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Continuous fertilization on non-humiferous acid Oxisols in Rwanda “Plateau Central”: Soil chemical changes and plant production

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Crop rotation system of maize and beans, established at Rubona (Rwanda) from 1984 to 1992, was used to evaluate different types and rates of fertilizers in improving the productivity of acid Oxisols. Continuous cropping of maize followed by beans for a period of 8 years gave no yield in control plots. A single application of 2 t per ha of lime increased significantly ($p = .01$) the soil pH, Ca^{2+} content, cationic exchange capacity, and decreased the level of the exchangeable aluminium. This quantity of lime when applied every two years for a period of eight years led to overliming. The application of more than 8 t per ha of fresh farmyard manure (annually), combined to 300 kg per ha of NPK 17:17:17 (every six months) significantly improved soil organic C and crop production at Rubona. The high rate (35 t per ha) of fresh manure or the combination of “lime, manure and NPK fertilizers” gave the best crop performance. Ten tons of farmyard manure (dry matter) per ha and per year seems to be the minimum acceptable amount which can effectively substitute for inorganic fertilizers.
Keywords. Acid Oxisols, maize, beans, rotation al cropping, farmyard manure, NPK fertilizers, liming, Rwanda.

Fertilisation continue des Oxisols acides non humifères du “Plateau Central” au Rwanda : Évolution des propriétés chimiques du sol et des rendements des cultures. De 1984 à 1992, un essai en rotation de maïs/haricot a été installé à Rubona (Rwanda) en vue d’étudier différentes fumures et doses capables de régénérer la productivité des cultures en sols acides où les espèces comme le maïs et le haricot, une fois plantées sans apport de fumures, ne produisent rien. L’application unique de 2 t de chaux par ha a significativement augmenté le pH du sol, la teneur en Ca^{2+}, la CEC et a réduit la teneur en Al^{3+} échangeable. L’apport régulier de cette dose tous les deux ans pour une période de huit ans a cependant provoqué un surchaulage. L’application de plus de 8 t de fumier de ferme par ha par an, combinée à celle de 300 kg de NPK 17-17-17 par ha et par saison (mars et septembre) ont sensiblement augmenté le carbone dans le sol et la productivité des cultures. La forte dose de fumier (35 t par ha) ou l’apport combiné de chaux, fumier et engrais NPK ont permis d’obtenir des rendements satisfaisants à Rubona. Dix tonnes de fumier (sur base de matière sèche) par ha et par an paraissent être la quantité minimum requise pour ne pas nécessiter l’apport d’engrais minéraux.
Mots-clés. Oxisols acides, maïs, haricot, rotation culturale, fumier, engrais NPK, chaulage, Rwanda.

INTRODUCTION

High population density in Rwanda has led to land fragmentation, resulting in farms generally smaller than one ha (MINAGRI, 1989). Farmers can no longer use fallow system for soil fertility restoration. Therefore, infertile or badly eroded lands are under cultivation. Data obtained from liming experiments in the cool humid Zaire-Nile ridge of Rwanda (Rutunga and Neel, 1980), in Africa (Wey *et al.*, 1987), and in the World (Adams, 1984; IBSRAM, 1989) showed that addition of lime alone is insufficient to rehabilitate poor or depleted soils. A combination of lime, organic manure and inorganic fertilizers was the most efficient technique of enhancing soil fertility. These soil amendments alleviate aluminium (Al) and manganese (Mn) toxicity, but also deficiencies in phosphorus (P), exchangeable bases (Ca, Mg, K) and micro-nutrients as well as low pH, and they improve soil cationic exchange capacity (CEC) (Adams, 1984; IBSRAM, 1989).

