Reclamation of an acidic soil of Rwanda's central upland by composts based on natural vegetation biomass

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Abstract

A study on total acidity reduction and the exchangeable aluminium neutralization by composts made from natural vegetation biomass was carried out on an acidic soil of Rwanda. The initial soil analysis showed that the average pH_W *(pH measured in water) was 4.4; the average concentration of exchangeable Al and the total acidity were respectively 3.70 and 4.45* $cmol_c.kg^{-1}$ *of soil. Five types of composts and* $NPK_{17\text{-}17\text{-}17}$ *fertilizer were applied to the soil under a* ***split-plot*** *experimental design. Two doses of composts (30 and 60* $t.ha^{-1}$*) were applied while the NPK fertilizer was applied to a dose of 300* $kg.ha^{-1}$*. The experiment lasted two years and four samplings were carried out to evaluate the impact on pH, exchangeable aluminium and total acidity. The results at the end of two years show that the* pH_W *increased by 0.2 units with only the application of the compost at the beginning of the experiment at a dose of 60* $t.ha^{-1}$*. In addition, the results show that the pH remained low in the control plots and those received NPK. After only five months, the* Al^{3+} *was reduced of 32 and 53 % respectively with 30 and 60* $t.ha^{-1}$ *of compost. At the end of the two years of experimentation, the concentration of* Al^{3+} *increased again but without reaching the initial level except for the plots treated with the mineral manure NPK. The same trend was observed for the case of the exchange total acidity.*

Keywords: *acidic soil, compost, exchangeable aluminium, soil pH, Rwanda*

Résumé

Une étude de la réduction de l'acidité totale et de la neutralisation de l'aluminium échangeable par les composts fabriqués à base de biomasse des espèces végétales naturelles «sauvages» a été réalisée sur un sol acide du Rwanda. L'analyse de sol au laboratoire à l'état initial révèle que le pH moyen du sol du site mesuré à l'eau est de 4,4; les teneurs moyennes de l'aluminium échangeable et de l'acidité totale d'échange sont respectivement de 3,70 et 4,45 $cmole_{(+)}.kg^{-1}$ *de sol. Cinq types de composts et un engrais minéral* $NPK_{17\text{-}17\text{-}17}$ *ont été appliqués au sol sous un dispositif expérimental en* ***spli-plot****. Deux doses de compost ont été administrées (30 et 60* $t.ha^{-1}$*), alors que l'engrais NPK a été apporté à la dose de 300* $kg.ha^{-1}$*. L'essai a duré deux ans et quatre échantillonnages ont été effectués le long de l'expérimentation pour évaluer l'impact sur le pH, l'acidité totale d'échange et l'aluminium échangeable. Le bilan au terme de deux ans montre que le pH mesuré à l'eau augmente de 0,20 unité avec une application unique de compost effectuée au début de l'essai à la dose de 60* $t.ha^{-1}$*. En plus, les résultats montrent que le pH reste bas dans les parcelles témoins et celles amendées au NPK. Après seulement cinq mois, la teneur en* Al^{3+} *avait été réduite de 32 et de 53 % respectivement avec les doses de 30 et de 60* $t.ha^{-1}$ *de compost. Au bout de deux ans ces teneurs ont augmenté de nouveau mais sans atteindre le niveau obtenu à l'état initial sauf pour les parcelles traitées avec l'engrais minéral NPK. La même tendance s'observe pour le cas de l'acidité totale échangeable.*

Mots clés : *Sols acides, compost, aluminium échangeable, pH du sol, Rwanda.*

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1. Introduction

The pedogenesis in the humid tropical regions has particularities in the sense that the soil formation factors help to a rapid degradation. The high temperatures, the intense precipitations and the nature of the bed-rock lead to a formation of soils often poor and highly weathered. The leaching of fine elements (clays, mineral particles and organic matter) make the upper horizons have a low cation exchange capacity (Ulrich, 1991). The minerals that remain dominants in that case are Fe and Al sesquioxydes and kaolinite (Duchaufour, 1993; Voundi Nkana, 1998). Basic cations that are removed from the complex are replaced by the protons H+ coming from the degradation of some minerals and the nitrification of ammoniacal nitrogen in the soil. The H+ ion that is produced can in turn react with the minerals to mobilize Al in the soil (Rowell, 1994; Ponette *et al.* 1996). This reaction produces an important quantity of H+ and exchangeable Al3+ ions while the soluble products are washed out. This phenomenon is considered as responsible of soil acidification in the humid tropical regions including Rwanda (Mutwewingabo, 1984; Rutunga, 1997, Brady and Weil, 2002, Wong and Swift, 2003).

Also most of Rwanda's bed-rocks such as granite, gneiss and sandstone naturally lead, in particular conditions, to acid soils (Duchaufour, 1993). The high exchangeable Al^{3+} concentration constitutes the main limiting factor of acidic soils productivity in Rwanda (Vander Zaag, 1982, Vander Zaag *et al.*, 1984, Yamoah *et al.*, 1990).

The traditional practice used to reduce the soil acidity in Rwanda is the liming. Other mineral fertilizers and amendments are also used to maintain the yield on acidic soils but their impact on the soil life is still ephemeral and sometimes contributes to the degradation of soils, which make them vulnerable to the erosion. In fact, the addition of nitrate fertilizers for instance on degraded soils push the micro-organisms to consume the little of organic matter stock available in the soil and induce an unbalance of the ratio C/N while there exists numerous vegetable species who better exploits tropical poor soils and which may be developed as organic amendment source (compost, green manure, mulch, etc.).

