeño sequia as compared to the control. ATP-SR-Y had significantly higher grain yield (57%) over Tuxpeño sequia. The relatively poor performance observed on these plots, was partially due the regrowth of mucuna which used maize plants as support during the maize growing season and might have contributed to the lower plant stand, especially with Tuxpeño sequia. Differential cvr x rotation responses were observed. ATP-SR-Y gave a higher yield after the leafy legume rotation (3404 kg ha^{-1}) and Tuxpeño sequia performed better (2574 kg ha^{-1}) after grain legume rotation than the fallow, slash and burn rotation. It was noted that no significant differences were detected among the three rotation schemes. However, it was observed that maize in rotation with grain legume had the advantage of producing both maize and cowpea grains during the second cropping season (Table 3).

3.1.2 Maize grain yield of the two maize cultivars as affected by the application of 250 kg ha^{-1} lime

Application of 250 kg ha^{-1} of dolomitic lime did not significantly change the yield (3352 kg ha^{-1}) of ATP-SR-Y, as compared to its performance on acid soil (Table 3). Tuxpeño sequia yielded 2720 kg ha^{-1} which corresponded to 14% grain yield increase, compared to its performance on acid soils. The grain yield superiority of ATP-SR-Y decreased from 40% on acid soil to 24% with the application of 250 kg ha^{-1} of lime. Here again, no significant grain yield differences were detected between plots planted after fallow, slash and burn rotation (3173 kg ha^{-1}) and grain legume (3186 kg ha^{-1}). Grain yield obtained on these two plots were better than those on plots which underwent leafy legume rotation by at least 14.7%.

Differential varietal responses to the application of 250 kg ha^{-1} of lime were observed. After fallow, slash and burn scheme, ATP-SR-Y had 3351 kg ha^{-1}, while Tuxpeño sequia produced 2995 kg ha^{-1}, which represented a 12% increase in grain yield than Tuxpeño sequia. Compared to their respective performances on acid soil, ATP-SR-Y exhibited a grain yield increase of 3%, compared to 25 % obtained with Tuxpeño sequia. It was therefore noted that, with the yearly application of 250 kg ha^{-1} of lime for four consecutive years, the highest grain yield was obtained from ATP-SR-Y in plots planted with the grain legume (3724 kg ha^{-1}), while Tuxpeño sequia yielded 2995 kg ha^{-1}.

3.1.3 Maize grain yield of the two maize cultivars as affected by application of 2250 kg ha^{-1} lime

The yearly application of 2250 kg ha^{-1} of dolomitic lime for four consecutive years generally resulted in 18% and 32% grain yield increase for ATP-SR-Y (3969 kg ha^{-1}), and for Tuxpeño sequia (3164 kg ha^{-1}) cultivars, respectively (Table 3). ATP-SR-Y out yielded Tuxpeño sequia by 25%. ATP-SR-Y yielded 4174 kg ha^{-1} in rotation with the grain legume, 4085 kg ha^{-1} after fallow, slash and burn, and 3647 kg ha^{-1} after leafy legume. Tuxpeño sequia produced 3494 kg ha^{-1} after grain legume, 3315 kg ha^{-1} on plot fallowed, slashed and burned, and 2684 kg ha^{-1} after leafy legume. Plots with maize/grain legume yearly rotation, had the greatest maize grain yield and had the advantage of producing additional income during the second cropping season.

Table 3. Maize grain yield of the two maize cultivars as affected by lime doses and rotation schemes

Lime dose (kg ha^{-1})	Rotation scheme				
	Varieties	**Fallow/slash burn**	**Grain legume**	**Leafy legume**	**Means**
0	ATP-SR-Y	3261	3390	3404	3352
	Tuxpeño	2444	2574	2165	2394
	Mean	2853	2982	2785	2873
250	ATP-SR-Y	3351	3724	3014	3363
	Tuxpeño	2995	2647	2518	2720
	Mean	3173	3186	2766	3042
2250	ATP-SR-Y	4085	4174	3647	3969
	Tuxpeño	3315	3494	2684	3164
	Mean	3700	3834	3166	3567
	Grand mean	3242	3334	2906	
Least significant difference (0.05)		388			

<u>3.1.4 The responses of soil properties to treatments/factors tested</u>

The effect of lime was generally highly significant on maize yield. In fact, plots which received lime generally yielded 15% higher than those which did not (3305 kg ha^{-1} vs 2873 kg ha^{-1}).