Continuous and regular manuring in a non-humiferous soil (value of organic carbon: ≤ 1.0 %) in the United States of America increased soil organic matter and biological activity, and improved crop productivity (Collins *et al*., 1992). Organic manure alone produces an effect that is proportional to its nutrient content and to the quantities applied (Bouldin *et al*., 1984; Merillo *et al*., 1995). Soil organic compounds such as fulvic and humic acids do form complexes with cations like Al^{3+}, Fe^{2+}, Cu^{2+}, Zn^{2+} and Mn^{2+} present in the soil solution (Hue *et al.*, 1986). This results in a decrease of the levels of toxic cations to plants. The organic chelates increase the availability of phosphorus previously fixed by the Al^{3+}, Fe^{2+} and Ca^{2+} cations (Tan, 1993). The objective of this study was to assess the effect of manure, lime and inorganic fertilizer on soil chemical properties and crop performance at Rubona, in Rwanda.

MATERIALS AND METHODS

The experiment was conducted in Rubona, at the “Institut des Sciences Agronomiques du Rwanda (ISAR)”, in Butare, Rwanda. The trial was carried out from September 1984 to February 1992, with two growing seasons per year. However, crop data presented in this work were only for the 1986–1992 period. The site is situated at an elevation of 1,600 m above sea level, and on a 25% slope. The climate is tropical with three dry months (Aw3) according to Köppen System (ILACO, 1985). During the experimental period, the average annual rainfall was 1,100 mm with water deficit experienced in December 1987, May and December 1988, January and May 1990. The average mean annual temperatures over the 8 years was 19°C. The natural vegetation before establishing the trial was mainly composed of *Hyparrhenia filipendula* Hochst and *Digitaria* species. The soil in the trial plots was a deep Typic Hapludox (Soil Survey Staff, 1992). Its initial characteristics are presented in **table 1**. The fertilizers used were: NPK 17:17:17, lime from Ruhengeri having 39% CaO, 4.0% MgO; fresh farmyard manure containing 40 % humidity, 0.60% N, 0.57% P_2O_5, 1.71% K_2O, 1.39% CaO and 1.21% MgO. The treatment combinations and their nutrient contents are shown in **table 2**.

The experiment was laid out in a randomized complete block design with 3 replicates. The net plot size was 4.5 m × 4.0 m. The fresh manure was broadcast and incorporated in 10 cm soil depth just before planting beans in March of each year. In September, residual effect of manure was tested, using maize as the test crop. NPK fertilizer was broadcast each season (March and September) except in March for treatment (T4) where farmyard manure was mixed with NPK fertilizer before application. Lime was broadcast and incorporated immediately in 10 cm soil depth 15 days before planting in September of every two years (T7). In September 1990, treatments (T2 to T7) received 2 t of lime per ha in order to improve crop growth.

Recommended seed varieties namely, maize Nyirakagoli, and no-climbing beans Ikinimba and Rubona 5 were used for the experiment. A crop rotation system of maize and beans was used because of its efficiency in improving cropping sustainability and reducing N rate requirement for maize fertilization (Peterson, Varvel, 1989). The maize was planted in September and harvested in January, while beans were sown in March and harvested in June. The spacing of maize was 60 cm × 50 cm with 3 seeds in a hole and

Table 1. Soil characteristics before the trial establishment in 1984 — *Caractéristiques du sol avant l’établissement de l’essai en 1984.*

Parameters	Soil depth	
	0–10 cm	10–60 cm
Organic carbon (C per kg soil)	14 g	2 g
pH in water	4.6	4.5
pH in KCl	3.5	3.4
Exchangeable calcium (Ca) per 100 g soil	0.7 meq	< 0.7 meq
Exchangeable magnesium (Mg) per 100 g soil	0.1 meq	< 0.1 meq
Exchangeable potassium (K) per 100 g soil	0.1 meq	< 0.1 meq
Exchangeable sodium (Na) per 100 g soil	trace	trace
Exchangeable aluminium (Al) per 100 g soil	2.6 meq	2.4 meq
Cationic exchange capacity (CEC) per 100 g soil	4.8 meq	4.5 meq
Base saturation	13%	15%
Phosphorus (P) Bray 1 per 100 g soil	8 mg	6 mg
Texture		
Clay (diameter < 2 mm)	36%	38%
Silt (2 mm–20 mm)	2%	2%
Sand (0.02 mm–2.00 mm)	62%	60%
Coarse gravels (> 2mm)	13%	15%