Recent studies have shown that certain wild plant species grown on degraded soils of Rwanda have an important fertilizer potential (Reck, 1995; Bizimana and Zaongo, 2000; Mbonigaba *et al.,* 2002a; Musabyimana *et al.*, 2002; Drechsel *et al.*, 1998) compared to mineral fertilizer. Their recycle in the form of composts have also shown positives impacts relatively durable on soils physical, chemical, and biological properties (Anid, 1983; Epstein, 1997; Prosser, 1997; Mbonigaba *et al.*, 2002b).

Table 1: N, P, K, Ca and Mg levels in some wild plant species biomass grown on poor soils in the central upland zone of Rwanda (Bizimana and Zaongo, 2000).

	N	*P*	*K*	*Ca*	*Mg*
Species			*(%)*		
Tithonia diversifolia	*4,5*	*0,4*	*3,4*	*2,4*	*0,4*
Lantana camara.	*4,1*	*0,4*	*1,7*	*1,0*	*0,4*
Sebania Sesban	*3,6*	*0,2*	*1,2*	*1,5*	*0,2*
Sena spectabilis	*3,3*	*0,2*	*1,2*	*1,2*	*0,2*
Tephrosia vogelii	*3,3*	*0,3*	*1,2*	*1,3*	*0,2*
Calliandra calothyrsus	*3,2*	*0,2*	*0,6*	*1,3*	*0,5*
Desmodium intortum	*3,1*	*0,3*	*2,2*	*1,2*	*0,4*
Albizia facatalia	*2,7*	*0,1*	*0,4*	*2,5*	*0,4*
Tecoma stans	*2,7*	*0,3*	*1,6*	*1,2*	*0,3*
Acacia mearnsii	*2,6*	*0,1*	*0,4*	*1,0*	*0,2*
Mimosa scabrella	*2,4*	*0,2*	*0,4*	*1,4*	*0,2*
Jacaranda mimosaefolia	*2,3*	*0,2*	*0,7*	*0,8*	*0,3*
Flemingia macrophylla	*2,1*	*0,2*	*0,8*	*0,9*	*0,2*
Alnus nepalensis	*2,1*	*0,1*	*0,4*	*1,8*	*0,2*

Most of those wild plant species that grow on poor soils, have a deep root system that allow them to take mineral nutrients from the deep layers and then bring them to upper organs such as the stem, leaves and flowers (vertical transfer). The recycle of that foliar biomass after composting gives back the mineral nutrients in the arable layers exploited by the crops in addition to the reconstitution of the organic matter stock (humus), hence a sort of horizontal transfer of fertility.

Once applied to the soil, the compost provides not only the humus for the soil restructuration, but also the mineralization releases mineral nutrients of plants whose certain cations replace the Al^{3+} and H^+ on the exchange complex.

The research consists then to try to increase the value of numerous wild plant species by compost production based on their biomass, which composts may be used for acidic soils reclamation and therefore the growth of crops yield.

From what was said above, there are few quantifiable data, in the case of Rwanda in particularly and of tropical soils in general, on the impact of the compost on the soil total acidity reduction at medium and long term.

This study was carried out with different composts compared to the mineral fertilizer $NPK_{17-17-17}$ and the process was observed over two years. Different parameters of soil fertility were taken into account but this paper has particularly focused on the pH, total acidity and exchangeable aluminium.

2. Materials and methods

2.1. Experimental site

The site used for the experiment is a strip set up on terrace and located on the bottom/foot of Tonga hill in an experimental station of the Faculty of Agriculture/National University of Rwanda. The last time that this site was used for crop production is in 1992-1993. The region under study is located at 1.700 m of altitude and its geographical position is at S 2° 35' 2,8" and E 29° 43' 43,1". The soils in this regions are well known for their acidity, the pH varies form 4.3 to 5.1; the exchangeable Al and the total acidity vary respectively from 3 to 4 $cmol_c.kg^{-1}$ and from 3.5 to 4.5 $cmol_c.kg^{-1}$ depending on plots under study (Chapelle, 1985; Mbonigaba *et al.* , 2002b).

In the state of fallow the soil is covered by several wild plants among others are the species such as *Lantana camara* L., *Titonia diversifolia* (Hemsley) A. Gray, *Acantus pibescens* Thomson ex Oliv., *Eragrostis* sp., *Digitaria abyssinica* Hochst. ex A. Rich., *Bidens pilosa* L., *Galisoga* sp., *Clerodendrum* sp. *and Vernonia amygdalina* Del.; who, until few years, where not used in any farming activities.

2.2. Experimental design and statistical analysis

A split-plot experimental design was used in this study. This design allowed to assess the degree of interaction between two factors: the factor "dose" and the factor "type of fertilizer" or "treatment". The factor "dose" considered as main factor, is composed of two varied doses of compost while the factor "type of fertilizer", considered as secondary factor, had five types of compost, inorganic manure (NPK) and a control.

The experiment was repeated three times and each repetition (bloc) had 14 pixels that comprised 7 from the dose 1 and 7 from dose 2, which come to a total of 42 plots. The different treatments were randomized in the three repetitions. The size of each single plot was 16 m^2 .The two doses of compost used were 30 $t.ha^{-1}$ and 60 $t.ha^{-1}$; the NPK $_{17-17-17}$ was applied at the rate of 300 $kg.ha^{-1}$. The corn, beans and carrots were used as plant-test. The analysis of variance (ANOVA) was realised by MSTAT-C software (Michigan State University, version 2.10) and the means ranking was done by Duncan's Multiple Range Test.

2.3. Sampling and soil analytical methods

The soil samples were picked with appropriate tools (drill) at 5 different places of each plot and at 30 cm of depth. Then the soil was perfectly mixed to form one composite sample representative of the plot for chemical analyses.

