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Effect of Applying Low Rates of Agricultural Lime and Chicken Manure on Selected Soil Properties on *Ferralsols* of Lake Victoria Agro-Ecological Zone, Uganda

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Abstract

Ferralsols form a dominant type of soil on which most crops are grown in the Lake Victoria agro-ecological zone. Soil acidity has been recognized among the most important agricultural problems in such soils, which adversely affect crop production and productivity. A study was conducted with the objective of determining the effect of applying low rates of lime and chicken manure on selected soil chemical properties. Using a Split Plot Factorial Randomized Complete Block Design, agricultural lime (0.0, 0.5, 1.0, 1.5 & 2.0 t·ha^{-1}) as the main plot and chicken manure (0.0, 1.0, 2.0 & 3.0 t·ha^{-1}) as sub-plot were applied, replicated three times. The test crop was common bean var. NABE 15. The experiment was conducted for three rainy seasons, two seasons on-station and one season on-farm on *Ferralsol* soil in the Lake Victoria crescent of central Uganda. The results showed that applying low rates of lime with chicken manure significantly ($p < 0.05$) increased pH, CEC, P, N, K, BS and Mn changes at Mukono but not Masaka. A strong positive significant ($r^2 = 0.987$) relationship with pH change was obtained when 0.5 t·ha^{-1} lime was applied with the four chicken manure rates in Mukono. From the study, we recommend the application of small quantities of lime at 1.0 t·ha^{-1} with either 2.0 or 3.0 t·ha^{-1} chicken manure.

Keywords

Agricultural Lime, Chicken Manure, Soil Acidity, Tropical Soils

1. Introduction

Ferralsols are mostly found in the humid and sub-humid tropics, where temperatures and precipitation are high [1]. In East Africa, they cover about 13% of the land area, and in Uganda, they are the most dominant of the 22 soil types with 25% spatial coverage [2]. The high temperatures and precipitation cause increased chemical weathering, decomposition of organic matter and leaching of base cations. This makes them chemically poor with low weatherable minerals and weak cation retention by the mineral soil fraction [3]. The natural processes of weathering have been intensified by farmers' practices of continuous low-input cultivation, consequently resulting in the physical breakdown of soil aggregates and soil fertility degradation [4] [5].

Soil acidity has been recognized as a major agricultural problem in such soils, which adversely affects crop production and productivity in central Uganda [6] [7]. The small average farm sizes of about 0.8 hectares per household [8] render farms on these soils to inadequate fallow periods and exposure to severe erosion resulting in land degradation. Degradation of *Ferralsols* is manifested in low soil pH, Cation Exchange Capacity (CEC), nutrient availability, and presence of toxic levels of Aluminium (Al) and Manganese (Mn) and consequently declining production and productivity. Liming is a means of raising the pH of soil because it combats Al toxicity and raises the effective CEC. Previous studies have recommended the application of 15 to 20 $t \cdot ha^{-1}$ agricultural lime on such soils [6] [7]. However, for resource poor smallholder farmers who cannot afford such high rates of lime, other practical approaches have to be sought. Use of chicken manure which is readily available among farmers either alone or in combination with small quantities of lime can be utilized by smallholder farmers, but there is a paucity of information on the liming effect of chicken manure and the extent to which pH, CEC, nutrient availability, Al and Mn levels can be changed.

An experiment was therefore, set up using different rates of agricultural lime and chicken manure with the objective of determining the effect of applying low rates of lime and chicken manure on selected soil chemical properties.

2. Materials and Methods

2.1. Site Description

On-station experiments were set up at two stations: the first at Kamenyamiggo located in the Lwengo district within the Masaka region, situated at 0˚18'45.4"S 31˚39'61.4"E, 1280 meters (m) above sea level. The soil at the station is described as *Rhodic Ferralsol* with the pH range between 4.4 to 4.8, Organic Matter (OM) 2.9% to 4.1%, Bray-Phosphorus (P) is trace to 0.2 $mg \cdot kg^{-1}$, Calcium (Ca) 1.79 to 3.94 $mg \cdot kg^{-1}$, Magnesium (Mg) 0.17 to 0.52 $mg \cdot kg^{-1}$, Potassium (K) 0.02 to 0.11 $mg \cdot kg^{-1}$, CEC 18.5 to 26.1 meq 100 g^{-1}, Base Saturation (BS) 15.6% to 18.1% and the textural class is clay [9]. Prior to setting up the experiment, for season 2019A, the area had been cropped with cassava, then maize followed by fallow for four months. No fertilizer had been applied on this site. The common weeds were *Digitaria scalarum*, *Panicum maximum*, *Cynodon dactylon*, *Bidens pilosa* and Brachiaria sp. For season 2019B, another site was used, situated on the same farm. In the previous season, this site had been under sweet potato for three years and no fertilizer had been applied. The common weeds were *Digitaria scalarum*, *Bidens pilosa* and *Commelina benghalensis*.

A similar on-station experiment was established at Ntawo located in the Mukono region situated at 0˚23'07.5"N 32˚43'94.3"E, 1150 m above sea level. The soil at this site is described as *Rhodic Ferralsol* with the pH range between 4.9 to 5.7, OM 3.8% to 7.7%, Bray-P, trace to 1.6 $mg \cdot kg^{-1}$, Ca 1.35 to 15.69 $mg \cdot kg^{-1}$, Mg 1.94 to 7.27 $mg \cdot kg^{-1}$, K trace to 0.07 $mg \cdot kg^{-1}$, CEC 9.6 to 32.2 meq 100 g^{-1}, BS 26.1% to 80.1% and the textural class is sandy clay loam and clay [9]. Previously the site for season 2019A was cropped with maize with no fertiliser application. Common weeds were *Digitaria scalarum* and *Brachiaria* sp. For season 2019B, another site was used situated on the same farm and in the previous seasons, the site was under a short fallow of four months. The common weeds were *Digitaria scalarum* and *Brachiaria* sp.

