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CORRECTION OF ACID INFERTILITY OF THE RWANDAN OXISOLS FOR SUSTAINABLE CROPPING WITH LIME FROM AN INDIGENOUS SOURCE[1]

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SUMMARY

Sustainable crop production of the Rwandan Oxisols is limited by widespread soil acidity due primarily to high levels of exchangeable Al. This study was designed to test the effectiveness of an indigenous lime material to counteract the acidity problem and enhance crop yields. Lime application significantly raised pH, Ca and ECEC and reduced exchangeable Al and total acidity. Ca was directly proportional to ECEC (r=0.962**) and inversely related to Al (r= -0.955**). Lime in combination with *Sesbania* pruning controlled soil acidity better than pruning alone. Consequently, yields of wheat, beans and potatoes that served as test crops were significantly increased by liming. Root and floret development of wheat and number of pods/plant for beans were the yield components significantly affected by liming. Lime at high rates (4-8 t/ha) had a longer residual effect than lime at low rates (0-2 t/ha), suggesting frequent applications when low lime rates are used. The following formula is proposed for routine estimate of lime requirement (X) based on a target pH (Y): X=(Y - 4.32)/0.154.

INTRODUCTION

The Oxisols of the northern sector of Rwanda are predominantly acid (Vander Zaag et al., 1984; Yamoah et al., 1990) with subsoil pH sometimes as low as 4.0, but generally < 5. High levels of exchangeable Al, which frequently exceeds 70% of the exchange complex (Vander Zaag et al., 1984; Yamoah et al., 1990), and erosion of the fertile top soils are the main causes of low crop productivity on hillsides where farming is normally done.

Liming is known to check Al toxicity, increase pH, increase P availability, improve N efficiency and supply Ca (Abruna et al., 1975; Cassel, 1980; Evans and Kamprath, 1970; Fox et al., 1962; Kunishi, 1982; Sanchez, 1976). Furthermore, the ability of organic matter to detoxify deleterious effects of excess solution and exchangeable Al through formation of organo-Al chelates is well established (Hester, 1936: Ahmad and Tan, 1986: Brogan, 1967).

To overcome the acid infertility constraint of the Rwandan Oxisols, organic matter-generating cropping systems in the form of alley cropping and improved fallows are advocated in combination with liming (Yamoah et al., 1991). *Sesbania sesban, Leucaena diversifolia* and *Calliandra calothyrsus* are potential hedgerow shrubs, while vetch, by virtue of its fast growth and tolerance to acid soils, is an excellent fallow species for the Rwandan Highlands (Yamoah et al., 1989; Yamoah et al., 1990; Potts et al., 1989).

Lime deposits exist in some parts of northern Rwanda, but the agronomic value of this lime is largely unknown. At present, farmers mine and use it to whitewash their houses. The purpose of this study is to investigate the effect of this local lime material on yields of some common food crops and soil fertility status in two agroecological zones of northern Rwanda.

MATERIALS AND METHODS

The studies, which are mainly in the form of agronomic field trials, were comprised of exploratory and validation components.

Exploratory Trials

Preliminary investigations were carried out in the Buberuka Highlands and Central Plateau agroecological zones of Rwanda. Detailed site characteristics of the above two areas are found in Franzel et al. (1985) and Yamoah et al. (1990).

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The trial at the Central Plateau region examined the effect of lime and NPK fertilizer on yield of climbing beans (variety G 2333). There were two levels of lime and four fertilizer levels as follows: Lime, O and 2 t/ha; NPK, O-O-O, 60-30-30, 120-60-60, 150-75-75 kg/ha, in a factorial combination. The design was a randomized complete block (RCB) with eight treatments replicated four times on a plot size of 4 x 5 m.

