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Comparative Liming Power of Chicken Manure and Selected Dolomitic Sources on an Acidic High Altitude Burundi Surface Soil

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ABSTRACT

A research initiative was set up to evaluate the comparative liming power of locally available dolomitic products and chicken manure, using an amaranth (Amaranthus viridis L.) test crop. The soil used was acidic, of low % base saturation and risks of Al toxicity, deficient in available P, exchangeable Mg, Ca and K. The experimental setup was a completely randomized design with 11 treatments and 3 replicates which included : a control treatment (equivalent to 100 kg DAP/ha), 4 mineral amendments (Moso Lime, Moso Ground Dolomite, Bubanza Ground Dolomite and Busiga Ground Dolomite) applied at equivalents of 1 T/ha and 2 T/ha, and chicken manure applied at equivalent of 10 and 20 T/ha. The study duration was three months with three test crop harvests at one-month interval. Monthly measured plant growth and production parameters were plant height, root length, shoot length, root biomass, shoot biomass and their summation (total biomass). Soil pH, available P and exchangeable acidity (Al^{3+} + H^{+}) were assessed at the start and the completion of the pot study. Obtained results could be summarized as follows : (i) the highest available P accumulation was associated with the equivalent of 20 T/ha of chicken manure ; (ii) application of equivalents 20 T/ha of chicken manure, 2 T/ha Moso Ground Dolomite and 2 T/ha Moso Lime increased soil pH by 0.2 to 0.5 pH-units and reduced exchangeable acdity ; (ii) DAP fertilized treatment was characterised by the lowest pH value and the highest Al^{3+} and H^{+} exchangeable acidity, illustrating the acidifying effect of this NH_4^{+}-bearing fertilizer ; (iv) amarant growth (root and height) and biomass (root + shoot) production were highest with 20 T/ha chicken manure, 2 T/ha Moso Ground Dolomite and 2 T/ha Moso lime. Application rate was only statisticallt detectable for Moso Ground Dolomite (+ 162 %) and chicken manure (+ 182 %). Overall, 20 T/ha chicken manure showed the highest and most stable amaranth root + shoot biomass yields, demonstrating its potential residual effect, which should be evaluated and confirmed under field conditions.

Keywords : Biomass, Chicken manure, Dolomite, Liming power, pH value.

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1. INTRODUCTION

Soil acidification is a natural as well as an anthropogenic process consisting of rainfall controlled losses of major basic cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) from the clay-organic matter complex, leaving behind exchangeable Al^{3+} and H^{+} acid cations and to some extent Fe^{3+}/Fe^{2+} [1-5]. However, in the Burundi context, it appears that nutrient losses are observed through soil erosion and plant residues exportations, which might constitute major sources of acidification. In fine, Al^{3+} phytotocicity depends on predominant clay minerals, soil organic matter and its composition, concentrations of basic cations, anions, salts and crop species [6-11].

Systematic rehabilitation of Al^{3+}-affected soils by calcitic ($CaCO_3$) or dolomitic ($CaCO_3.MgCO_3$) is limited by their costs. Amendments based on lime as well as calcitic and finely-ground limestones are more reactive than grossely-ground ones and convene to clay soils. Netherless, their prohibitive costs limit their extensive use at the farmers' level. Very often, medium- and grossely-ground limestones, with slow chemical action are more convenient to light-textured soils due to their reduced costs [8].

Soil liming economic effiecieny is determined by its inferred costs balanced by additionnal production generated throughout its duration of action, often of 2-years. Yield gains and economic efficiency of liming will largely depend on levels of soil acidity, application dosages of amendments as well as concerned crops [8, 12-14].

Limestone and lime react differently : limestone is less soluble than lime. Their respective efficiency is controlled by their fineness. Their modes of action are also contrasting. Through their dissolution, limestones leave a shightly acidic residue (HCO_3^-), whereas lime produces OH^- ions alcaline in nature, with intensive and rapid effect on soil pH dynamics which is not necessarily an agronomic advantage [8, 12].

Recent published mapping data [9] indicate that 73 % of Burundi high altitude soils are acidic (pH < 5.5) (Figure 1). In that quite alarming agronomic context, sustainable food production must go through soil acidity alleviation by exchangeable Al^{3+} mitigation. The recommended approach is the combination of calcitic/dolomitic resources and soil organic matter [7, 15-19]. The present investigators advance that, in the context of Burundi prone to soil erosion, the priority in such integrated soil fertilization approach is a follows : soil acidity correction by dolomitic lime application, organic matter application completed in the end by mineral fertilizers application, the whole package duly completed by soil erosion mitigation and crop biomass management [10-11].