3.1.4.1 Maize grain yield response without lime application

Soil analyses conducted at the onset of the experiment and three years later (Table 4), revealed that the mean pH changed from 4.89 to 4.38 after four years cultivation of maize, which represented 0.51 unit (10%) decrease in pH. The soil available Al and H increased by 37% and 107% respectively, resulting in 20% increase in Al saturation. The soil nutrient content was depleted and this was evidenced by the decrease in the available Ca and K by 12% and 14%, respectively. These results suggested that cultivation on an acid soil without any soil amendment further increases the acidity of the soil. The magnitude of this soil acidification varied however from one rotation scheme to another.

Soil analysis of the fallow, slash and burn plots indicated an increase in soil acidification, with 0.42 unit (9%) decrease in soil pH, and an increase in soil exchangeable Al (19%), H (171%), and Al saturation (9%). The soil fertility status indicated a decrease in available Ca (17%), but an improvement of the available Mg and P of the soil by 36% and 78%, respectively. Therefore, fallow, slash and burn practice on acid soil, resulted in further soil acidification. Similar changes in soil characteristics were observed on plots planted with the farmers' check variety, which was also yearly fallowed, slashed and burned. These plots had the smallest decrease in pH (0.35 unit), and a corresponding increase in the exchangeable Al (5%) with the best available P (121%), and the second best for CEC (10%). These plots also exhibited a significant increase in H (89%) and a 13% decrease in soil Ca. Soil analysis of plots with grain legume showed 0.50 unit decreases in soil pH (10%), 23% increase in exchangeable Al, and only 5% increase in Al saturation. The fertility of the soil was comparatively better with this rotation scheme, evidenced by an increase in available Ca, Mg and P by 2%, 85%, and 75%, respectively having the highest CEC (14%). Soil analyses of plots with leafy legume rotation revealed the highest decrease in soil pH of 0.62 units (14%), as well as the highest increase in exchangeable Al, H, and Al saturation of 84%**,** 92%, and 55%, respectively. Even though soils on fallow, slash and burn improved available P by 83%, this rotation scheme yielded as much as the grain legume rotation, and contributed mostly to increased soil acidification which in the long run could lead to soil infertility.

3.1.4.2 Response of grain yield and soil properties to lime doses 250 kg ha^{-1} application

Changes in soil characteristics after four years of 250 kg ha^{-1} of lime application, average over rotation schemes, revealed the following: the soil pH decrease by 0.39 unit (9%) which showed a slight improvement over the 0.51 unit on acid soils. The exchangeable Al, H and the Al saturation also increased by 30%, 177% and 7%, respectively. The soil nutrients: Ca, Mg and P increased by 4%, 81% and 62%, respectively. Results from soil analysis of plots after the fallow, slash and burn rotation, revealed pH decrease by 0.42 unit (8%), similar to what was obtained on acid soil. The available Al, H and Al saturation of the soil increased by 42%, 200% and 11%, respectively, while exchangeable Ca, Mg, and P increased by 18%, 33% and 90%, respectively. With the rotation of maize and grain legume, the soil pH decreased by 0.25 unit (5%), and the exchangeable Al decreased by 1%. The H+ increased by 86%, compared to 200% observed after the fallow, slash and burn rotation. The Al saturation dropped by 14%, and soil nutrients were improved by 5%, 121%, and 41% for Ca, Mg, and P, respectively, resulting in a small improvement of CEC by 11%. With the rotation of maize and leafy legume, the soil pH decreased by 0.49 unit (11%), coupled with an increase in exchangeable Al (46%), H (246%), and the highest increase in Al saturation (20%). In addition, this scheme allowed 15% soil depletion of available Ca, and only permitted 100%, and 62% increase in available Mg and P content of the soil, respectively (Table 5).