The second trial, conducted at the Buberuka Highland region, investigated the effect of the lime material and P on yields of an improved bean variety (Rubona 5) and a local variety. There were two levels of lime (O and 2 t/ha), three levels of phosphorus (O, 60 and 120 kg P_2O_5/ha) and two bean varieties (Rubona 5 and a local). The 12 treatment combinations were replicated three times on a plot size of 4 x 5 m.

Validation Trial

An experiment was carried out at the Buberuka Highlands to further explore the findings of the preliminary studies. The site was under vetch fallow prior to trial establishment. Baseline soil characteristics include pH, 4.0; exchangeable Al, 4.5 meq/100 g; effective CEC, 8.3 meq/100 g; calcium, 2.0 meq/100 g; available P, 4.4 ppm. The objective of the study was to determine the effects of four lime rates and their residual effects on crop yields and soil fertility in an alley cropping system with *Leucaena diversifolia*. Treatments were lime at four levels (0, 2, 4 and 8 t/ha) and NPK fertilizer at two levels (0 and 60-60-60 kg/ha). Lime was applied once to the first crop of wheat, and NPK was applied to each of the three test crops, i.e wheat (*Triticum aetivum* L.) variety Rugezi, beans (*Phaseolus vulgaris* L.) variety Bataaf and potatoes (*Solanum tuberosum* L.) variety Cruza for the first, second and third seasons, respectively. Wheat was drilled at 0.2-m centers. Bean was seeded at a spacing of 0.5 x 0.2 m, and potato was planted on ridges at 0.4 x 0.6 m. Lime was incorporated to a 15-cm depth with a hoe and allowed to incubate in the soil for two weeks before seeding the first test crop.

Since low environmental temperatures normally delay germination, the NPK fertilizer was broadcasted four weeks after planting when roots of the crops had been formed. This practice ensured efficient utilization of mobile nutrients by minimizing leaching. The eight treatment combinations were replicated four times in a RCBD. Leucaena hedgerows were spaced 5 m apart and 0.5 m within rows. The shrub was cutback after 12 months prior to planting the third potato crop. Plot size was 3.5 x 20 m.

Soil was sampled before trial initiation and after the third potato crop. In addition, soil ameliorating value of the lime was further explored by sampling plots of a *Sesbania* alley cropping trial initiated in 1985 and for which lime was incorporated as treatment in April 1990. Soil samples were collected from this plot after two months of lime application. Samples were analyzed for pH, N, P, K, OC and ECEC by the following methods: pH (Peech, 1965); organic carbon (Walkley and Black, 1934); exchangeable acidity (Barnhisel and Bertsch, 1982); total nitrogen; available phosphorus (Bray and Kurtz, 1945); exchangeable Ca, Mg, K and Na (Thomas, 1982); and effective cation exchange capacity (ECEC) as the sum of Ca, Mg, K, Al and H. Exchangeable Al, pH and total acidity were monitored in the course of the experiment.

Data were analyzed with MSTAT software using Analysis of Variance (ANOVA) with LSD at 0.05.

RESULTS AND DISCUSSIONS

Exploratory Trials

Yield of pole bean (Var G 2333) was significantly increased by both lime and fertilizer (Table 1). A combination of 2 t of lime and 120-60-60 kg NPK/ha gave the highest bean yield. Use of lime alone without NPK fertilizer resulted in 85% yield increase relative to the control. Addition of lime increased yield at all levels of fertilizer, suggesting efficient utilization of applied fertilizer in the presence of lime. Interaction between lime and fertilizer, however, was not significant. Overall, there was a 55% yield increase attributed to liming. Since this soil is relatively infertile (Yamoah et al., 1990), use of lime and fertilizer is recommended to assure sustainable crop yields.

Yield data on the effect of lime and P on the performance of two bean varieties is shown in Table 2. The beans responded significantly to P application but not to lime. However, the interaction effects between lime and P as well as among lime, P and varieties were significant. The bean varieties responded to P when no lime was applied, but there was lack of response in the presence of liming. Soil P was tied up by exchangeable Al in the unlimed plots as compared to the limed plots where the effect of exchangeable Al was neutralized (Sposito, 1989; Sanchez, 1976; Singh and Singh, 1983; Foth and Ellis, 1988).