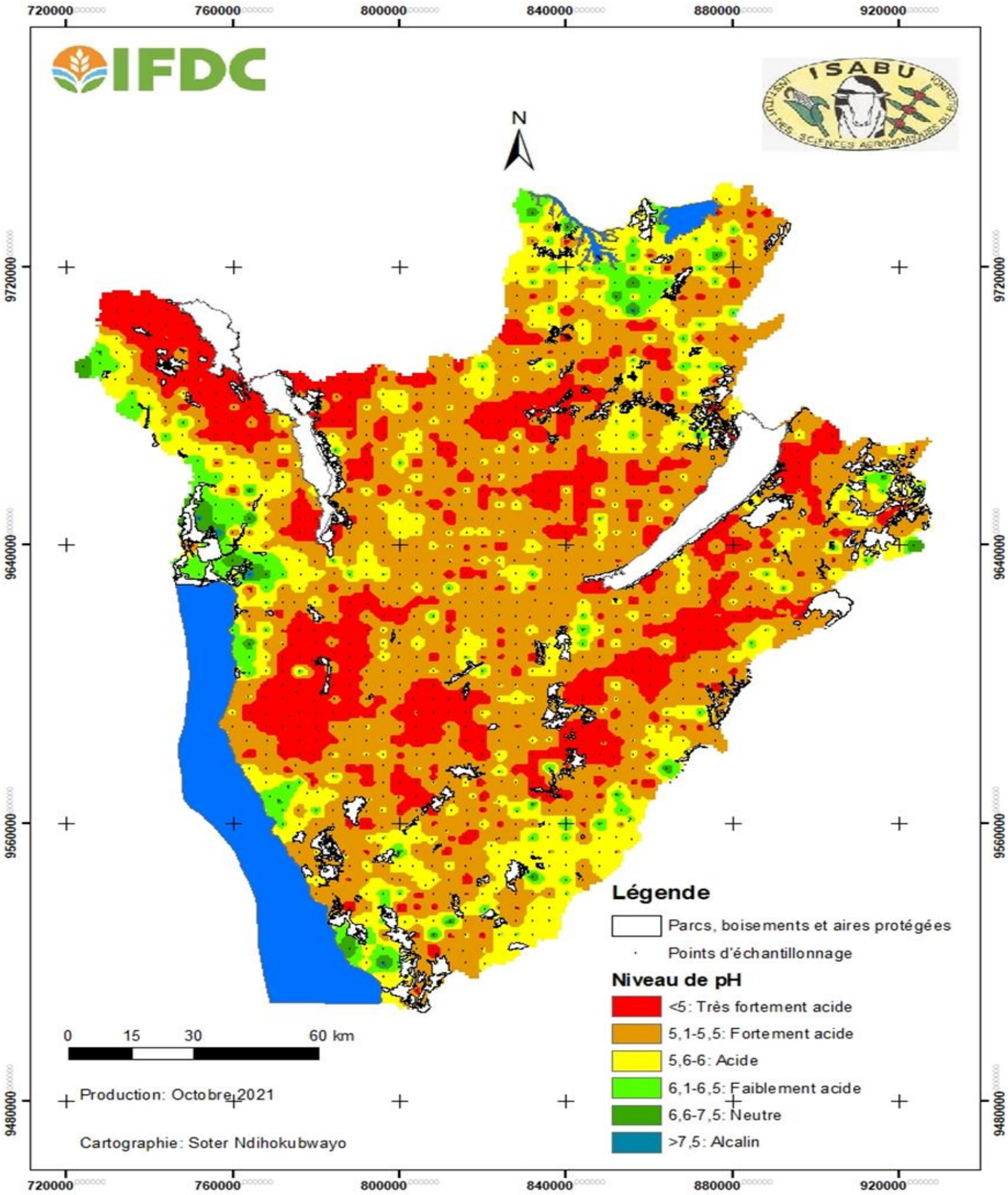

Figure 1. Burundi soil fertility mapping [9]

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In the framework of this integrated approach of soil fertility management, a research initiative was set up to evaluate the comparative liming power of locally available dolomitic products and chicken manure, an organic animal material recognized as of some liming power [17-20]. This paper highlights major findings of the present research iniative on comparative liming power of chicken manure and Burundi selected dolomitic sources.

2. MATERIALS AND METHODS

2.1 Chemical Analyses and Calculations

Prior to trials installation, composite soil samples were randomly collected at 0-20 cm depth, air-dried, bulked, crashed and sieved through a 2-mm sieve. Soil chemical analyses were performed on % organic C, total N, pH, available P, Cation Exchange Capacity (CEC) and exchangeable K, Al and H. Soil pH was measured in a 1:5 soil/water suspension [21]. Nitrogen was measured based on the Kjeldahl method [22] and organic C by the Walkey-Black method [23]. CEC and exchangeable K were measured by the 1 N ammonium acetate buffered at pH=7.0. Exchangeable Ca, Mg and K were measured by atomic absorption spectrophotometry [24]. Adsorbed ammonium was desorbed by percolation using a 10 % KCl solution at pH=3,0, distilled and titrated to determine soil CEC. Exchangeable Al and H were determined by analytical protocols described in C. Kibiriti et al. (1986a) [21] and C. Kibiriti et al. (1986b) [25]. Selected chemical properties are shown in Table 1.

Chicken manure samples were analyzed for pH, % C, % Total N, % P, % Ca, % Mg and % K. Total N was determined by digestion with sulphuric acid (H_2SO_4) and hydrogen peroxyde (H_2O_2) followed by steam distillation [22]. Total C was determined by wet combustion [23]. Total P, K, Ca, and Mg were analyzed by ICP spectrometry after digestion with HNO_3 and H_2O_2 at 120^oC for 3 hours [24]. Selected chicken manure analytical data are presented in Table 2.

Liming materials were characterized for pH, % Ca, % Mg and their oxyde forms (% CaO and % MgO) by multiplying the atomic form by 1,4 factor for Ca and 1,67 for Mg. Equivalent $CaCO_3$ of tested dolomitic materials were also calculated through their ratios of molecular weights (MW) $CaCO_3$ over CaO and MgO MW. Dolomitic materials percent size distribution as estimated by physical sieving is given in Table 4. Respective finess indices or factors relative to the given % size distribution were calculated according to Brady (1990) [8]. From $CaCO_3$ equivalents and finess factors, neutralizing powers were calculated as the products of the two quality factors of dolomitic materials [8].

2.2 Experimental Set up

Pot studies is a simple, rapid and cheaper means to investigate fertilization problems. It isolates a specified parameter under study and follows its dynamics. However, we must be aware that this research approach remains artificial and not depicting the real field conditions and, as such, generated results can not be quantitatively extrapolated in the field, and so need further confirmations in the field.

Amaranth (*Amaranthus viridis* L.) crop has been selected for the present study for its short growing cycle. Soil used in the experiment was collected from ISABU experimental station at Gisozi. The soil was considered representative of Burundi high altitude acid soils. Gisozi experimental station is located South of the Mugamba agro-ecological zone at 2097 m of altitude with 1360 mm mean annual rainfall and mean annual temperature of 16^o C. Vegetation of the site from which the soil was collected is mainly characterized by *Eragrostis olivacea*, indicative of the pronounced soil chemical degradation. Chicken manure was obtained from a private poultry farm near by Bujumbura City.

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2.3. Experimental design and measured parameters

Experimental design was a completely randomized with 11 treatments and 3 replicates. The control treatment received 100 kg DAP per hectare. Each of the mineral amendments was applied at 2 levels : 1 T/ha and 2 T/ha. Chicken manure was applied at 20 and 10 T/ha. Each pot was sown with amaranth (*Amaranthus viridis* L.) seeds thinned to 5 plants for the rest of the experimental study. Pots were watered when needed. Bean harvest under vegetation stage was done after one month vegetative amaranth crop growth. Entire plants were carefully uprooted to estimate root and shoot biomass. Measured parameters were plant height, root length, shoot length, root biomass, shoot biomass and their summation (total biomass). Amaranth (*Amaranthus viridis* L.) dry biomass was estimated following oven drying at 105^{o}C for 48 h.