The soil pH_W and pH_{KCl} (1 N) were measured by potentiometric method in a suspension of soil-solution at the ratio 1:2.5; the exchangeable acidity was determined by the titrimetric dosage of ions H^+ and Al^{3+}. Those ions were measured together with the NaOH 0.01 N. The solution obtained was then removed with HCl 0.01 N after the formation of a complex of Al by NaF 4 % to determine the exchangeable Al. The exchangeable hydrogen was found by subtraction of the Al from the total acidity.

2.4. Chemical characterization of the composts used

The composts used in the experiment were made mainly from natural vegetation biomass harvested on ground. In the purpose of varying the composition of different composts, other organic materials were added and the methods of composting were diversified. The characteristics given in the table 2 are those of the composts during the sixth month of decomposition.

Table 2: Physico-chemical and chemicals characteristics of used composts

	pH_W	TOC	$N_{org.}$	NH_4^+	NO_3^-	C/N	K_{tot}	Ca_{tot}	Mg_{tot}	Na_{tot}	P_{tot}	M_w	DM	Ashs
		...% DM...		...$mg.kg^{-1}$ RM...			................$mg.kg^{-1}$ RM.............					..........%...........		
C1	6,0	26,3	0,81	6,96	55,0	32	2290	7180	2940	640	1744	61	39	75
C2	6,1	37,8	1,1	3,80	12,0	34	3050	6650	2240	470	1114	66	34	66
C3	6,8	38,1	1,1	15,7	28,9	35	7240	7180	2190	600	1996	65	35	63
C4	7,6	35,8	1,3	11,9	19,5	27	8020	13480	5560	930	3235	67	33	69
C5	8,0	39,0	1,1	6,63	17,9	35	10050	10600	5670	1410	4554	64	36	64

** TOC- total organic carbon, M_w- moisture, RM- row matter, DM- dry matter.*

** C1- compost formed only by plant biomass prepared at the surface[BV(s)], C2- compost formed only by plant biomass prepared in pit[BV(p)], C3- compost formed by plant biomass (80%) + household refuse (20%) prepared at the surface[BV+OM(s)], C4- compost formed by plant biomass (50%) + household refuse (25%)+ cow manure (25%) prepared at the surface[(BV+OM+F(s)], C5- compost formed by plant biomass (70%) + cow manure (30%), prepared at the surface [BV+F(s)].*

2.5. Steps and length of the study

The study was carried out on a period of 2 years. The first soil sampling and the first sow have taken place on July 2001. The harvest of the first trial and the second soil sampling were done in November 2001. The same field was farmed 11 months later, meaning the first 2002 crop season. During that period the third soil sampling was made. The harvest of the second trial occurred in February 2003, followed by the last soil sampling in March

2003. The same plant-test were used during the second trial, but crops were interchanged to occupy different positions in each single plot, from the ones they occupied in the previous trial.

2.6. Field characteristics at the initial state

The site acidity level at the initial state of the experimentation is illustrated in the table 3.

Table 3: Level of acidity in the field at the initial state. The data are means for the 42 plots.

	pH			Total acidity (cmol$_c$.kg^{-1} of soil)		
Replication	KCl	H_2O	ΔpH	Total	Al^{3+}	H^+
I	3,8	4,3	-0,49	4,39	4,16	0,23
II	3,9	4,4	-0,46	3,62	3,33	0,29
III	3,9	4,4	-0,48	4,00	3,63	0,37
Mean	3,9	4,4	-0,48	4,45	3,70	0,29

2.7. Rainfall during the experimental period

Table 4: Rainfall recorded during the composting and first cultural trial period (data from PASI station- Ruhande/Butare).

	Rainfall (mm)											
	Jan.	Feb.	Ma	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2000	-	-	-	-	-	-	-	0,00	12,3	93,3	196	142
2001	160	147	190	190	61,4	16,7	140	55,5	180	136	159	-
Total for the experimental period (mm) : 1879,2												

3. Results and discussion

3.1. Results presentation

The tables 5 and 6 gives respectively the analysis of variance and the means ranking according to the treatment factor for the pH$_W$, Al^{3+} and total acidity (Al^{3+}+H^+) parameters at the first crops harvest (2nd sampling).

The means values analysis of variance of pH$_W$ and the total acidity (Al^{3+}+H^+) within the plots at the first crop harvest shows that there is a significant difference at 5 % threshold for the factor "treatment", but not for the factor "dose" and "the interaction" between the two factors (table 5). With regard to Al^{3+}, the significance difference is observed only for the factor "treatment" and for the "interaction" between the two factors considered.

The table 6 illustrates the means ranking by Duncan's multiple range test at 5 % threshold according to treatments applied on the soil. The means values of the pH_W, Al^{3+} and total acidity (Al^{3+}+H^+) form respectively 6, 2 and 2 homogeneous groups with the $LSD_{0,05}$ values of 0,148; 0,608 and 0,702.

Before the second site farming, the third sampling was made. Analysis results are recorded in the table 7.