Table 2. Treatments and nutrients applied in the trial — *Traitements appliqués lors des essais ; les quantités d'éléments nutritifs apportés sont renseignées pour chaque traitement.*

Treatment		**N-P_2O_5-K_2O** (kg.ha^{-1}per year)	**N-P_2O_5-K_2O** (kg.ha^{-1} per season)
T1	Control	0-0-0	0-0-0
T2	2.5 t·ha^{-1} DM per year + 600 kg·ha^{-1} NPK per year	127-126-173	63-63-86
T3	5.1 t·ha^{-1} DM per year + 600 kg·ha^{-1} NPK per year	153-150-247	76-75-123
T4	10.2 t·ha^{-1} DM per year + 600 kg·ha^{-1} NPK per year	204-199-393	102-99-196
T5	21.0 t·ha^{-1} DM per year	210-200-599	105-100-299
T6	21.0 t·ha^{-1} DM per year + 600 kg·ha^{-1} NPK per year	312-302-701	156-151-350
T7	2 t·ha^{-1} lime every two years + 600 kg·ha^{-1} NPK per year	102-102-102	51-51-51

DM = Dry matter amount of manure.

thinned to 2 plants at the first weeding, 30 days after sowing. Beans were planted at a spacing of 40 cm × 5 cm. Weeding was done when needed. At maturity, the above ground materials (stover, thrash, grains) of the respective crops were harvested and removed from the plots. Grains were separated from residues, weighed and sampled. The samples were air dried, weighed and used to quantify the grain crop yield.

Soil sampling was done in August 1990 and 1992. The soil pH was determined in water and 0.1M KCl at the ratio of 1:2.5 (Hesse, 1971) while organic carbon was determined by modified Walkley and Black colorimetric method (Anderson, Ingram, 1993). Total P and assimilable P were determined by ammonium vanado-molybdate and Bray 1 method, using the spectrophotometer (Baize, 1988). Cation exchange capacity (CEC) was determined by the titrimetric method where bases were displaced by 1 N ammonium acetate solution (Baize, 1988). Ca^{2+} and Mg^{2+} were determined by adsorption atomic spectrophotometer (AAS). K^+ and Na^+ were determined by flame photometer. Exchangeable Al was titrated after extraction with 1 N KCl (Mclean, 1965).

Data recorded from crops and soils were analyzed to evaluate treatment effects on soil properties and productivity improvement, using the analysis of variance (ANOVA) method (Gomez, Gomez, 1984). The treatment means were compared, using the Duncan's multiple range test. The correlation between crop yields and soil parameters (pH, Ca^{2+}, C, SB—sum of bases—P and Al^{3+}) were calculated, using SAS computer programme.

RESULTS AND DISCUSSION

Soil properties in the trial plots

Data on soil characteristics at the end of the experiment are shown in **table 3**. Changes in soil properties were highly significant (p = .01) for pH, organic carbon, phosphorus, bases, aluminium and CEC. Liming over years (September 1984, 1986, 1988 and 1990), i.e., 8 t per ha of lime in 8 years raised the pH to 7.5 in T7. Addition of manure annually applied until August 1990 bore slight but significant increase on the soil pH: from 4.5 in control plot to 4.9 in T6 (data not shown).