2.4 Data analyses

Field and laboratory data were analysed with SAS package [26]. Chemical parameters were subjected to a descriptive analysis completed by an one factorial analysis of variance (ANOVA 1). Application of the Student-Newman-Keuls test allowed to compare and classify mean values in homogenous groups at 5 % probability level based on the LSD (Least Significant Difference) method [27].

3. RESULTS AND DISCUSSION

3.1. Soil Chemical Analyses

Soil was analyzed for soil pH, % C, % N, Cation Exchange Capacity (CEC), Exchangeable Al^{3+}, H^{+}, Ca^{2+}, Mg^{2+} and K^{+}. Data analysis are indicated in Table 1 below. They show chemical characteritics of an acidic soil, of low % base saturation and risks of Al toxicity (24 % Al), deficient in available P, poor in Mg, very por in Ca and K [28].

Table 1. Selected Soil Chemical Characteristics.

Parameter	Value
pH_{eau}	5.10
% C	2.62
% N	0.24
P Olsen-Dabin (ppm)	10
Exchangeable Al^{3+} ($cmol_c$/kg soil)	1.41
Exchangeable H^{+} ($cmol_c$/kg soil)	0.17
Exchangeable Ca^{2+} ($cmol_c$/kg soil)	1.19
Exchangeable Mg^{2+} ($cmol_c$/kg soil)	0.62
Exchangeable K^{+} ($cmol_c$/kg soil)	0.15
CEC (méq/100 g de sol)	5.80

3.2 Chicken manure and dolomitic materials chemical Analysis

Chicken manure has been evaluated for pH, % C, % N, % P, % Ca, % Mg, % CaO, % MgO and % K. Table 2 depicts chicken manure chemical analysis and calculated parameters. These analyses show that the used chicken manure has an optimal pH, with poor N content counterbalanced by richness in P, Ca and Mg [29], allowing some liming power to this animal manure. In actual fact, in comparison with other animal manures, chicken manure generally contains higher amounts of N, P and K [16].

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Table 2. Chicken manure chemical characteristization.

Parameter	Value
pH_{eau}	7.87
% C	19.73
% N	1.62
C/N	12.18
% P	0.87
% Ca	5.10
% CaO	7.14
% Mg	0.47
% MgO	0.78
% K	1.10

Liming materials were characterized for size distribution, pH, % CaO, % MgO, neutralizing value, equivalent $CaCO_3$, fineness factor and neutralizing power (Tables 3 and 4). Table 3 indicates that Moso Ground Dolomite had a higher propotion of small particles (< 50 µ), but also bigger ones in proportion (46,5 % in the 500-1000 µ), against 44 % for Busiga Ground Dolomite, 41 % for Bubanza Ground Dolomite and 30 % for Moso Lime.

Table 3. Percent (%) particle size distribution of selected dolomitic materials

Dolomitic materials	Size (µ)					
	1000	500	250	100	50	< 50
Moso Lime	15	15	15	32	16	7
Moso Ground Dolomite	**21.5**	**25**	**12**	**10.5**	**11**	**20**
Bubanza Ground Dolomite	17	24	17	20	18	4
Busiga Ground Dolomite	17	27	17	17	16	4

As illustrated in Table 4, pH values of different mineral amendments are classified in the following decreasing order : Moso Lime > Bubanza GD > Moso GD > Busiga GD. Busiga Ground Dolomite had the lowest pH value (8.07) coupled with the lowest fineness factor (0.68). When equivalent $CaCO_3$ and fineness factor are taken into account to obtain liming materials neutralizing power, we obtain the following ranking : Moso Lime (NP=0.95) > Busiga GD (NP=0.83) > Moso GD (NP=0.75) > Bubanza GD (NP=0.72). Based on this chemical criteria (Neutralizing Power=NP), one would expect Moso Lime to perform better in the present experiment, in comparison with the other three liming product (Moso GD, Bubanza GD and Busiga GD).

Table 4. Chemical characteristics of selected dolomitic materials

Dolomitic material	pH	% CaO	% MgO	Equivalent $CaCO_3$	Fineness Factor	Neutralizing Power
Moso Lime	12.47	30.65	27.04	1.23	0.78	0.95
Moso Ground Dolomite	10.10	25.97	23.83	1.06	0.71	0.75
Bubanza Ground Dolomite	10.91	35.06	15.21	1.01	0.71	0.72
Busiga Ground Dolomite	8.07	32.89	25.65	1.22	0.68	0.83

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3.3 Available P, active and exchangeable acidity

At the end of the amaranth pot experiment, available P content, pH and exchangeable acidity (Al^{3+}+H^+) have been evaluated. Table 5 summarizes the findings.

Table 5. Effect of chicken manure and dolomitic sources on available P (mg/kg soil), active and exchangeable acidity ($cmol_c$/kg soil).

Treatment	P	pHeau	Al^{3+}+H^+	Al^{3+}
20 T/ha CM	**33,0a**	**5,6ab**	1.44bc	**0.72bcd**
10 T/ha CM	23.0b	5.5bc	1,50bc	0.94bcd
100 kg DAP/ha	20.3b	5.2^e	2.80a	2.10a
2 T/ha Moso GD	16.0c	**5.7a**	1.33bc	1.00bcd
1 T/ha Moso GD	16.0c	5.4cd	1.66bc	1.17bc
2 T/ha Moso Lime	16.0c	**5.6ab**	**0.95c**	**0.34d**
1 T/ha Moso Lime	16.0c	5.5bc	1.28bc	**0.58cd**
2 T/ha Bubanza GD	16.0c	5.3de	1.83b	1.22bc
2 T/ha Busiga GD	16.0c	5.3de	1.82b	1.29bc
1 T/ha Busiga GD	16.0c	5.3de	2.00b	1.44ab
1 T/ha Bubanza GD	15.3c	5.2^e	1.51bc	1.37ab
General Mean	18.5	5.5	1.65	1.14
LSD	4.0	0.1	0.74	0.73
Probability	< 0.001***	< 0.001***	0.007**	0.01*
C.V (%)	12.9	1.3	26.5	37.9

Mean values with identical letters within the same column are not statistically different at $p < 0.05$.
Note : GD= Ground Dolomite ; CM=Chicken Manure.
*** = Very highly significant ($p < 0.001$)
** = Highly significant ($p < 0.01$)
* = Simply significant ($p < 0.05$)

Available P

Significant effects ($p < 0.05$) of organic and chemical amendments have been observed on available P, pH, exchangeable acidity (Al^{3+}+H^+) and exchangeable Al^{3+}. The highest available P accumulation was associated with the equivalent of 20 T/ha of CM followed in the order by 10 T/ha CM and 100 kg DAP/ha. All other treatments, which represented half of the available P accumulation of 20 T/ha CM application, were significantly inferior to the top three treatments (20 T/ha CM, 10 T/ha CM ans 100 kg DAP).