Table 5: Analysis of variance table for pH_W, Al^{3+} and (Al^{3+} + H^+) at the first crops harvest

	Sources of variation	DF*	Sum of squares	Mean squares	F value	Probability	
pH_W	Replication	2	0,004	0,002	0,0476		C.V** : 2,59% G.M***: 4,530
	Dose (factor A)	1	0,070	0,070	1,7493	0,3169	
	Error A	2	0,080	0,040			
	Treatment (factor B)	6	0,526	0,088	8,1159	0,0012	
	Error B	12	0,130	0,011			
	Dose & treatment (AB)	6	0,093	0,016	1,1301	0,4017	
	Error C	12	0,165	0,014			
	<u>Total</u>	41	1,067				
Exchangeable Al	Replication	2	0,582	0,291	0,6097		C.V : 9,59% G.M : 2,670
	Dose (factor A)	1	1,509	1,509	3,1582	0,2175	
	Error A	2	0,955	0,478			
	Treatment (factor B)	6	20,365	3,394	18,3414	0,0000	
	Error B	12	2,221	0,185			
	Dose & treatment (AB)	6	2,555	0,426	6.4984	0,0030	
	Error C	12	0,786	0,066			
	<u>Total</u>	41	28,973				
Total acidity	Replication	2	0,766	0,383	0,3950		C.V : 13,08% G.M : 3,280
	Dose (factor A)	1	2,981	2,981	3,0766	0,2215	
	Error A	2	1,938	0,969			
	Treatment (factor B)	6	25,284	4,214	17,0762	0,0000	
	Error B	12	2,961	0,247			
	Dose & treatment (AB)	6	2,836	0,473	2,5663	0,0777	
	Error C	12	2,210	0,184			
	<u>Total</u>	41					

** DL- Degree of Freedom, **C.V.- Coefficient of variation, ***G.M.- Grand mean*

Table 6: Means comparison for pH, Al^{3+} and (Al^{3+} + H^+) according to "treatment" factor at the first crop harvest (Duncan's multiple range test).

pH_W		(Al^{3+})		$(Al^{3+} + H^+)$	
Treatment	Mean	Treatment	Mean	Treatment	Mean
BV+OM+F(s)	4,63a*	To	3,775a	NPK	4,555a
BV+F(s)	4,63a	NPK	3,762a	To	4.000a
BV(p)	4,60a	BV(f)	2,298b	BV(f)	2,962b
BV(s)	4,59a	BV+OM(s)	2,292b	BV+OM(s)	2,880b
BV+OM(s)	4,54ab	BV+OM+F(s)	2,235b	BV+OM+F(s)	2,775b
NPK	4,39bc	BV(s)	2,202b	BV(s)	2,760b
To	4,33c	BV+F(s)	2,130b	BV+F(s)	2,592b
$LSD_{0,05}$**: 0,148		$LSD_{0,05}$: 0,608		$LSD_{0,05}$: 0,702	

*Means values followed by different letter (s) are significantly different ($P < 0,05$)
**LSD- Least significant difference

Table 7: pH and exchange acidity within plots before the second site farming. Values are means of each treatment in the three replications.

	Composts at 30 $t.ha^{-1}$					Composts at 60 $t.ha^{-1}$				
	pH		Exchange acidity $cmol_c.kg^{-1}$			pH		Exchange acidity $cmol_c.kg^{-1}$		
Treatment	H_2O	KCl	Al^{3+}	H^+	Total acid.	H_2O	KCl	Al^{3+}	H^+	Total acid.
To	4,3	3,9	3,87	0,96	4,83	4,3	3,9	3,78	1,05	4,83
BV+F(s)	4,4	4,1	2,69	0,95	3,64	4,5	4,2	2,26	0,80	3,06
NPK	4,3	3,9	3,84	1,08	4,92	4,3	3,8	3,82	1,03	4,85
BV+OM+F(s)	4,4	3,9	2,91	1,40	4,31	4,6	4,1	2,59	0,87	3,46
BV+OM(s)	4,3	3,9	2,89	1,32	4,21	4,6	4,0	2,29	1,11	3,40
BV(p)	4,6	4,0	2,61	1,43	4,09	4,4	4,1	2,54	0,94	3,39
BV(s)	4,5	3,9	2,86	0,84	3,70	4,4	4,0	2,36	1,32	3,68

The tables 8 and 9 gives respectively the analysis of variance and the means ranking (according to the treatment factor) for the pH_W, Al^{3+} and (Al^{3+}+H^+) parameters at the second crops harvest (4th sampling).

Table 8: Analysis of variance table for pH_W, Al_{3+} and (Al^{3+} + H^+) at the first crops harvest.

	Source of variation	DF	Sum of squares	Mean squares	F value	Probability	
pH_W	Replication	2	0,021	0,011	1,5129	0,3979	C.V. : 1,97% G.M. : 4,339
	Dose (factor A)	1	0,300	0,300	42,2477	0,0229	
	Error A	2	0,014	0,007			
	Treatment (factor B)	6	0,207	0,034	3,3520	0,0354	
	Error B	12	0,123	0,010			
	Dose & treatment (AB)	6	0,466	0,078	10,6136	0,0003	
	Error C	12	0,088	0,007			
	Total	41	1,219				
Exchangeable Al	Replication	2	1,032	0,516	1,4140	0,4142	C.V. : 15,13% G.M. :3,594
	Dose (factor A)	1	1,251	1,251	3,4303	0,2052	
	Error A	2	0,730	0,365			
	Treatment (factor B)	6	7,893	1,315	4,7692	0,0104	
	Error B	12	3,310	0,276			
	Dose & treatment (AB)	6	2,429	0,405	1,3695	0,3021	
	Error C	12	3,547	0,296			
	Total	41	20,192				
Total acidity	Replication	2	0,045	0,022	0,0916		C.V. : 8,49% G.M. : 4,165
	Dose (factor A)	1	1,652	1,652	6,7539	0,1216	
	Error A	2	0,489	0,245			
	Treatment (factor B)	6	9,412	1,569	9,8924	0,0005	
	Error B	12	1,903	0,159			
	Dose & treatment (AB)	6	2,0898	0,348	2,7849	0,0619	
	Error C	12	1,500	0,125			
	Total	41	17,089				

Table 9: Means ranking order for pH_W, Al^{3+} and (Al^{3+} + H^+) according to treatment factor at the second crop harvest (Duncan's multiple range test).