3.1.4.3 Response of grain yield and soil properties to lime dose 2250 kg ha^{-1} application

Lime dose application of 2250 kg ha^{-1} against rotation schemes revealed that the pH of plots increased from 4.97 to at least 5.90, and the exchangeable Al and H were completely neutralized (less than 0.03). In addition, the available Ca, Mg, and P content of the soil increased by 238%, 986% and 13%, respectively. This resulted in 102% improvement of the CEC. The pH ranged from 5.9 to 6.06. The three farming systems exhibited exchangeable Al and H of less than 1%, and Al saturation of less than 0.1%. Soil fertility was improved with all the practices. The available Ca increased by 238%, 355% and 289% with maize/grain legume, maize/leafy legume, and maize/fallow, slash and burn rotations respectively. The available Mg also increased by at least 986% with all the rotation schemes, especially with maize/fallow, slash and burn (1917%). The P content of the soil increased by 27% and 17% with maize/fallow, slash and burn and maize/leafy legume rotations, respectively, but decreased by 5% on plot undergoing maize/ grain legume rotation**.** The CEC of the soil was high with all practices, especially with maize/grain legume rotation (107% increase). Therefore, acidity of the soil due to Al toxicity was completely neutralized after four years, regardless of rotation scheme used. When soil acidity was neutralized, slash and burn practices permitted additional increase in Ca, Mg, P, and K, also the leafy legume increased the Ca and Mg status of the soil (Table 6).

Table 4. Exchangeable elements, CEC, and pH at the beginning of experiment (2001) and after three growing seasons without lime application

Soil properties Treatments (Rotation schemes)	Years	pH (H_2O)	Al(Cmol (+)Kg^{-1})	H(Cmol (+)Kg^{-1})	Ca(Cmol (+)Kg^{-1})	Mg(Cmol (+)Kg^{-1})	P(Cmol (+)Kg^{-1})	CEC(Cmol (+)Kg^{-1})	K(Cmol (+)Kg^{-1})	Al Sat (%)
Local Maize (Check)	2001	4.85	1.75	0.18	1.44	0.24	43.95	5.56	0.14	-
	2003	4.54	1.83	0.34	1.25	0.33	97.00	6.13	0.16	-
Maize/Fallow and	2001	4.82	1.82	0.16	1.45	0.25	56.40	5.64	0.18	50.00
burn	2003	4.40	2.04	0.36	1.24	0.34	109.70	5.98	0.14	54.25
Maize/Grain legume	2001	4.91	1.81	0.14	1.35	0.27	54.66	5.37	0.17	50.00
	2003	4.41	2.24	0.23	1.37	0.50	96.00	6.14	0.13	52.70
Maize/Leafy legume	2001	4.95	1.22	0.13	1.54	0.37	49.25	5.82	0.17	36.97
	2003	4.33	2.25	0.25	1.27	0.27	90.50	5.62	0.13	57.40
Means on acid soil	2001	4.89	1.64	0.14	1.45	0.30	57.55	5.65	0.16	45.65
	2003	4.38	2.25	0.29	1.29	0.37	103.00	5.85	0.14	54.78
LSD (0.05)		0.25	0.54	0.10	0.76	0.58	9.44	1.17	0.01	8.51

Exchangeable elements were determined by the cobaltihexamine method (Orsini and Remy, 1970). Soil-water ratio for pH determination was ½.