The local bean variety appeared less susceptible to diseases and, therefore, outyielded the improved variety (Rubona 5) under the various lime and fertilizer treatments. Our results indicate that for this soil type, liming might have primed release of P from existing soil organic matter and consequently enhanced its availability to crops. Thus, high doses of P required in the unlimed soil are not necessary when lime is used. Also, liming may be unimportant if adequate amounts of P and manure are available.

Validation Trial: Crop Yields

The effect of lime and NPK on wheat yield is shown in Table 3. Fertilizer application increased wheat yield. Lime application significantly increased wheat yield in a linear fashion. Yield increase due to liming is principally ascribed to improved root development and better formation of florets (Table 5). There was no interaction between lime and fertilizer application. Al toxicity has been shown to impair root development and inhibit Ca and P uptake (Sanchez, 1976; Adams and Lund, 1966; Brenes and Pearson, 1973). Ritchey et al. (1988) adopted wheat root length as a measure of acid tolerance. Foy et al. (1965) attributed tolerance of some wheat varieties to their abilities to modify soil pH and Al solubilities around their root systems.

Folscher et al. (1986) reported significant wheat yield increase with 4 t/ha lime. Even though it was realized that doses around 20 t did not cause a further yield increase, they proposed application of high lime rates to maintain adequate reserve in order to offset periodic occurrence of soil acidification caused by continuous cropping.

Bean yield as affected by residual lime and fertilizer application is shown in Table 4. Like that of wheat, bean response to residual lime was significant and linear. Number of pods/plant was the only bean yield component significantly affected by liming (Table 5). The yield difference between the use of 4 and 8 t/ha lime was not significant. However, yield at this higher rate (4 - 8 t/ha) differed significantly from that of the lower rate (0 - 2 t/ha), suggesting a better residual effect when higher rates are used.

Aluminum toxicity and P deficiency have been recognized as factors that limit bean yield in acid soils and that are rectifiable through liming (Noble and Lea, 1985; Munns and Fox, 1977). Ramos and Boddey (1987) achieved increased nodule weight and bean pod yield with lime application and also identified the Rhizobium strain CO5 as unique for its ability to survive and nodulate Phaseolus beans at pH 5. Lime applied at 1723 kg/ha neutralized exchangeable Al and significantly increased nodulation, pod yield, kernels and haulms of peanuts (Anandan et al., 1985). At higher rates, lime promoted proper establishment and vigorous growth of beans, which in turn suppressed weeds in the limed plots. The respective weed yields in the 0, 2, 4 and 8 t lime-treated plots were 166, 106, 122 and 89 g/m^2 after bean harvest.

Growth of the hedgerow Leucaena benefited from the applied lime as well. Plant height after 8 months was 1.36, 1.65, 1.97 and 2.19 m for the respective lime treatments. In a glass house study in Australia, Sivasupiramanian et al. (1986) obtained significant increase in *Leucaena* shoot, leaf, stem, root and nodule dry weights at 75 but not at 50 days or earlier. In the field, response of *Leucaena* to lime increased with time as the roots developed and exploited the soil. Reduced Al and Mn toxicities as well as improved soil Ca, resulting from liming, favored the growth of *Leucaena* (Fox and Whitney, 1981).

Effect of residual lime on potato yield is found in Table 6. Potato yield was significantly increased by residual lime. Yields at the lower lime rates differed from those at the higher rates by about 30%, again substantiating a much longer residual effect with the use of higher rates (Folscher et al., 1986). Growth of potato was observed to be more vigorous in the high lime plots than in the low lime plots. The inference from the above results is that lime may be required once every two seasons for the low rates (<2 t/ha) whereas less frequent application may be sufficient to sustain crop yields at the higher (>4 t/ha) rates.