pH_W		(Al^{3+})		(Al^{3+} + H^+)	
Treatment	Mean	Treatment	Mean	Treatment	Mean
BV+OM+F(s)	4,48a*	NPK	4,430a	NPK	4,825a
BV+F(s)	4,38ab	To	3,998ab	To	4,775a
To	4,35ab	BV(s)	3,578bc	BV(s)	4,405ab
BV(p)	4,31b	BV+OM (s)	3,483bc	BV+OM (s)	4,020bc
BV+OM (s)	4,27b	BV(p)	3,323bc	BV+OM+F(s)	3,895bc
BV(s)	4,26b	BV+F(s)	3,250bc	BV(p)	3,672c
NPK	3,83b	BV+OM+F(s)	3,095c	BV+F(s)	3,560c
$LSD_{0,05}$** : 0,141		$LSD_{0,05}$: 0,742		$LSD_{0,05}$: 0,563	

*Means values followed by different letter (s) are significantly different ($P < 0,05$)

**LSD- Least significant difference

The analysis of variance of the pH_W data obtained during the second crop harvest (4th sampling) shows a significant difference for the factors "treatment" and "dose" like for their "interaction" (table 8). About Al^{3+} and total acidity data, the same analysis reveals the significant difference only for the factor "treatment" (table 8). The means ranking according to the factor "treatment" at that 4th sampling reveals a range of answers divided into 3, 4 and 4 homogeneous groups, respectively for the pH_W, Al^{3+} and total acidity (table 9).

3.2. Results interpretation and discussions

Soil pH

To have a good production of staple crops, the soil pH measured in water has to be greater than 5.5 (Bonneau and Souchier, 1994). The average pH_W of the soil used in this study, at the beginning, was 4.4 (table 3); hence a strong acidity (Soltner, 1985). The figure 1 shows the evolution of the soil pH_W two years later after the application of compost and NPK manure.

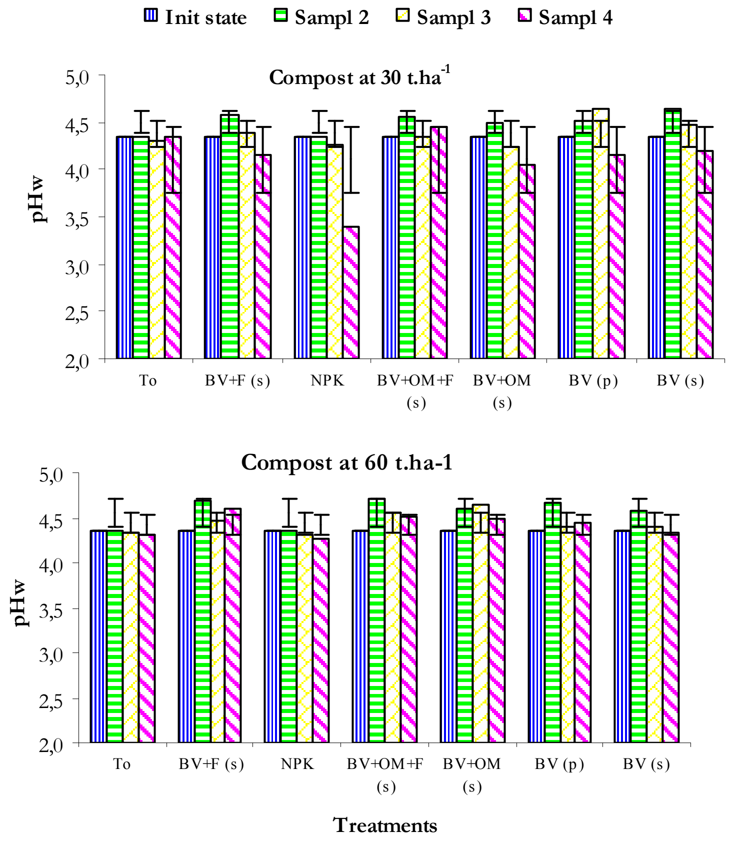

Figure 2. pH_W evolution according to treatments during the experimentation period. Error bars represent standard deviations.

In general, the figure shows that the organic fertilizers added to the soil slightly increased the soil pH; it is specifically at the dose of 60 t.ha^{-1} that we notice a big increase. To illustrate that, at the end of the first crop season, the pH_W measured in water showed an increase of 0.3 units in average in all the plots that have received 60 t.ha^{-1} of compost. The results after 2 years show that the pH_W has increased of 0.2 units with a single application of the compost done at the beginning of the study.

It is good to keep in mind that the composts used in this study came from natural vegetation biomass collected on the ground and consequently, those plant material were poor in mineral nutrients simply because the soil gives to the plant what is at its disposal; hence the justification of the horizontal transfer of fertility in addition of the vertical. That concept of horizontal transfer is illustrated here by the fact that there are composts that benefited from the addition of farm manure and/or household wastes that gave very interesting values of pH_W compared to those that were only made of vegetable biomass (figure 1). According to Wong and Swift (2003), the principal mechanisms involved in increasing soil pH by organic matter vary for the type of materials. Composts, manures, peat, and coal products are more stable to decomposition than undecomposed plant materials and contain humic-type substances. The functional groups of these humic substances confer metal binding and pH buffering capacities, which are important in determining the pH of the treated soil.

Until recently, one of the main problems encountered when considering the use of composts products to treat acid soils was their compositional variability. This meant that their acid-ameliorating properties were uncertain and the use of these materials for ameliorating acid soils was risky because of insufficient knowledge of the mechanisms involved and unpredictable benefits. The mechanisms postulated for explaining their effect on soil pH include specific adsorption of organic anions on hydrous Fe and Al surfaces and the corresponding release of hydroxyl ions (Hue, 1992; Hue *et al.*, 1986), proton consumption during reduction of metallic ions due to oxygen consumption during decomposition of composts, and ammonification of labile organic nitrogen in composts (Wong and Swift, 2003).