Table 5. Exchangeable elements, CEC, and pH of the soil at the beginning of the experiment (2001), and after three growing seasons with yearly application of 250 kg ha^{-1} of dolomitic lime

Soil properties Treatments (Rotation schemes)	Years	pH (H_2O)	Al(Cmol (+)Kg^{-1})	H(Cmol (+)Kg^{-1})	Ca(Cmol (+)Kg^{-1})	Mg(Cmol (+)Kg^{-1})	P(Cmol (+)Kg^{-1})	CEC(Cmol (+)Kg^{-1})	K(Cmol (+)Kg^{-1})	Al Sat (%)
Maize/Fallow and burn	2001	5.03	1.27	0.12	1.43	0.45	46.35	6.01	0.17	38.25
	2003	4.61	1.80	0.36	1.69	0.60	88.00	5.94	0.14	42.55
Maize/Grain legume	2001	4.90	1.29	0.15	1.55	0.37	58.83	5.82	0.16	38.28
	2003	4.65	1.28	0.28	1.63	0.82	83.25	6.47	0.15	32.99
Maize/Leafy legume	2001	4.98	1.52	0.13	1.52	0.26	60.44	5.86	0.17	43.80
	2003	4.49	2.22	0.45	1.32	0.52	97.75	5.93	0.12	52.61
Means	2001	4.97	1.36	0.13	1.50	0.36	55.20	5.90	0.17	40.10
	2003	4.58	1.77	0.36	1.56	0.65	89.67	6.11	0.14	42.71
LSD (0.05)		0.25	0.54	0.10	0.76	0.58	9.44	1.17	0.01	8.51

Exchangeable elements were determined by the cobaltihexamine method.(Orsini and Remy,1970). Soil-water ratio for pH determination was 1/2.

Table 6. Exchangeable elements, CEC, and pH of the Soil properties at the beginning of the experiment (2001), and three growing seasons after, with yearly application of 2250 kg ha-1 of dolomitic lime

Soil properties										
Treatments (Rotation schemes)	**Years**	**pH (H_2O)**	**Al(Cmol (+)Kg^{-1})**	**H(Cmol (+)Kg^{-1})**	**Ca(Cmol (+)Kg^{-1})**	**Mg(Cmol (+)Kg^{-1})**	**P(Cmol (+)Kg^{-1})**	**CEC(Cmol (+)Kg^{-1})**	**K(Cmol (+)Kg^{-1})**	**Al Sat (%)**
Maize/Fallow and	2001	4.95	1.52	0.14	1.33	0.18	51.30	0.15	5.56	47.80
burn	2003	6.03	0.01	0.03	5.17	3.63	65.25	0.17	10.86	0.11
Maize/Grain	2001	4.95	1.30	0.17	1.75	0.37	62.45	0.20	6.17	35.91
legume	2003	6.06	0.03	0.02	5.92	4.02	59.50	0.13	12.83	0.01
Maize/Leafy	2001	5.01	1.44	0.18	1.17	0.23	52.30	0.17	5.69	47.84
legume	2003	5.90	0.00	0.01	5.32	3.65	61.25	0.11	11.48	0.11
Means	2001	4.97	1.42	0.16	1.42	0.26	55.35	0.17	5.81	43.85
	2003	6.00	0.01	0.02	5.47	3.77	62.00	0.13	11.72	0.08
LSD (0.05)		0.25	0.54	0.10	0.76	0.58	9.44	1.17	0.01	8.51

LSD Least Significant Difference
Al Sat Aluminium Saturation
Exchangeable elements were determined by the cobaltihexamine method. (Orsini and Remy,1970). Soil-water ratio for pH determination was 1/2.5