Lime efficiency in increasing soil pH was possibly due to the texture of the soils which was recorded as sandy clay (IRAZ, 1990) with a low soil organic matter content (≤ 2.4 %). The soil also has a udic-ustic isothermic regime (van Wambeke, 1982) and the ratio of ETP (potential evapotranspiration) to rainfall in the region varies between 0.5 and 1.0 (Gasana, 1991). These conditions reduce mineral hydrolysis and cation leaching which accelerate soil mineral dissolution and soil acidification (Thomas, Hargrove, 1984). However, high Ca^{2+} level in T7 plots could saturate soil site exchange and result in K^+ and Na^+ cation leaching losses (Duchaufour, 1977). After one application of lime at 2 t per ha in 1990, the plots for treatments T4, T5 and T6 recorded pH values of 5.4 to 5.6 (**Table 3**) which are normally suited to good crop production (Gillman *et al.*, 1989; Sys, 1989; Tan, 1993). In the plots for treatments T2 and T3 where a low rate of manure had been applied, the pH values remained below 5.2 and the Al^{3+} content was higher than 0.5 meq per 100 g of soil. This means that one or two lime applications should be needed, according to the quantity of manure already applied.

Addition of manure, lime and NPK improved soil organic carbon content from 1.2 in the control to 1.9 % in T5. The carbon content increase was due to the manure addition and the crop biomass (litterfall and roots). Such improvement on soil organic matter has been reported by Woomer and Swift (1994) and Kapkiyai (1994).

The low C value in control plots can be justified by the absence of or scarce vegetation growth and by the mixture of soil horizons with high (0–10 cm) or low (10–20 cm) levels of organic matter. Tillage also increases mineralization rate (Ismail *et al*., 1994) and hence may have reduced the organic matter content in

Table 3. Soil properties in August 1992 (values are means of 3 replicates) — *Propriétés du sol en août 1992 (moyennes de 3 répétitions).*

Treatment	**pH** (water)	**pH** (KCl)	**Organic C** (g/kg)	**Total P** (mg/kg)	**Assimilable P** (mg/kg)
T1	4.5 a*	3.5 a	12 a	75	6 a
T2	4.9 b	3.7 b	14 b	99	17 b
T3	5.1 c	3.8 b	17 c	112	22 b
T4	5.4 d	4.1 c	18 c	126	37 c
T5	5.6 e	4.3 d	19 d	176	20 b
T6	5.5 de	4.2 c	18 c	118	39 c
T7	7.5 f	6.5 e	19 d	102	11 a
Cv %	1.8	3.2	7.1	nd	15.7
LSD (.05) treatment	0.18	0.20	2.0	nd	6

Treatment	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**Na^{+}**	**SB**	**CEC**	**A1^{3+}**
	(meq/100g soil)						
T1	0.6 a	0.1	0.1 a	tr	0.8 a	4.5 a	2.7 d
T2	2.6 b	0.1	0.2 a	tr	2.9 b	5.0 a	0.8 c
T3	3.8 c	0.2	0.4 b	tr	4.4 c	5.1 a	0.8 c
T4	4.4 d	0.2	0.7 c	tr	5.3 d	6.1 b	0.5 b
T5	4.5 d	0.1	0.9 d	tr	5.5 d	6.5 b	0.0 a
T6	4.3 d	0.4	0.9 d	tr	5.6 d	6.8 b	0.2 a
T7	11.5 e	1.0	0.3 ab	tr	12.8 e	12.9 c	0.0 a
Cv %	5.2	nd	15.8	nd	5.8	12.0	21.8
LSD (.05) treatment	0.4	nd	0.14	nd	0.5	1.5	0.3

* Means with the same letters in the column are not significantly different; Cv = coefficient of variation; LSD = least significant difference; nd = not determined; SB = sum of exchangeable bases; tr = trace.

the bare plots. The plots for treatment T2 received a low rate of manure and showed less crop productivity (see later, **tables 6 and 7**). The high C content (1.9%) and poor crop performance in presence of lime (T7) may have been due to low micro-organism activity in a nutrient-imbalanced soil (Adams, 1984). Assimilable P was low in control and T7 plots. It increased in the plots of other treatments, where mineral or organic P was applied.