Doubling chicken manure application from 10 to 20 T/ha did not double available P (+ 43.5 %), but was 63 % more efficient than 100 kg DAP in terms of available P and two-times all other remaining treatments which were not significantly different among them. No statistically detectable effect of liming materials application rate was observed on available P.

pHeau

For pH, three treatments ranked high and were not significantly different : 2 T/ha Moso GD, 2 T/ha Moso Lime and 2 T/ha CM. Doubling chicken manure application only increased pH of 0.1-unit. No significant application rate effect was observed for CM, Moso lime, Bubanza and Busiga GD, the only application rate effect was registerered with Moso GD. Application of DAP was associated with the lowest soil pH (pH=5.2) statistically equivalent to pH values observed with Bubanza and Busiga GD (pH=5.2-5.3). Kwowing that the

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original soil had a pH value of 5.1, it shoud be noted that application of CM and mineral amendments increased soil pH by 0.2 to 0.5 pH-units within the 3-month duration of our experiment.

Exchangeable Acidity

Highest reduction of total exchangeable acidity (Al^{3+}+H^+) was obtained with 2 T/ha Moso Lime (0.95 cmolc/kg soil), followed in order by 1 T/ha Moso Lime (1.28 cmolc/kg soil), 2 T/ha Moso GD (1.33 cmolc/kg soil) and 20 T/ha CM (1.44 cmolc/kg soil). A similar trend was observed for Al^{3+} exchangeable acidity, where the first 3 more efficient liming materials reduced Al^{3+} exchangeable acidity to 35 to 50 % of the total acidity (Al^{3+}+H^+). DAP fertilizd treatment was not only characterised by the lowest pH value but also by the highest Al^{3+} and H^+ exchangeable acidity, illustrating the acidifying effect of this NH_4^+-bearing fertilize as was previously eluded in this scientific medium [30].

3.4 Amaranth Root Length

Amaranth root lenght (cm) was one of the growth parameters evaluated in this study. Data related to amaranth root growth during three successive harvests are indicated in Table 6.

Table 6. Effect of chicken manure and dolomitic sources on amaranth root length (cm)

Treatment	Harvest 1	Harvest 2	Harvest 3
100 kg/ha DAP	31.8a	23.8c	16.0c
2 T/ha Moso Lime	**37.8a**	32.3ab	**26.8ab**
1 T/ha Moso Lime	31.5a	**35.9ab**	23.5abc
2 T/ha Moso GD	34.8a	33.1ab	**29.9a**
1 T/ha Moso GD	**37.1a**	**36.7ab**	23.7abc
2 T/ha Bubanza GD	31.2a	33.3ab	22.2abc
1 T/ha Bubanza GD	37.1a	26.5bc	18.1bc
2 T/ha Busiga GD	31.9a	32.5ab	16.9bc
1 T/ha Busiga GD	34.0a	26.4bc	18.5c
20 T/ha CM	**37.8a**	**37.3a**	**27.9a**
10 T/ha CM	32.9a	26.1bc	21.7abc
General Mean	34.4	31.2	22.3
LSD	7.5	6.3	8.8
Probability	0.4NS	0.001***	0.016*
C.V (%)	12.9	11.8	23.2

Mean values with identical letters within the same column are not statistically different at $p < 0.05$.
NS = Non significant ($p > 0.05$)
*** = Very highly significant ($p < 0.001$)
* = Simply significant ($p < 0.05$)

During the first amaranth harvest, no significant differences were observed among all tested treatments ($p > 0.05$). Nevertheless, the 4 top treatments in amaranth root length were : 2 T/ha Moso Lime, 20 T/ha CM and 1 T/ha Moso GD. The lowest root lenghts were noted with : 2 T/ha Bubanza GD, 1 T/ha Moso Lime, 100 kg DAP/ha and 2 T/ha Busiga GD. No application rate effect of either fertilizer (DAP) or amendements was observed during the first amaranth harvest.

As for the second harvest, top treatments in amaranth root length were : 20 T/ha CM ≥ 1 T/ha Moso GD ≥ 1 T/ha Moso Lime. On the other side, the lowest root lenght growths were registered, in the decreasing order with : 100 kg DAP/ha, 10 T/ha CM, 1 T/ha Busiga GD and 1 T/ha Bubanza GD. Contrarily to the first havest. Application rate effect was observed with CM, as doubling the rate from 10 to 20 T/ha increased amaranth root growth by 42 %.

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After a peak in root length growth observed with the second amarant harvest, the third harvest showed a decline in root length (abscence of residual effects), more noticeable with Bubanza and Busiga GD, as well as the DAP treatments. The top 3 treatments in amaranth rooth length were in the decreasing order : 2 T/ha Moso GD, 20 T/ha CM, 2 T/ha Moso Lime, while the lowest were : 100 kg DAP/ha, 2 T/ha Busiga GD and 1 T/ha Busiga GD. Moreover, no application rate effect was observed in either treatments.

3.5. Amarath Shoot Height

Amaranth shoot height data as affected by DAP, CM and dolomitic sources throughout three harvests are shown in Table 7 below.

Table 7. Effect of chicken manure and dolomitic sources on amaranth shoot height (cm).