Elsewhere, potato response to lime has not been consistent. In the United States, for instance, Hester (1936) reported 25 to 29% increase in potato yield due to small applications of lime on soil with a pH of 5.2. Brown (1938) registered no increase except on very low pH soils while Carpenter and Murphy (1965) recorded a yield decrease of potato when an overdose of lime was used. In northern Rwanda, potato is largely grown on valley bottom soils (marais) that have high organic matter content and a pH < 5. A similar observation was made by Wessels (1932) on Long Island.

Soil Fertility

From the standpoint of soil fertility improvement, liming is purported to raise pH, Ca, Mg (if dolomitic) and ECEC and to reduce exchangeable and solution Al (Sanchez, 1976; Evans and Kamprath, 1970; Ahmad and Tan, 1986; Krampath; 1970; Pavan et al., 1984; Couto et al., 1985). Our results (Tables 7 and 8) indicate that application of the local lime, which contained 38% Ca, accomplished the above-mentioned desired effects. Specifically, the lime substantially raised Ca, pH and ECEC and lowered exchangeable Al. The highly significant and negative correlation (r= -0.955**) between exchangeable Ca and Al underscores the importance of the lime in checking soil acidity. As well, Ca was positively and significantly related to ECEC (r=0.962**), which also implies improved nutrient holding capacity with liming. As noted earlier, the observed soil fertility improvement was matched by a corresponding increase in crop yields. Yield enhancement is attributed principally to a decrease in exchangeable Al, which varied significantly and inversely with yields of all the test crops. This finding partly corroborates the results of Burleigh et al. (1991) who identified Al toxicity and N deficiency as the most significant soil factors that affect wheat cultivation in the Buberuka Highland region of Rwanda.

Table 7 demonstrates that a combination of lime and *Sesbania* pruning controlled soil acidity better than pruning alone. Ahmad and Tan (1986) obtained a more striking response of soybean growth to application of lime and wheat

straw than to the use of either alone. However, one is cautioned about the use of organic materials to curb soil acidity problems. First, materials with high carbon to nitrogen ratios, such as wheat straw, can cause a temporary immobilization of N (Ahmad and Tan, 1986). Secondly, incorporation of large amounts of organic materials increases the soil's buffer power and consequently elevates its P and lime requirements (Le Mare and Leon, 1989).

Experience of Gillman (1983) revealed that the effect of lime on highly weathered soils is transient, especially under high rainfall conditions. Thus, we suggest periodic monitoring of soil pH or exchangeable Al to enable determination of the amounts of supplemental lime to be added during subsequent seasons to ensure sustainable yield. To facilitate routine lime requirement (LR) estimates, we propose the formula $X=(Y - 4.32)/0.154$ where X is LR and Y is the target soil pH. The equation is derived from the lime response curve shown in Fig. 1.

Even though exchangeable Al correlated well with lime (Fig. 2) and is known to predict LR better than pH (Krampath, 1970), due to its simplicity, we encourage the use of the relation based on pH for the Rwandan situation.

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Mrs. Janet Parsch of the University of Arkansas made the inter-library computer search in the USA and gathered the relevant literature for this study. We thank the staff of the International Ag. Prog. and Department of Agronomy of the University of Arkansas, Fayetteville, for their administrative and technical support.

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Table 1: Effect of lime and NPK on pole bean yield.

Fert (kg/ha)	Yield (kg/ha) 0 Lime	Lime	Mean
0-0-0	623	1154	889
60-30-30	986	1680	1333
120-60-60	1448	2324	1986
150-75-75	1335	1959	1647
Mean	1184 a	17796 b	
LSD (0.05) Fertilizer: 590			

Table 2: Effect of lime and phosphorus on yield of improved and local beans.