Exchangeable bases were low at 0.8 meq/100g of soil in control plots (**Table 3**), and this indicates a possibility of deficiencies to crops (Sys, 1989; Tan, 1993). All the treatments (T2 to T7) increased the exchangeable base content (from 2.9 to 12.8 meq/100 g) in the soil (**Table 3**). Although the treatments T5 and T6 provided more CaO (4.7 t·ha^{-1}) to the soil than T7 (3.1 t·ha^{-1}) in 8 years (**Table 4**), the treatment T7 was however more efficient in raising both the soil pH and Ca^{2+} content. This was probably due to the direct and rapid contact of CaO from lime with the soil than the CaO added in combination with farmyard manure which may have formed organic complexes upon being incorporated into the soil. The K^{+} level was low in T2 and T7 plots which received less or no farmyard manure. The Mg^{2+} content was too low compared to the K^{+} level in T1 to T6 plots (see cations ratio in **table 5**). Such a situation where Mg^{2+} deficiency is induced is inadequate to agriculture (Boyer, 1982; Sys, 1989). The annual amount of 51 kg MgO applied in the T2 plots and that applied at the rate of 423 kg MgO in T5 and T6 (**Table 4**) may have been taken up by the crops and removed through the biomass harvest.

The low CEC (4 meq to 5 meq/100 g of soil) of the soil (**Table 1**) has been increased by manure and by lime which was applied in September 1990 (T1 to T6) or by lime alone regularly applied (T7). The increase in CEC by organic matter addition to soils with variable charge has also been reported by Gillman *et al*. (1989) but was small because in acid soils with high levels of exchangeable aluminium, organic matter finds difficulty to less or has no ability to improve soil CEC (Thomas, Hargrove, 1984; van Wambeke, 1995). Haïlé *et al.* (1985), Sanchez and Uehara (1980), Gillman *et al*. (1989) and Gupta *et al*. (1989) reported an increase in CEC due to liming in acid soils with a high Al^{3+} content. Improvement of CEC is also dependent on temperature, soil humus content, soil texture, status of the soil solution (Garrison, 1989) and pH value (Thomas, Hargrove,

Table 4. Total nutrient applied (t·ha^{-1}) with different treatments during the experimental period. Nutrient amount is estimated from mean nutrient content of applied fertilizers. It includes available and non-available forms — *Quantités totales d'éléments nutritifs (t·ha^{-1}) apportés par les différents traitements durant les huit années de l'essai.*

Treatment	N	P_2O_5	K_2O	CaO	MgO
T1	0	0	0	0	0
T2	1.0	1.0	1.4	1.2	0.4
T3	1.2	1.2	2.0	1.7	0.8
T4	1.6	1.6	3.1	2.7	1.6
T5	1.7	1.6	4.8	4.7	3.4
T6	2.5	2.4	5.6	4.7	3.4
T7	0.8	0.8	0.8	3.1	0.3

Table 5. Base and Al^{3+} saturation, and cation ratios of the soils at the end of the experiment — *Taux de saturation en bases, pourcentage d'Al^{3+} échangeable et rapports cationiques des sols soumis aux différents traitements, à la fin de l'expérimentation.*

Treatment	Base sat. (%)	Al^{3+} sat. (%)	Ca^{2+}/Mg^{2+}	Mg^{2+}/K^+	$(Ca^{2+}+Mg^{2+})/K^+$
T1	12	40	6	1.0	7
T2	45	12	26	0.5	14
T3	88	16	19	0.5	10
T4	88	9	22	0.3	7
T5	92	0	45	0.1	5
T6	92	3	11	0.4	5
T7	99	0	12	3.0	42

1984; van Wambeke, 1995). Abiotic and biotic parameters experienced at the experimental site were unfavourable for improvement of CEC in the control plots.