Treatment	Harvest 1	Harvest 2	Harvest 3
100 kg/ha DAP	19.6abcd	17.0de	10.3f
2 T/ha Moso Lime	**24.2a**	**22.3abc**	16.5bcd
1 T/ha Moso Lime	**24.5a**	16.9de	19.7ab
2 T/ha Moso GD	21.7abcd	**24.5a**	**22.7a**
1 T/ha Moso GD	22.3abcd	18.1bcde	17.4bc
2 T/ha Bubanza GD	18.7bcd	21.7abcd	14.8cde
1 T/ha Bubanza GD	18.6cd	16.0^{e}	12.6def
2 T/ha Busiga GD	18.6cd	19.9abcde	16.0bcd
1 T/ha Busiga GD	17.2d	19.7abcde	11.6ef
20 T/ha CM	**22.7abcd**	**23.0ab**	**22.1a**
10 T/ha CM	**23.6abcd**	**17.5cde**	**19.4ab**
General Mean	21.1	19.7	16.6
LSD	5.5	4.9	4.2
Probability	0.10NS	0.02*	0.001***
C.V (%)	15.4	14.6	15.0

Mean values with identical letters within the same column are not statistically different at $p < 0.05$.
NS = Non significant ($p > 0.05$)
*** = Very highly significant ($p < 0.001$)
* = Simply significant ($p < 0.05$)

Statistical analysis performed on amaranth shoot growth during the first harvest did not show any effect of tested treatments ($p > 0.05$). However, beyond the statistics, the four top treatments in amaranth shoot growth were : 1 T/ha Moso Lime, 2 T/ha Moso Lime, 20 T/ha and 10 T/ha CM. Lowest shoot growth values were obtained with Busiga and Bubanza GD, independently of application rates. And for that matter, no application rate effect of tested treatments was statistically found on amaranth shoot growth.

However, wiith the second harvest, statistical differences among tested treatments were found ($p < 0.05$). Hence, top 3 treatments in amaranth shoot growth were as follows, in the decreasing order : 2 T/ha Moso GD, 20 T CM and 2 T/ha Moso Lime. Lowest shoot growths were observed with 1 T/ha Bubanza GD, 1 T/ha Moso Lime and 100 kg DAP/ha. With the exception of the Busiga GD, amaranth shoot growth increased with increasing application rates with a magnitude variation ranging from + 31 % for chicken manure (CM) and + 36 % for Bubanza GD.

At the third harvest, the soil stock showed some fatigue, as amaranth shoot growth declined for most tested treatments except two of them : 2 T/ha Moso GD and 20 T/ha CM which showed more persistence in shoot growth. At the bottom of amaranth shoot growth were : 100 kg DAP/ha, 1 T/ha Busiga GD and 1 T/ha Bubanza GD. Application rate effect was only statistically significant with Moso GD and Busiga GD.

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3.6 Amaranth Root Biomass

Amaranth biomass through its below- and aboveground components was followed during the 3-month pot experiment. Table 8 summarizes the findings relative to root biomass accumulation during three harvests.

Table 8. Effect of chicken manure and dolomitic sources on amaranth root biomas (g DM/pot).

Treatment	Harvest 1	Harvest 2	Harvest 3	Total
100 kg/ha DAP	0.4cd	0.3cd	0.1b	0.8c
2 T/ha Moso Lime	**1.0a**	0.5bc	0.2b	1.7ab
1 T/ha Moso Lime	**0.8ab**	0.4cd	0.2b	1.4ab
2 T/ha Moso GD	**0.6bc**	**0.8a**	**0.6a**	**2.0a**
1 T/ha Moso GD	0.4cd	0.3cd	0.3ab	1.0b
2 T/ha Bubanza GD	0.3cd	0.5bc	0.3ab	1.1b
1 T/ha Bubanza GD	0.2d	0.2d	0.3ab	0.7b
2 T/ha Busiga GD	0.5bcd	0.4cd	0.3ab	1.2bc
1 T/ha Busiga GD	0.3cd	0.3cd	0.2b	0.8c
20 T/ha CM	**0.8ab**	**0.7ab**	**0.6a**	**2.1a**
10 T/ha CM	0.3cd	0.3cd	0.3ab	0.9c
General Mean	0.5	0.4	0.3	1.3
LSD	0.3	0.2	0.2	0.7
Probability	0.005**	0.0004**	0.002***	0.000**
C.V (%)	40.1	34.3	33.8	31.7

Mean values with identical letters within the same column are not statistically different at $p < 0.05$.
*** = Very highly significant ($p < 0.001$)
** = Highly significant ($p < 0.01$)

Statistical analysis performed on the three harvest results showed significant differences among tested treatments. With regard to the first harvest, the top 3 treatments in amaranth root biomass production were : 2 T/ha Moso Lime, 20 T/ha CM and 1 T/ha Moso Lime. On the other hand, the lowest root biomass producing treatments were : 100 kg DAP/ha, 1 T/ha Moso GD, 1 T/ha Bubanza GD, 10 T/ha CM, 1 T/ha Busiga GD and 2 T/ha Bubanza GD. The effect of application rate was perceived with only CM. In fact, root biomass generated by 20 T/ha CM was almost 3 times that obtained with 10 T/ha CM.

Throughout the second amarant harvest, it appeared that the top 2 treatments were constituted by 2 T/ha Moso GD and 20 T/ha CM, whereas the lowest root biomass productions were observed with 1 T/ha Bubanza GD, 100 kg DAP/ha, 1 T/ha Busiga GD, 1 T/ha Moso GD and 10 T/ha CM. Application rate effect was demonstrated with Moso GD (+ 270 %), Bubanza GD (+ 250 %) and CM (+ 230 %).

Similarly to the previous two harvests, amaranth root biomass production was highest with 2 T/ha Moso GD and 20 T/ha CM. The lowest producing root biomass treatments were : 100 kg/ha DAP, 2 T/ha Moso lime, 1 T/ha Moso lime and 1 T/ha Busiga GD. No satistically significant effect of the application rate factor was observed during the third amaranth harvest.

When all three harvests of amaranth root biomass were combined, the top three most performing treatments were 20 T/ha CM, 2 T/ha Moso GD and 2 T/ha Moso lime. On the other side, the least performing treatments appeared to be : 1 T/ha Bubanza GD, 100 kg DAP/ha, 1 T/ha Busiga GD and 10 T/ha CM. Overall, the application rate effect on amaranth root biomass production only stood out for the Moso GD (+ 200 %) and CM (+ 230 %).