3.2 Discussion

Results from the soil properties in the study site and maize grain yields indicated that there were no significant grain yield differences among the three rotation schemes. ATP-SR-Y in rotation with grain legume was the best practice and comparatively exhibited the highest grain yield, while contributing in the long run to the least soil acidification. In addition, maize cultivation after fallow, slash and burn, a common practice in the humid forest, gave similar grain yield with maize cultivation after grain legume, but tended to further increase the acidification of the soil. Furthermore, ATP-SR-Y after leafy legume rotation out yielded the two other rotation schemes. Empirical estimates of the reduction of maize grain yield due to acidic soils in the tropical zone with genotypes showing contrasting responses to acid soils have been reported [17,1] . Grain yield losses due to soil acidity ranged from 46% to 76% [17]. Losses of 57%, 73% and 61%, were reported [1] for ATP-SR-Y, Tuxpeño sequia and the local check compared to 26%, 72%, and 47% obtained in the present study. Except for Tuxpeño sequia, these yield losses due to soil acidity, were smaller. This might be partly attributed to the cumulative effect of the treatments. In this study, ATP-SR-Y exhibited 36% and 17% grain yield increase over Tuxpeño sequia, and the local check, respectively. Similar reports on grain yield advantage of the acid soil tolerant genotypes were reported by [18] and [17]. These genotypic responses were correlated with changes in soil properties such as exchangeable Al, Ca and Mg, which has been reported as important factors determining grain yield on acid soils [3, 1]. These authors also suggested the possibility of breeding for both Al tolerance and efficient use of Ca and Mg simultaneously. In the present study, except for the first year of cultivation, the grain yield superiority of the tolerant over Tuxpeño sequia, increased over years of cultivation. Therefore, with these results, the breeding for acid soil tolerance in maize is worthwhile confirming that the use of acid soil tolerant cvrs, has the potential of bringing unproductive acid soils in Africa into productive cultivation [1]. This suggests that acid soil tolerant cultivars should be a component of any integrated option for the management of the acid soils, especially as they add nothing to the cost of production besides the cost of the seed. This agrees with the findings of [19] who stated that if input intensive management options are not economically feasible for acid soils, both Al resistance and the efficiency of P use should be considered to improve yield and yield stability in maize based cropping systems. The fallow, slash and burn rotation planted with local maize exhibited lesser dose of soil acidification, with some improvement of the Mg, P, and CEC of the soil than the sensitive Tuxpeño, indicating its better adaptation. Generally, when no attempt was made for soil corrections, acidity increased with continuous maize cultivation regardless of the rotation scheme used. This was evidenced by the increase in soil pH (5% to 23%), increase in exchangeable Al (5% to 23%), and H (64% to 171%). The observed grain yield differences obtained among the rotation schemes could therefore be attributed to their differential ability to impact soil fertility. This study also indicated that the slash and burn system improved the Mg and P content of the soil but not the Ca most needed in acid soils. Leafy legume rotation improved only the P content, but depleted the soil of Ca and Mg. Grain legume rotation on the other hand had more impact on the Ca, Mg and P content of the soil. It was evident that none of the treatments significantly had positive impact on the soil pH, Al and H content, demonstrating that continuous maize cultivation on acid soil increases the acidity of the soil. However, among the different rotation schemes studied, maize in rotation with grain legume which improved the soil nutrient content, could give room for multiple cultivations on the same plot. This partially explained, the different fallow period (2 to 7 years) used by the farmers with shifting cultivation in the humid forest zone of sub-Saharan Africa. With maize leafy legume rotation, ATP-SR-Y and Tuxpeño sequia yielded 3014 kg ha^{-1} and 2518 kg ha^{-1}, respectively, which represents a 20% increase in grain yield of the acid tolerant cultivar. These grain yields were 10% and 19 %

lower, compared with the performance of ATP-SR-Y after slash and burn (3351 kg ha^{-1}) and after grain legume (3724 kg ha^{-1}), respectively. A similar trend was observed with Tuxpeño sequia. The lowest maize grain yield observed with this practice was partially attributed to mucuna competition which lowered the plant stand of these plots and increased the soil acidification as evidenced by a decrease in pH of 0.49 unit (11%), increase in exchangeable Al (46%), H (246%), and the highest increase in Al saturation (20%). In addition, this scheme allowed 15% soil depletion of available Ca, and only permitted 100%, and 62% increase in available Mg and P content of the soil, respectively. The soil acidity level was reduced on grain legume plots as evidenced by the 5% soil pH decrease. There was also an improvement on exchangeable Al (1%), least increase in exchangeable H (86%), and a decrease in Al saturation (14%).