Control plots had a low base saturation (12%) coupled to a high (40%) exchangeable aluminium saturation (**Table 5**). Treatments T2 to T7 increased the base saturation and gradually reduced the exchangeable Al saturation to a neutral level with the maximum level of lime application (T7). Similar observations were reported by Hue *et al*. (1986), James *et al*. (1983) and Gillman *et al*. (1989). However, it is known that addition of a small amount of inorganic nutrients in a soil with low level of CEC increases the base saturation rate, but this does not necessarily mean that a sustainable and high agricultural productivity of the soil has been achieved.

Crop yield

Grain yield for maize and beans from 1987 to 1993 are presented in **tables 6** and **7** respectively. A significant ($p \leq .05$) increase of yield for the two crops was recorded where fertilizers were applied. No harvest was obtained from the control plots and this was possibly due to the nutrient depletion coupled to the high exchangeable Al in this soil as reported by Wey *et al*. (1987) in Senegal and Morrison *et al*. (1989) in Fiji. Addition of fresh manure alone at a rate of 35 t per ha (T5) provides sufficient nutrients (Rutunga, Neel, 1980), but these high rates are not applicable to most of smallholder farmers (Andreae, 1980). Yields obtained with this high rate (T5) were almost equal in the plots where a combination of lime, mineral fertilizer and farmyard manure at 10 t dry matter per ha (T4) were applied. In these two treatments, the amount of nutrient applied was almost the same (**Table 2**).

Although the application of fertilizers increased the yields of maize and beans from 1986 to 1990, the effect was still limited and the crop yields were low compared to the average potential yields of 2.5 t maize grains per ha and 1.2 t bean grains per ha reported by ISAR (unpublished data). This was possibly due to environmental constraints such as water deficiency, high Al^{3+} levels and mineral nutrient imbalances. After liming all plots (except for the control) in 1990, the yields of the two crops were raised in plots with manure alone or combined with NPK. The effect of the rate of manure on crop yield from 1986 to 1992 was statistically significant. The total removal of the above ground crop residues from the plots and the leaching losses might have been the main cause of the low nutrient replenishment in the soils during the period of the experiment.

Correlation between grain yields and soil chemical properties

Correlation data are shown in **table 8**. A high positive correlation ($r \geq .83$) was found between maize or bean grain yield and Ca^{2+}, total C, sum of bases and P in the soil. This confirmed the fact that the larger the nutrient content of the soil, the better the plant growth and yield (Smalling, 1993). The good yields in September 1990 season were due to the liming which suppressed aluminium toxicity.

The soil calcium and base content were positively correlated with pH in water. This indicates that the level of base saturation has positive influence on soil pH (Tan, 1993). Calcium, exchangeable bases and pH correlated positively with soil organic C. The reason is that a raise of those soil parameters improves crop growth and consequently litterfall and root biomass which increase soil organic matter content (**Table 3**). However, pH, exchangeable Ca, SB and Al^{3+} were only correlated with crop yield when treatment T7 was excluded. This indicates the positive effect of liming

Table 6. Maize grain yield (t·ha^{-1}) from September 1986 to September 1991 — *Rendements en grain pour le maïs (t·ha^{-1}) de septembre 1986 à septembre 1991.*

Treatment	**Sep 86**	**Sep 87**	**Sep 88**	**Sep 89**	**Sep 90**	**Sep 91**
T1	0 a*	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
T2	0.8 b	0.9 b	1.0 bc	0.8 bc	1.3 c	1.0 c
T3	1.0 c	1.1 c	1.2 c	0.9 bcd	1.5 cd	1.1 c
T4	1.3 d	1.3 d	1.3 cd	1.1 d	1.9 e	1.5 d
T5	1.2 d	1.1 c	1.1 bc	1.0 cd	1.7 de	1.5 d
T6	1.5 e	1.6 e	1.5 d	1.4 e	2.4 f	2.1 e
T7	0.9 bc	1.1 c	0.9 b	0.7 b	0.7 b	0.6 b
Cv %	11.0	11.0	15.2	21.1	13.8	15.0
LSD (.05)	0.2	0.2	0.3	0.3	0.3	0.3

* Means with the same letters in the column are not significantly different; Cv = coefficient of variation; LSD = least significant difference.