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3.7 Amarath Shoot Biomass

Table 9 presents the results of the amaranth shoot biomass across three successive harvest and tested treatements. Statistical analyses performed on experimental treatments within each of the three harvests and their summation demonstrated significant differences at 0.05 probability.

Table 9. Effect of chicken manure and dolomitic sources on amaranth shoot biomass (g DM/pot).

Treatment	**Harvest 1**	**Harvest 2**	**Harvest 3**	**Total**
100 kg/ha DAP	0.5cd	0.4cd	0.1d	1.0d
2 T/ha Moso Lime	**1.0a**	**0.7ab**	0.5bc	**2.2ab**
1 T/ha Moso Lime	**0.9ab**	0.5bc	0.4c	1.6bcd
2 T/ha Moso GD	0.5cd	**0.8ab**	**0.7b**	**2.0bc**
1 T/ha Moso GD	0.5cd	0.5bc	0.4c	1.4c
2 T/ha Bubanza GD	0.3d	0.4cd	0.3cd	1.0d
1 T/ha Bubanza GD	0.4d	0.4cd	0.3cd	1.1d
2 T/ha Busiga GD	0.5cd	0.4cd	0.3cd	1.2d
1 T/ha Busiga GD	0.6bcd	0.6bc	0.3cd	1.5cd
20 T/ha CM	**0.8abc**	**0.9a**	**1.1a**	**2.8a**
10 T/ha CM	0.5cd	0.7ab	0.4c	1.6bcd
General Mean	0.6	0.6	0.4	1.7
LSD	0.2	0.2	0.2	0.6
Probability	0.006**	0.02*	0.001***	0.001***
C.V (%)	26.5	26.8	33.6	22.2

Mean values with identical letters within the same column are not statistically different at $p < 0.05$.

*** = Very highly significant ($p < 0.001$)

** = Highly significant ($p < 0.01$)

* = Simply significant ($p < 0.05$)

For the first harvest the application rate effect was absent throughout all tested treatments. Treatments with 2 T/ha Moso Lime, 1 T/ha Moso Lime and 20 T/ha CM gave the highest amaranth shoot biomass productions, while 2 T/ha Bubanza GD and 1 T/ha Bubanza GD were associated with the lowest shoot biomass yields.

The interpretation of amaranth shoot biomass for the second harvest puts atop three treatments : 20 T/ha CM, 2 T/ha Moso GD, 2 T/ha Moso Lime and 10 T/ha CM. The same ranking approach places at the bottom the following tratments : 2 T/ha Bubanza GD, 2 T/ha Busiga GD, 1 T/ha Bubanza GD, 1 T/ha Bubanza GD and lastly 100 DAP/ha. No application rate effect was observed in any of the tested treatments.

Amaranth shoot biomass production associated with the third harvest outlined top 2 treatments : 20 T/ha CM, 2 T/ha Moso GD. In addition, 4 lowest shoot biomass yields were noted with 100 kg/ha DAP, 2 T/ha Bubanza GD, 1 T/ha Bubanza GD, 2 T/ha Busiga GD and 1 T Busiga GD. Contrarily to the first two harvests, 2 T/ha Moso GD produced 175 % more shoot biomass than 1 T/ha of the same liming material. Similarly, CM at 20 T/ha more than doubled amaranth shoot biomass (+ 275 %) than 10 T/ha. A proof of the application rate effect for these two treatments for the third amaranth shoot biomass.

With the combination of the three amaranth shoot biomass harvests, top 3 treatments emerged : 20 T/ha CM, 2 T/ha Moso Lime and 2 T/ha Moso GD. Among 3 other tested treatments (2 T/ha Bubanza GD, 1 T/ha Bubanza GD and 2 T/ha Busiga GD), 100 kg/ha DAP ranked low in amaranth total shoot biomass. The application rate effect was only observed with CM (+ 175 %).

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3.8 Amarath Cumulative Root and Shoot Biomass

Combined amaranth root and shoot biomass (Harvest 1, 2, 3 and their combination) was subjected to statistical analaysis summarized in Table 10 below. Mean comparisons based on the Newman-Keuls test showed differences among tested treatments based on a 0.05 probability.

Table 10. Effect of chicken manure and dolomitic sources on amaranth cumulative (Root + Shoot) biomass (g DM/pot).

Treatment	Harvest 1	Harvest 2	Harvest 3	Total
100 kg/ha DAP	1.0cd	0.9cd	0.3d	2.2de
2 T/ha Moso Lime	**2.0a**	1.2bc	0.7bcd	**3.9abc**
1 T/ha Moso Lime	**1.7ab**	1.0cd	0.7bcd	3.4bcd
2 T/ha Moso GD	1.2bcd	**1.7a**	**1.3ab**	**4.2ab**
1 T/ha Moso GD	0.9cd	0.9cd	0.8bc	2.6de
2 T/ha Bubanza GD	0.7cd	0.9cd	0.6bcd	2.2de
1 T/ha Bubanza GD	0.7cd	0.6d	0.6bcd	1.9[e]
2 T/ha Busiga GD	1.1cd	0.8cd	0.7bcd	2.6cde
1 T/ha Busiga GD	1.0cd	1.0cd	0.5bcd	2.5de
20 T/ha CM	**1.6ab**	**1.6ab**	**1.7a**	**4.9a**
10 T/ha CM	0.9cd	1.0cd	0.8bc	2.7cde
General Mean	1.2	1.0	0.8	3,0
LSD	0.5	0.4	0.4	1,3
Probability	0.002*	0.001*	0.001***	0.001***
C.V (%)	28.8	21.8	29.8	26.5

Mean values with identical letters within the same column are not statistically different at $p < 0.05$.
*** = Very highly significant ($p < 0.001$)
* = Simply significant ($p < 0.05$)

In summary, based on the root+shoot biommass the 3 top treatments based on amaranth cumulative biomass for the first harvest were : 2 T/ha Moso Lime, 1 T/ha Moso Lime and 20 T/ha CM. The lowest cumulative biomass productions were registered with 2 T/ha Bubanza GD, 1 T/ha Bubanza GD, 1 T/ha Moso GD and 10 T/ha CM. Only the CM treatment showed an effect of the application rate, as 20 T/ha increased the amaranth cumulative biomass by 180 %.