The histograms of the figure 1 show in addition that from the second year after application, the pH started to decrease until it reached the initial level and even less depending on places. This was due to the fact that the few bases released by the composts and that served to compensate the losses from the exportation and washing, started to deplete; hence the necessity to bring supplementary organic amendment.

Another important aspect to point out in this case is the compared decrease of pH in control plots and those received NPK mineral manure. In fact, the histograms show that the decrease is more rapid in the second case, which prove once again the problem of adding chemical fertilizers on the soils that have low cation exchange capacity (Mbonigaba *et al.,* 2002b, Russel *et al.*, 2006).

A biological explanation of this phenomenon was mentioned at the beginning of this paper. In fact, the addition of mineral manure that contain nitrogen creates an unbalance of the C/N ratio and the micro-organisms start consuming the little organic carbon that made up the clay-humus complex of the soil. Undoubtedly, this leads to the reduction of the cation exchange capacity and consequently to the reduction of the soil pH.

Exchangeable aluminium

Initially, the level of exchangeable Al of the site was 3.70 $cmol_c.kg^{-1}$ (table 3). That value stays logical since it was shown a longtime ago that the exchangeable Al was significantly and negatively correlated to the soil pH. The level of Al^{3+} considered as toxic for the majority of crops is 2 $cmol_c.kg^{-1}$ (Bertsch, 1983; Mutwewingabo et Rutunga, 1987).

The presence of aluminium under the exchangeable form (Al^{3+}) in the root zone influences the porosity of the cellular membrane of the plants roots and then limits the solutions movement, which impact negatively the relation water-plant and the uptake of mineral nutrients (Blamey and Dowling, 1995).

In acidic soils, the Al^{3+} is mobilized in the soil solution which influences negatively the plant growth, and in this case, to avoid those negative effects of exchangeable Al, Ingual *et al.* (1997) and Budianta (1999) suggested to eliminate Al^{3+} in the soil solution. In the same line, Wong and Swift (1995) have found that the presence of humic acids in the soil solution, as it appears in many tropical soils, reduces the aluminium toxicity. The organic matter from which come the humic acids can also be added on acidic soils as an amendment. The Adsorption of Al by organic matter sites and the subsequent dissolution of the inorganic phase to maintain the equilibrium Al activity in soil solution have also been postulated to increase soil pH (Wong *et al.*, 1998).

The figure 2 shows the behaviour of the exchangeable Al two years later after the application of the compost at different doses (30 and 60 t.ha^{-1}).

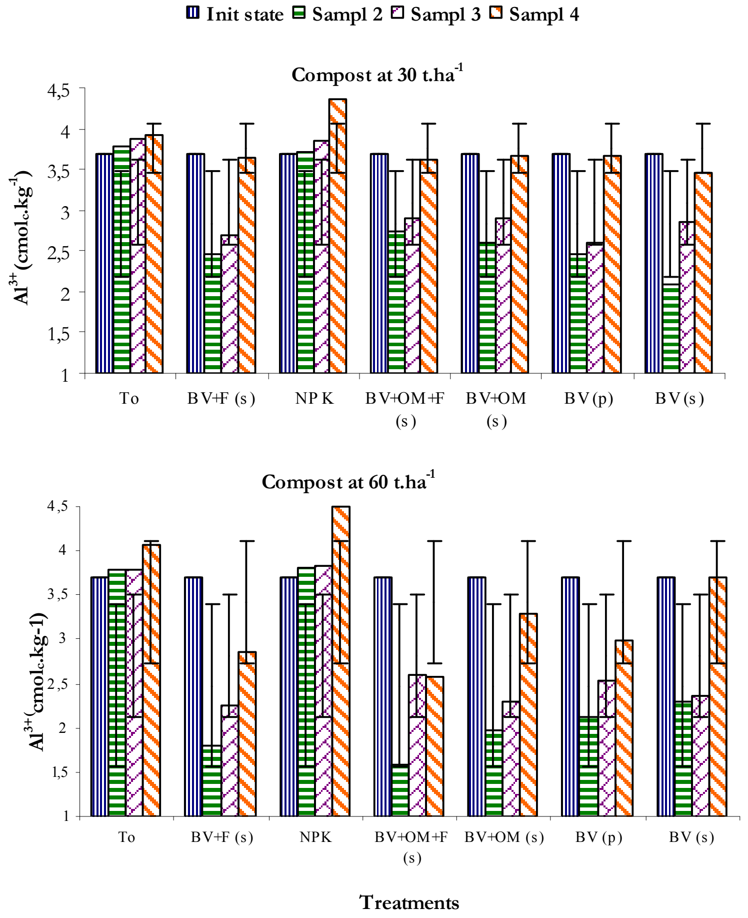

Figure 2: Exchangeable aluminium evolution according to treatments during the experimentation period. Error bars represent standard deviations.

The histograms of that figure show a remarkable neutralization of aluminium by the organic matter after only a period of 5 months (2nd sampling- at the harvest of the first crop); a reduction of the Al^{3+} concentration has been more important in the plots that received 60 t.ha^{-1} than those received 30 t.ha^{-1} of compost. For illustration, at the harvest of the first crop (second sampling), the Al^{3+} content was reduced from 32 and 53 % respectively for the doses of 30 and 60 t.ha^{-1}, which equals in average to the reduction of 1.25 and 1.75 cmol$_c$.kg^{-1}.