Table 7. Bean grain yield (t·ha^{-1}) from February 1987 to February 1992 — *Rendements en fèves pour le haricot (t·ha^{-1}) de février 1987 à février 1992.*

Treatment	**Feb 87**	**Feb 88**	**Feb 89**	**Feb 90**	**Feb 91**	**Feb 92**
T1	0.0 a*	0.00 a	0.0 a	0.00 a	0.0 a	0.0 a
T2	0.4 b	0.40 b	0.5 b	0.20 b	0.6 c	0.8 c
T3	0.5 c	0.60 c	0.6 bc	0.37 c	0.8 d	0.9 c
T4	0.6 d	0.70 c	0.7 cd	0.50 cd	1.1 e	1.3 d
T5	0.6 d	0.73 cd	0.7 cd	0.47 c	1.1 e	1.4 d
T6	0.7 e	0.87 d	0.8 d	0.63 d	1.3 f	1.3 d
T7	0.5 c	0.67 c	0.5 b	0.40 c	0.3 b	0.3 b
Cv %	14.6	16.5	18.9	24.0	13.8	15.9
LSD (.05)	0.1	0.17	0.2	0.16	0.3	0.2

* Means with the same letters in the column are not significantly different; Cv = coefficient of variation; LSD = least significant difference.

Table 8. Correlation values (r) between crop grain yield and soil chemical properties (after exclusion of treatment T7) — *Coefficients de corrélation (r) entre les rendements et différents paramètres de propriétés chimiques du sol (le traitement T7 n'est pas pris en compte).*

	pH water	**Ca**	**C**	**SB**	**P**	**Al**
Bean	0.92	0.97	0.81	0.98	0.83	- 0.95
Maize	0.86	0.92	0.83	0.94	0.87	- 0.93
pH water		0.89	0.89	0.99	0.74	- 0.67
Ca			0.90	0.98	0.74	- 0.94
C				0.91	0.71	- 0.83
SB					0.80	- 0.92
P						- 0.71

(T2 to T6) and the negative effect of overliming (T7) on soil nutrient balance (Gillman *et al*., 1989) and productivity. Al^{3+} content was highly and negatively correlated to crop yield, Ca^{2+} and SB. This showed the importance of high exchangeable aluminium content, nutrient deficiencies or Al-induced nutrient deficiencies in limiting the crop production in acid soils (Adams, 1984).

CONCLUSION

Non-humiferous acid Oxisols developed in the semi-humid "Plateau Central" region of Rwanda have a high exchangeable Al content and low productivity. The Al^{3+} should be neutralized before any improvement of maize and bean production is expected. The current moisture and temperature regimes (Udic/ustic isothermic) in these soils may lead to a moderate intensity of soil mineral hydrolysis. Thus, 2 t per ha of lime applied every two years over a period of 8 years raised the soil pH, Ca^{2+}, CEC significantly, and neutralized exchangeable Al in the soils. Soils were however overlimed and were unsuitable to good crop production. One liming at a rate of 2 t per ha or perhaps better liming at first and third year would be enough. Application of NPK (twice a year) and /or manure (annually) has a positive effect on crop production but application of 10 t manure per ha (dry matter basis) seems to be the minimum amount required to substitute for inorganic fertilizers. These ten tons of manure contain on average 51 kg N, 48 kg P_2O_5 and 145 kg K_2O. With the removal of all above ground crop biomass at the harvesting period, the annual application of up to 35 t per ha of manure alone or combined with seasonal application of 300 kg NPK during a 6 year period raised the pH (from 4.5 to 5.0). These observations imply that use of organic manures alone would not be adequate in neutralizing the high exchangeable Al found in very strong acid soils.

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