When it comes to the second harvest, two top treatments in amaranth cumulative biomass arise : 2 T/ha Moso GD and 20 T/ha CM, while the lowest cumulative yields were observed with 1 T/ha Bubanza GD, 2 T/ha Busiga GD, 2 T/ha Bubanza GD, 1 T/ha Moso lime and finally 100 kg/ha DAP. Application rate effect was noticed only with two treatments, namely Moso GD (+ 190 %) and CM (+ 160 %).

Harvest 3 was characterised by a separation of two top treatments in amaranth cumulative biomass : 20 T/ha CM and 2 T/ha Moso GD. Additionally the lowest performing treatment in terms of amaranth cumulative biomasse included 100 kg/ha DAP, 1 T/ha Busiga GD, 2 T/ha Bubanza GD and 1 T/ha Bubanza GD. Application rate effect was only observed with CM with + 213 % more cumulative biomass production of 20 T/ha compared 10 T/ha CM.

3.9. Total biomass and residual effect

We attempted to evaluate the residual effect of tested treatments by comparing the evolution of amaranth biomass throughout the 3 harvests, as well as the total biomass. Figure 2 was generated for that specific purpose. It highlights the superiority of 20 T/ha CM, 2 T/ha Moso GD and 2 T/ha Moso lime in amaranth

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total biomass. On the other hand, Figure 1 also show the lowest amaranth total biomass production associated with 1 T/ha Bubanza GD and 100 kg/ha DAP. The effect of application rate was only visible for Moso GD (+ 162 %) and CM (+ 182 %) treatments.

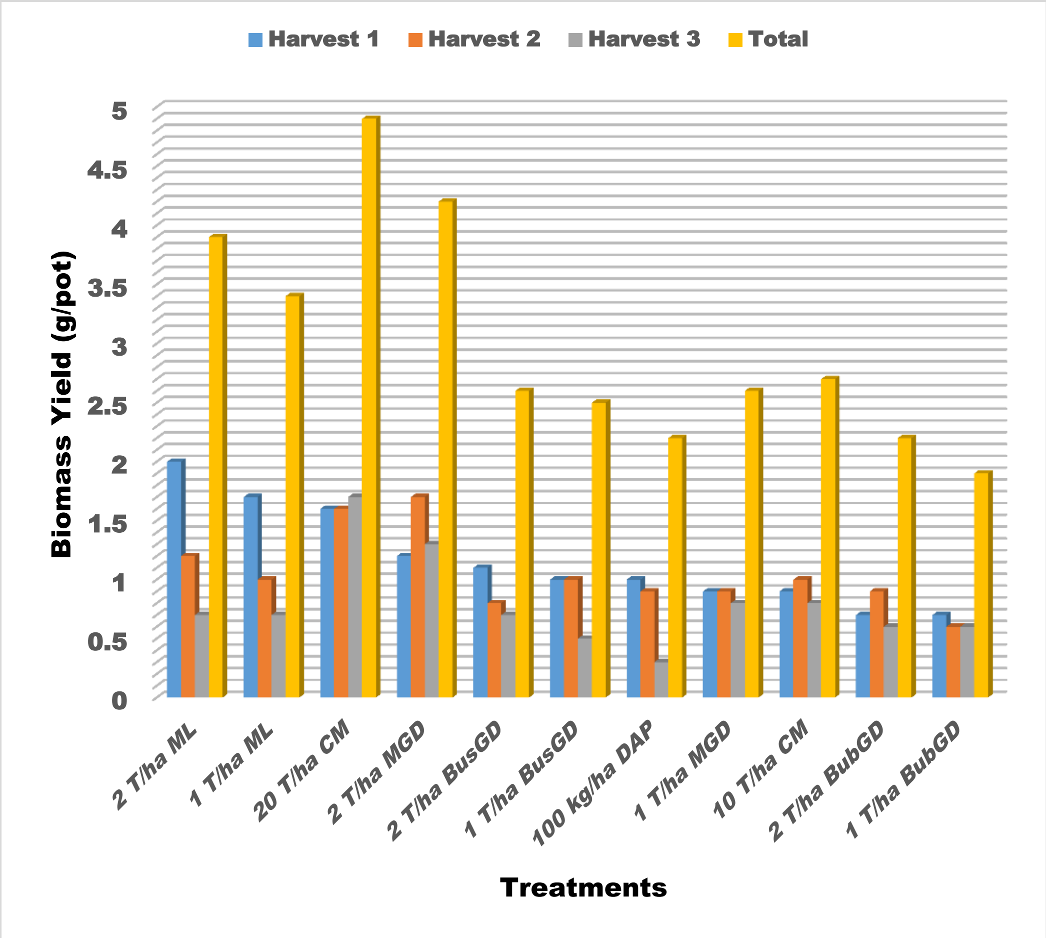

Figure 2. Residual effect of liming materials on amaranth biomass yields (g/pot)

As illustrated in Figure 2, total biomass yields decreased from harvest 1 to harvest 3 for 2 T/ha Moso Lime, 1 T/ha Moso Lime, 2 T/ha Busiga GD, and most notably with 100 kg/ha DAP. Stable but low total amaranth biomasses were observed with 1 T/ha Moso GD, 10 T/ha CM, 2 T/ha Bubanza GD, 1 T/ha Bubanza GD. The two high yielding treatments were 2 T/ha Moso GD only topped by 20 T/ha CM with the most stable high amaranth biomasse yield. Accross the three succesive harvest, 20 T/ha CM showed highest amaranth root+shoot biomass yields, demonstrating a high residual effect, doubled by an efficient liming power of this organic amendement, associated with its basic pH and basic cation content (Ca, Mg) (Table 2).

Results outlined in this paper are colloborated by other similar research works. In fact, soil physicochemical impovement impact of chicken manure has met the interest of a number of investigators, among them Marechera and Mkhabela (2002) [19]. In an incubation study, these researchers tested effects of lime and chicken manure (0, 5, 10, 2 T/ha) and litter leaf ash application rates (0, 3, and 5 T/ha) on soil properties dynamics. They subsequently reported an increase of soil pH (from 4,1 to 5,6), a decrease in excchangeable acidity concomitantly with an increase in exchangeable basic cations (Ca, Mg, K). The order of effectiveness observed by the authors was as follows : Lime > chicken manure > Litter leaf ash. Litter leaf ash represented 12 % of lime effectiveness, while that of chicken manure was 26 % of lime effectiveness. The same researchers advanced that chicken manure and litter leaf ash are potential liming materials.