Lime (kg.ha)	P (kg/ha)	Yield (kg/ha) Improved	Local	Mean
0	0	969	965	967
	60	1320	1815	1568
	120	1366	1647	1507
2	0	1289	1546	1410
	60	1584	1142	1363
	120	1259	1511	1385
LSD (0.05) P mean : 220				
LSD (0.05) P x Lime : 311				
LSD (0.05) P x Lime x Var : 440				

Table 3: Effect of lime and NPK on wheat yield

Lime	Yield (t/ha) 0 Fert	Fert	Mean
0	1384	1806	1595
2	1653	2000	1826
4	1884	2008	1946
8	2047	2164	2105
Mean	1742 a	1994 b	
LSD (0.05) Lime: 396			

Table 4: Effect of residual lime and fertilizer on beans yield

Lime (t/ha)	Yield (kg/ha) 0 Fert	Fert	Mean
0	643	1003	823
2	1054	1132	1093
4	1208	1441	1324
8	1029	1569	1389
Mean	1029	1286	
LSD (0.05) Lime: 213			

Table 5. Yield components of wheat and beans as affected by lime.

Lime (t/ha)	Wheat: Florets length (cm)	Wheat: Root wt/20	Beans: Pods/plt
0	5.2 c	6.9 b	5.0 b
2	5.6 bc	10.8 ab	6.4 a
4	5.45 a	12.4 a	6.9 a
8	6.2 ab	15.0 a	7.1 a

Table 6: Effect of residual lime and NPK on yield of potatoes.

Lime (t/ha)	Yield (t/ha): 0 Fert	Yield (t/ha): Fert	Mean
0	10.9	11.2	11.0
2	10.5	12.5	11.5
4	13.8	14.9	14.3
8	15.0	14.2	14.6
LSD (0.05) lime: 2.9			

Table 7: Soil chemical properties as affected by lime application after three cropping seasons of wheat, beans and potatoes.

Lime	Al	Al H	Ca	Mg	K	ECEC	pH	%OC	Av.P
t/ha	----------meq/100g----------								ppm
0	3.8	4.7	3.2	0.6	0.06	8.6	4.2	3.7	17.8
2	2.8	3.8	4.0	0.7	0.06	8.6	4.4	3.9	14.9
4	1.0	1.8	6.7	0.9	0.05	9.5	4.8	3.9	13.8
8	0.3	0.7	9.8	1.0	0.05	11.8	5.2	3.9	13.8
LSD	1.2	1.3	2.6	ns	ns	2.0	0.4	ns	ns

Table 8: Effect of lime on soil chemical properties in an alley cropping system with *Sesbania sesban*.

Trt	Al	Al H	Ca	Mg	ECEC	pH
	----------meq/100g----------					
Prunings (Pr)	3.2	4.1	2.9	0.7	7.8	4.4
Pr Lime (L)	0.6	1.2	8.2	0.8	10.0	5.1
Pr NPK	2.7	3.6	3.5	0.7	7.8	4.5
Pr L NPK	0.8	1.5	8.6	0.9	11.1	5.4
Control	3.1	4.0	3.1	0.7	7.9	4.5
LSD (0.05):	0.6	0.7	1.4	0.2	1.1	0.2