Lime application generally and significantly increased the maize grain yield. It was observed however that the application of only 250 kg ha^{-1} of lime for four years, did not significantly improve the yield of the tolerant genotype nor significantly improved the soil characteristics. It was however evident from these results that liming was more critical for maintaining yield of susceptible varieties. Similar conclusions were reached by [20]. The application of 2250 kg ha^{-1} of dolomitic lime resulted in significant grain yield increase for both ATP-SR-Y and Tuxpeño sequia. This could be explained by the improvement in soil pH (increase to 6.0), decrease in exchangeable Al, and H completely neutralized. The nutrient contents of the soil were higher, resulting in 102% increase in the CEC. Correlated responses between grain yield and exchangeable Al, Ca and Mg, were reported [1]. Exchangeable Al was the main determining factor of pH, and its reduction was related to increase in exchangeable Ca and Mg, and neutralization of H, which partially explained the high yield obtained with higher lime doses. Similar high and significant correlations were also reported between exchangeable Al and pH [21], and the existence of a link between the dynamics of H, Al and Ca was suggested [22]. Maize/leafy legume (mucuna) rotation on acid soil showed better performance with ATP-SR-Y, than Tuxpeño sequia. This was not in agreement with previous reports on the beneficial effect of mucuna for soil fertility improvement on succeeding cereal crops. With mucuna as a preceeding crop, 20% to 60% maize yield increase was obtained [23], as compared to cowpea. [24] reported that there was a 33% grain yield increase due to rotation of maize with mucuna. The difference might be due to the acidity level of our soil when both studies are compared. In addition, the use of mucuna as the preeceding crop generally results in regrowth of the leafy legume during the normal cropping season of maize, which could contribute to lower plant stand and therefore lower grain yield. This study showed that soil analysis of plots planted with mucuna had higher soil acidification, evidenced by more increase in pH, and exchangeable Al. Except for P, this rotation scheme on acid soil showed the highest depletion in the available Ca and Mg, and the highest increase in Al saturation. The resulting decrease in soil fertility could be explained partly by the lowest yields observed with this rotation scheme which could not be the best option in tropical rain forest acid soils meant for maize cultivation.

4. CONCLUSION

The practice of crop rotation (fallow, slash and burn, grain legume and leafy legume) on acid soils showed no effect within four years on maize yields. However, changes in soil characteristics resulted in the improvement of soil fertility by grain legume rotation. Application of 250 kg ha^{-1} of lime was not sufficient to correct soil acidity during the four years of experiment. Therefore, long term rotation of maize with grain legume can be recommended to farmers as a solution to soil acidity alleviation instead of fallow and burn.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. The C, Calba, H, Zonkeng C, Ngonkeu ELM, Adetimirin VO, Mafouasson HA, et al. Responses of maize grain yield to changes in acid soil characteristics after soil amendment. Plant and Soil. 2006;284:45-57.
2. Pandey S, Narro L, Friesen DK, Waddington SR. Breeding maize for tolerance to soil acidity. Plant Breed. 2007;Rev. 28:59-100
3. Borrero JC, Pandey S, Ceballos H, Magnacava R, Bahia AFC. Genetic variances for tolerance to soil acidity in tropical maize population. Maydica 1995;40:283-288.
4. Rutanga V, Neel H. Yield trends in the long term crop rotation with organic and inorganic fertilizers on Alisols in Mata (Rwanda). Biotechnol. Agron. Soc. Environ. 2006;10(3):217-228.
5. Nwite JC, Igwe CA, Obalum SE. The contribution of different ash sources to the improvement in properties of a degraded ultisol and maize production in southeastern Nigeria. Asian Journal of sustainable Agriculture. 2011;5(1):34-41. (ISSN 1495-0748)
6. Fagaria NK, Wright RJ, Baligar VC, Carvalho JRP. Response of Rice and common bean to liming on an Oxisol. In 2nd International Symposium on plant interaction at low pH, held on 24-29 June 1990, Becheley, West Virginia.
7. Smith FJ, Sanchez PA. Effect of lime Silicate and phosphorus application to an oxisol on phosphorus sorption and ion retention. Soil Sci. Soc. Am. J. 1980;44(3):500-505.
8. Gupta RRN, Singh RD, Prasad RN. Effect of liming acid soil on yield of some crops and soil characteristics. J. Indian Soc. Soil Sci. 1989;37:126-130.
9. Osei BA. Effects of different lime application doses 467 and time on some chemical properties of an acid soil in Ghana. Soil Use and Management. 1995;11(1):25-29.
10. Kauffman J, Sanford R, Cummings D, Salcedo I, Sampaio E. Biomass and nutrient dynamics associated with slash fires in neotropical dry forests. Ecology. 1993;74:140-151.
11. Van Reuler H. Nutrient management over extended cropping periods in the shifting cultivation system of south west Cote d'Ivoire. Doctodose thesis. Wageningen. The Netherlands: Wageningen agricultural University, 1996;189 .
12. Raison RJ, Khanna PK, Woods P. Mechanism of element transfer to the atmosphere during vegetation burning. Can. J. For. Res. 1985;15:132-140.
13. Perin A, Santos RHS, Urquiana S, Guerra JGM, Cecon PR. Efeite residual da adubacao verde no rendimento de brocolo (brassica oleraceae IL. Var itlico) cultivado em sucassao ao milho (*Zea mays* L.) Ciencia rural santa Maria. 2004;34(6):1739.
14. Yemefack M, Moukam A. Biophysical land resources inventory and characterization of Abs forest margin benchmark sites of Cameroon. IRA/ASB, Mimeo; 1995.
15. Orsini L, Remy JC. Utilisation du chlorure de cobaltihexammine pour la détermination simultanée de la capacité d'échange, et des bases échangeables des sols. Science du Sol. 1976;4:269-275.