The results of the samples analysis taken in the beginning of the second trial (3rd sampling) show that the Al^{3+} content have slightly increased and the plots that received 60 $t.ha^{-1}$ of compost have better resisted to that trend. Two years after the application of the compost (4th sampling), the Al^{3+} content did not stop increasing and in some plots that received 30 $t.ha^{-1}$ of compost, the level reached was close to the initial one. That dynamic shows the depletion, by exportation and washing, of the remainder of the mineral nutrients added by mineralization of the organic matter. Regarding the plots amended with 60 $t.ha^{-1}$ of compost, their content in Al^{3+} at the last sampling remained less than the one of the initial state of 17 % in average, which equals to 3.08 $cmol_c.kg^{-1}$.

The addition of lime to the organic applied matter, would allow keeping as low as possible the exchangeable aluminium content because, as it was mentioned above, the composts used were not well provided with the exchangeable bases which fill up the negative charges that are on the soil clay-humus complex.

Total exchange acidity

When low values of pH are found in the soil, it is always good to know the role played by the Al^{3+} ions and H^+ protons in the soil total acidity, even though it is known that at pH<5, the exchangeable aluminium becomes the dominant element in tropical acidic soils (Brady and Weil, 2002).

For instance, Al^{3+} ion contributes is in average 83 % in the total acidity for the soil of this site initially; the rest of acidity being caused by the H^+ proton. We notice from the tables 6, 7 and 8 that the contribution of Al^{3+} ion in the exchange acidity has diminished after the amendment was incorporated, while the H^+ ion has relatively increased. The increase of the H^+ ions is due to the release, in the system, of organic compounds by decomposition.

Showing the possible sources of soil acidification, Ulrich (1991) argues that the accumulation of the organic matter in the soil in the form of biomass impact negatively the saturation rate in bases in the root zone and consequently decreases the pH. However, the advantages gained from adding the organic matter (increase of CEC by the formation of a clay-humus complex, the release of mineral nutrients by mineralization, the stimulation of microbial activity, etc.) are greater than the negative effect.

The histograms of the figure 2 show that as the nutrients reserves decrease in the soil, the total exchange acidity (expressed essentially by Al^{3+}) increases dramatically until it exceeds the contents found initially for the control plots and the plots amended with NPK mineral manure (4th sampling).

4. Conclusion

The results of this study show that the corrective effects of the compost based on natural vegetation biomass on the soil pH and total acidity lasts only for two farming seasons. However, with the dose of 60 $t.ha^{-1}$, the effects can go up to 3-4 farming campaigns, all depend on factors like the quality of the compost (its fertilizing potential), the leaching, the crops varieties (exportations), the initial degree of soil fertility, etc. With low doses of that kind of compost, the organic mater supply must be repeated each two years.

This practice of valorisation of the wild plant biomass provides to be significant for all the country, even for all the degraded tropical soils. It remainder to consider the production of some of these vegetable species on the unexploited grounds (steep slopes, bank of the terraces and roads, etc.) to be able to carry out as well the vertical and the horizontal fertility transfer; and to ensure a significant reserve in biomass. For the case of the site concerned by the present study, the acknowledgement is that the majority of the species collected for composting push back very quickly by vegetative way.

The results confirm also the thesis of the intensification of the soil degradation with mineral manures when supplied alone on poor and acidic tropical soils.

In perspective, the later studies will be focused on the reproductive cycle of the majority of the used wild vegetable species, the relation soil-plant, the possibilities of cultivating these plants on a large scale on naked grounds, the land enriched fallow, the possibilities of associating these green composts with other sources of mineral elements founded locally (lime, travertine rock, etc.).

References

1. Anid P.J. (1983). *Contribution à la caractérisation des composts de déchets urbains : évaluation de leur état de maturation et des risques éventuels de contamination métallique des cultures.* Faculté des Sciences Agronomiques de l'Etat. Thèse de doctorat en sciences agronomiques. Gembloux, Belgique. 153 p.
2. Bertsch P.M. (1983). *The behaviour of aluminium in complex solutions and its role in the exchange equilibrium of soils.* University Microfilms International. Michigan. 249 p.
3. Bizimana J.C., Zaongo C. (2000). *Evaluation du potentiel fertilisant par le transfert de biomasse de quelques espèces agroforestières au Rwanda.* Butare, Rwanda, Université Nationale, Thèse d'Ingéniorat en agronomie (inédit). 130 p.