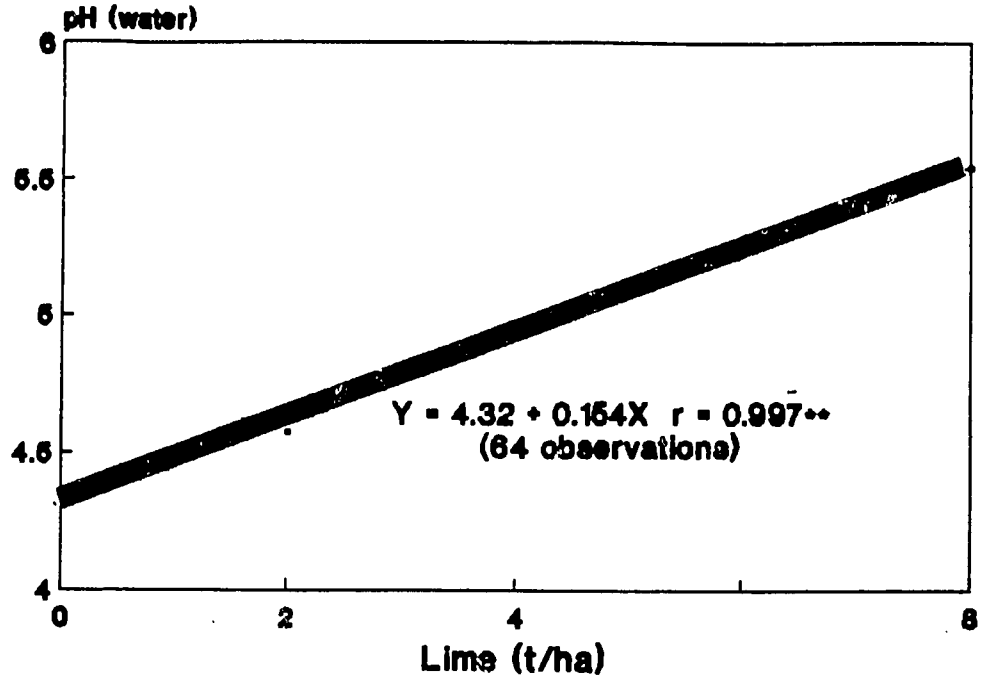

Fig. 1. Effect of lime on soil pH.

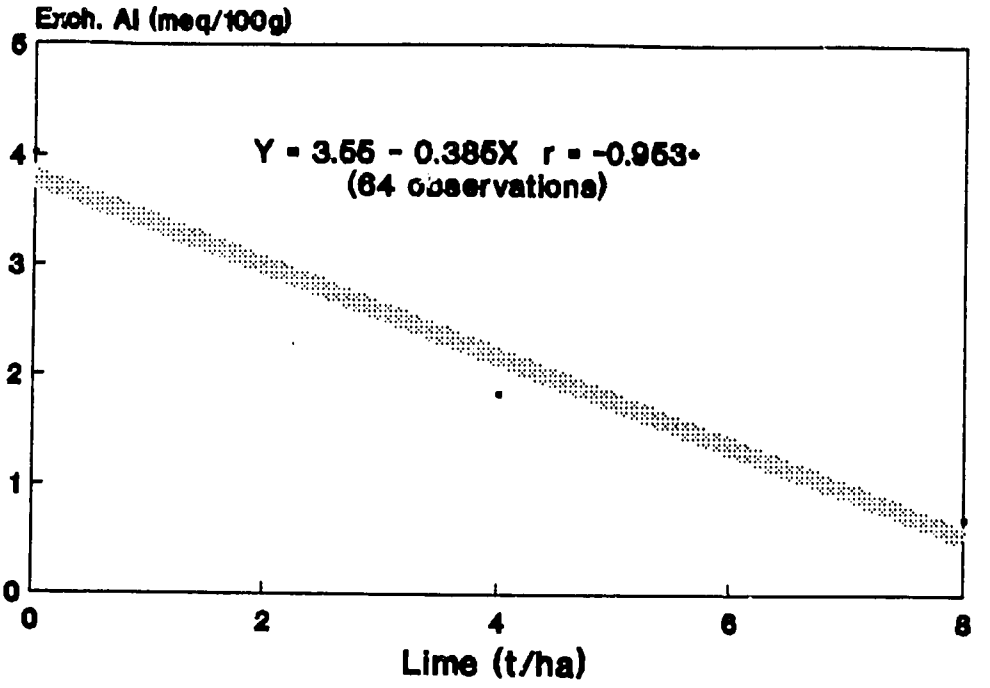

Fig. 2. Effect of lime on exchangeable aluminum.