16. S.A.S. Guide for personal computers. 6th edn. S.A.S. Institute Inc., Cary, NC, USA; 1998.
17. Welcker C, The C, Andreau B, Deleon C, Parentoni SN, Bernal FJ, et al. Heterosis and combining abilily for maize adaptation to tropical acid soils. Implication for future breeding stdosegies. Crop Sci. 2005;45:2405-2413.
18. The C, Horst WJ, Calba H, Welker C, Zonkeng C. Identification and development of maize genotypes adapted to Acid-soil of the tropic. In plant Soil interactions at low pH. Sustainable agriculture and forestry production; Proc. 4th international symposium on plant-soil interaction at low pH. Below horizonte MG, Brazil. 17-24 March 1996. Ed. AC monitz et al. Brazilia Soil Science Society, campinas, SP Brazil, 1997;265.
19. Sierra J, Ozier-Lafontaine H, Dufour L, Meunier A, Bonhomme R, Welcker C. Nutrient and assimilate partionning in two tropical maize cultivars in relation to their tolerance to soil acidity. Field Crop Res. 2006;95:234-249.
20. Baquerol JE, Rojas LA. Interaction effect of organic materials and lime on grain yield and nutrient acquisition of three maize varieties, grown on oxisols of the Colombian eastern plains. In plants nutrition-food security and sustainability of agro-ecosystems. Ed. Kluver Academic Publishers, Springer, Drodrecht. 2001;82-83.
21. Trinh S. L'aluminium échangeable dans les sols acides de quelques pays d'Afrique et de Madagascar. Cahier Orstom, Série pedologie. 1976;14(3):271-278.
22. Calba H, Cazevieille P, The C, Poss R, Jaillard B. The dynamics of protons aluminium and calcium in the rhizosphere of maize culitvated in tropical acid soils: Experimental studies and modelling. Plant and Soil. 2004;260:33-46.
23. Oyewole B, Carsky RJ, Schulz S. On farm testing of Macuna and cowpea double cropping with maize in the Guinea savanna of Nigeria. In over crops for integdosed Natural Resource Management in west Africa edited by R.J. Carsky, J.D.H. Keatinge, V.M. Manyong, and Etek; 1999.
24. Versteeg MNF, Amadji A, Eteka A, Gogass, Koudopkon V. Farmer's adoptability of Mucuna fallowing and agroforestry technologies in the coastal savanna of Benin. Agricultural Systems. 1998;56:269-287.

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