4. Blamey F.P.C., Dowling A.J. (1995). Antagonism between aluminium and calcium for sorption by calcium pectate. *Plant and soil.* **171**: 137-140.
5. Bonneau M., Souchier B. (1994). *Pédologie 2: Constituants et propriétés du sol.* Masson, Paris, France, 665 p.
6. Brady N.C., Weil R.R. (2002). *The Nature and properties of soils.* 13th edition. Pearson Education, Inc., New Jersey, USA. 960 p.
7. Budianta D. (1999). *Reclamation of an ultisol from South Sumatra using Mucuna L. and lime.* PhD Thesis/ University of Gent, Belgium, 159 p.
8. Chapelle J. (1985). Les sols du Rwanda. In: *Premier séminaire national sur la Fertilité des Sols du Rwanda.* Kigali, 17-20 Juin 1985, MINAGRI, pp 90-88.
9. Drechsel P., Reck B. (1998). Composted shrub-prunings and other organic manures for smallholder farming systems in southern Rwanda. *Agrofor. Syst.* **39**: 1-12.
10. Duchaufour P. (1993). *Pédologie: 1. Pédogenèse et classification.* 2ème édition. Masson, Paris, France, 491 p.
11. Epstein E. (1997). *The Science of Composting.* Technomic Publishing Company Inc., Lancaster, Pennsylvania, USA. 487 p.
12. Hue N.V. (1992). Correcting soil acidity of highly weathered Ultisol with chicken manure and sewage sludge. Commun Soil Sci. Plant Anal. **23**:241-264
13. Hue N.V., Craddock G. R., Adams F. (1986). Effect of organic matter acids on aluminium toxicity in subsoils. *Soil Sci. Soc. Am. J.* **50**: 28-34.
14. Ingual J.M., Rodriguez-Barrueco C., Cervantes E. (1997). The effect of aluminium on nodulation and symbiotic nitrogen fixation in *casuarinas cunninghamiana* Miq. *Plant and Soil.* **190**: 41-46.
15. Mbonigaba J.J. (2002). *Essai de compostage de déchets verts et évaluation des effets des composts obtenus sur des sols acides du Rwanda.* Faculté Universitaire des Sciences Agronomiques de Gembloux, travail de maîtrise. Gembloux, Belgique. 77 p.
16. Mbonigaba J.J., Culot M., Maniraguha J.D. (2002a). Comparaison de différents types de compostages de matières organiques diverses non valorisées par les paysans au Rwanda. Revue *Etudes rwandaises.* Série Sciences exactes, naturelles et appliqués. **5**: 40-55.
17. Mbonigaba J.J., Culot M., Bizimana R. (2002a). Effets des divers types de matières organiques en comparaison avec une fertilisation minérale sur les propriétés et la productivité d'un sol acide au Rwanda. Revue *Etudes rwandaises.* Série sciences exactes, naturelles et appliquées. **5**: 56-74.
18. Musabyimana J.C., Mbonigaba J.J., Ruganzu V. (2002). *Evolution des composantes chimiques et analyse socio-économique d'un essai de compostage à base de biomasse de Lantana camara et d'Acanthus pubescens.* Butare, Rwanda, Université Nationale, Thèse d'Ingéniorat en agronomie (inédit). 103 p.

19. Mutwewingabo B. (1984). *Pédogénèse et microbiologie de trois toposéquences de sol à horizon sombre de profondeur de Gikongoro et de deux pédons de Butare (Rwanda). Isothermes et caractéristiques d'absorption du phosphore par ces sols.* PhD Thesis/Laval University. 520 p.
20. Mutwewingabo B., Rutunga V. (1987). *Etude des sols des stations d'essai du Projet PIA-Gikongoro.* Série n°1. MINAGRI, Gikongoro, Rwanda, 114 p.
21. Ponette, Q., Andre D., Dufe J.E. (1996). Chemical significance of aluminium extracted from three horizons of an acidic forest soil, using chloride salt solution. *European J. Soil Sci.* **47**: 89-95.
22. Prosser J.I. (1997). Microbial processes within the Soil. *In* Dirk van Elsas J., Trevors J.T. Wellington E.M.H. (Eds.). *Modern soil microbiology.* Marcel Dekker Inc., New York, USA. pp. 183-213.
23. Reck B. (1995). *Die herstellung von hochwertigem kompost zur verbesserung de bodenflruchetbarkeit im Rahmen von agroforestmaßnahmen im Zentralplateau Rwandas.* Master's Thesis. Fachhochschule Rheinland-Pfalz. Bingen, Germany, 103 p.
24. Rowell D.L. (1994). *Soil science: Methods and application.* Longman Scientific and technical. Longman group UK Limited, 350 p.
25. Russell A.E., Laird D. A. Mallarino A. P. (2006). Nitrogen fertilization and cropping system impacts on soil quality in Midwestern Mollisols. *Soil Sci. Soc. Am. J.* **70**: 249-255.
26. Rutunga V. (1997). *Sols acides de la région d'altitude de la Crête Cong-Nil (Rwanda).* Potentialités agricoles et forestière. Lengo Publisher, Nairobi, Kenya. 68 p.
27. Soltner D. (1985). Les bases de la production végétale. Tome 1: le sol. 13ème édition. Angers: Collection Sciences et Techniques Agricoles. 338 p.
28. Ulrich B. (1991). An Ecosystem approach to soil acidification. *In* Ulrich B., M.E. Sumner (Eds). *Soil Acidity.* Sringer-Verlag Berlin Heidelberg, Berlin, Germany, p 29-75.
29. Van Der Zaag P. (1982). La fertilité des sols du Rwanda. *Bull Agric Rwanda.* **15** (1): 3-24.
30. Vander Zaag P., Yost R.S., Trangmar B.B., Hayashi K., Fox R.L. (1984). An assessment of chemical properties for soils of Rwanda with the use of geostatistical techniques. *Geoderma* **34**: 293-314.
31. Voundi Nkana J.C. (1998). *Utilisation des déchets de l'industrie du bois en vue de l'amélioration de la fertilité chimique des sols acides tropicaux.* Université de Gand, Thèse de doctorat. Gand, Belgique. 259 p.
32. Wong M.T.F., Akyeampong E., Nortcliff S., Rao M. R., Swift R. S. (1995). Initial response of maize and beans to decreased concentrations of monomeric inorganic aluminium with application of manure or tree prunings to an Oxisol in Burundi. *Plant Soil* **171**: 275-282.

33. Wong M.T.F., Norltcliff S., Swift R.S. (1998). Method for determining the acid ameliorating capacity of plant residue compost, urban waste compost, farm yard manure and peat applied to tropical soils. *Commun. Soil Sci. anal.* **29**: 2927-2937.
34. Wong M.T.F., Swift R.S. (2003). Role of organic matter in alleviating soil acidity. *In* Rengel Z. (Eds.). *Handbook of soil acidity.* Marcel Dekker Inc., New York, USA. pp. 337-358.
35. 100.Yamoah C.F., Burleigh J.B., Malcolm M.R. (1990). Application of expert systems to study of acid soils in Rwanda. *Agric. Ecosyst. Environ.* **30**: 203-218.