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Previous research works conducted in Burundi [17-18, 30] have indicated that limestone neutralises more Al generated acidity than animal manures. This conclusion is not colloborated by our work, as chicken manure (CM) at both 20 and 10 T/ha was as effective as some liming materials (Moso lime and Moso GD) in increasing soil pH and reducing Al toxicity (Moso Lime).

In general, double dose applications were more efficient than single dose applications accross all amendment types, either organic or mineral, in accordance with the mass action principle. With regard to chicken manure action on soil acidity alleviation, its effect in exchangeable and soil solution Al neutralisation is controlled by aliphatic organic acids of the oxalic, malic and citric acid group. This group of acids are known for their detoxification of exchangeable Al by complexation (Figure 3) proportionally to their abundance [4-7, 32].

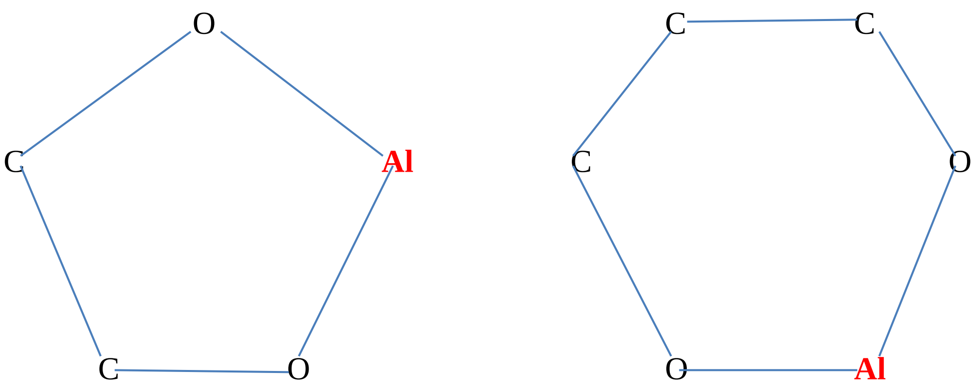

Figure 3. Schematic representation of Al complexation by short-chain organic acids [6].

According to Hue et al. (1986) [6], detoxification power of Al^{3+} by short-chained organic acids follows the order : Citric Acid > Oxalic Acid > Malic Acid > Succinic Acid.

Comparatively, the mode of action of mineral amendements such as $CaCO_3$ $MgCO_3$ used in our study vis-a-vis exchangeable acidity (Al^{3+}, H^+) neutralization is depicted by the following series of reactions [8]

$$2\ CaCO_3\ MgCO_3 \leftrightarrow 2\ Ca^{++} + 2\ Mg^{++} + 4\ CO_3^{2-} \quad [1]$$

$$(Al^{3+}H^+)\text{-Colloid-}(Al^{3+}H^+)+2\ Ca^{++} + 2\ Mg^{++} \leftrightarrow (2\ Ca^{++})\text{-Colloid–}(2\ Mg^+)+2\ Al^{3+}+2\ H^+ \quad [2]$$

$$2\ Al^{3+} + 6\ H_2O \leftrightarrow \mathbf{2\ Al(OH)_3\ (insoluble)} + 6\ H^+ \quad [3]$$

$$4\ CO_3^{2-} + 8\ H^+ \leftrightarrow 4\ H_2CO_3 \leftrightarrow 4\ CO_2 + 4\ H_2O \quad [4]$$

The present short-term pot study eluded some interesting findings. It was shown that chicken manure increased soil pH and available P and reduced Al exchangeable acidity, more or as much as some liming materials, partcicularly of Moso origin. Apparently, the positive influences of chicken manure goes beyond soil chemistry. For example, some investigators demonstated the effects of chicken manure on physical, chemical and biological properties [32-33]. These researchers stressed out the positive effects of chicken manure on soil bulk density and ultimately on soil porosity, soil water retention (humidity) and soil permeability to root growth, water and nutrient absorption.

4. CONCLUSION

As 73 % of Burundi high altitude soils are acidic (pH < 5.5), sustainable food production must go through soil acidity alleviation by the means of natural liming products ($CaCO_3.MgCO_3$) and organic matter. In that perspective, a research initiative was set up to evaluate the comparative liming power of locally available dolomitic products and chicken manure, using an amaranth (*Amaranthus viridis* L.) test crop in a 3-month

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pot study. The used soil was acidic, of low % base saturation and risks of Al toxicity, deficient in available P, Mg, Ca and K. The experimental design was a completely randomized with 11 treatments and 3 replicates, comprisinng of the control treatment (equivalent of 100 kg DAP/ha), 4 mineral amendments (Moso Lime, Moso Ground Dolomite, Bubanza Ground Dolomite and Busiga Ground Dolomite) applied at equivalents of 1 T/ha and 2 T/ha, and chicken manure applied at equivalents of 20 and 10 T/ha. Amaranth plant height, root length, shoot length, root biomass, shoot biomass and their summation (total biomass) were measured at one-month growth interval. Three succesive harvests were performed. Obtained results indicated the following : (i) the highest available P accumulation was associated with the equivalent of 20 T/ha of chicken manure ; (ii) application of equivalents 20 T/ha of chicken manure, 2 T/ha Moso Ground Dolomite and 2 T/ha Moso Lime increased soil pH by 0.2 to 0.5 pH-units ; (ii) DAP fertilized treatment was characterised by the lowest pH value and the highest Al^{3+} and H^{+} exchangeable acidity, illustrating the acidifying effect of this NH_4^+-bearing fertilizers ; (iv) amarant growth (root and height) and biomass (root + shoot) production were highest with 20 T/ha CM, 2 T/ha Moso Ground Dolomite and 2 T/ha Moso lime. Application rate was only visible for Moso Ground Dolomite (+ 162 %) and chicken manure (+ 182 %). Across three successive harvests, 20 T/ha chicken manure showed the highest and most stable amaranth root + shoot biomass yields, demonstrating its high residual effect, doubled by its efficient liming power, associated with its basic pH and basic cation content (Ca, Mg). Chicken manure potential residual effect should be evaluated under further field investigations as its positive influence goes beyond soil chemistry because it improves physical and biological properties as well, as was demonstrated elsewhere [33-34].

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