During the third season (2020A), the experiments were conducted at farmers' fields. Promising on station combinations of lime and chicken manure was validated. In Masaka district, three farmers from Kabonera sub-county situated at 0˚24'63.0"S 31˚36'62.9"E, 1218 m above sea level participated. The soil is a *Rhodic Ferralsol* with the pH range between 4.8 to 6.1, OM 2.1% to 2.3%, Bray-P, 0.9 to 3.4 $mg \cdot kg^{-1}$, Ca 4.31 to 6.77 $mg \cdot kg^{-1}$, Mg 0.93 to 1.09 $mg \cdot kg^{-1}$, K 0.27 to 1.61 $mg \cdot kg^{-1}$, CEC 13.7 to 22.01 meq 100 g^{-1}, BS 25.0% to 69% [9]. The first farmer's field was under grazing for over 30 years and the common weeds were *Hyparrhenia rufa and Cymbopogon afronardus*. The second farmer's field was under maize and the common weeds were *Commelina benghalensis* and *Panicum maximum*. The third farmer's field was previously under maize and beans and later under short fallow. The common weeds were *Digitaria scalarum* and *Bidens pilosa*. In Buikwe district within the Mukono region, three farmers were selected from the Najja sub-county situated at 0˚17'44.4"N 33˚05'39.0"E, 1240 m above mean sea level. The soil at Buikwe on the farm is a *Rhodic Ferralsol* with the pH range between 4.5 to 5.3, OM 0.7% to 2.7%, Bray-P, trace to 0.4 $mg \cdot kg^{-1}$, Ca 3.84 to 6.47 $mg \cdot kg^{-1}$, Mg 1.37 to 6.31 $mg \cdot kg^{-1}$, K trace, CEC 23.0 to 26.0 meq 100 g^{-1}, BS 20.1% to 55.5% and the textural class is sandy clay loam and clay [9]. The first farmer's field was under a short fallow. The common weeds were *Digitaria scalarum*, *Panicum maximum* and *Heteropogon contortus.* The second farmer's field was under a short fallow. The common weeds were *Digitaria scalarum* and *Heteropogon contortus*. The third farmer's field was also under a short fallow. The common weeds were *Digitaria scalarum* and *Bidens pilosa.*

Both Masaka and Mukono regions receive bimodal rainfall in the MAM (March-April-May) and SON (September-October-November) with an average of 1000 to 1300 mm annually [10] [11]. Before any treatment with agricultural lime and chicken manure, soil samples were collected from 0 to 15 centimeters (cm) from all the sites and analyzed for pH, CEC, Carbon (C), Nitrogen (N), P, K, Ca, Mg, Sodium (Na), Mn, Exch. Al, BS and soil texture at Crop Nutrition Laboratory Service Ltd (CropNuts) in Nairobi, Kenya.

2.2. Experimental Design

The experiment used a split plot factorial Randomized Complete Block design on each study site with three replications done over three seasons in two years of 2019 and 2020. Each season different sites were used. Treatments included five rates of agricultural lime applied once to the main plots at 0.0, 0.5, 1.0, 1.5, 2.0 tons per hectare ($t \cdot ha^{-1}$) incorporated using a rake in the top 15 cm depth a month before planting. Each main plot was then split into four sub-plots each measuring 2 × 2 m separated by 1.0 m between and then treated randomly with chicken manure at 0.0, 1.0, 2.0, 3.0 $t \cdot ha^{-1}$ at the time of planting Namulonge Beans (NABE) 15 common bean variety. The experiments in the first season of 2019A and 2020A were planted during the long rains in early April and the second season of 2019B in September during the short rains. Agricultural lime and chicken manure samples were similarly sent to CropNuts, Nairobi, Kenya for analyses.

2.3. Site Management

Before planting, all the identified and selected sites were sprayed with Glyphosate herbicide (480 $g \cdot L^{-1}$ SL) mixed with 2 - 4 D Amine at a rate of 80 milliliters (mls) with 50 mls respectively in 16-liters knapsack to eliminate stubborn weeds notably *Digitaria scalarum*, *Pennisetum clandestinum* and *Commelina benghalensis*. These operations were followed by deep ploughing and harrowing using a tractor. After the second ploughing, a field measuring 16 × 13 m was demarcated for every replicate. Out of that main block, five main plots were demarcated, each measuring 2 × 13 m and from each plot, four sub-plots, each measuring 2 × 2 m were demarcated. Agricultural lime was applied and raked into the soil at about 15 cm depth a month before planting to allow time for reaction. Chicken manure was then applied by broadcast and incorporated at a depth of 8 - 10 cm using a rake at the time of planting [12] [13]. Two bean seeds of NABE15 variety were planted per hole at a spacing of 50 × 20 cm at a depth of 3 - 5 cm [13] [14]. Spacing was followed using the string and stake technique [12] [7] and each individual plot had 5 rows with 55 planting stations. The first season of the experiment (2019A) was planted on April 1st and 2nd at Mukono ZARDI and Kamenyamiggo, respectively. In the 2nd season, planting was done on September 22nd 2019 at Kamenyamiggo and October 5th 2019 at Mukono ZARDI. In the 3rd season of the experiment, that is the long rainy season (MAM) of 2020, planting was conducted on April 1st 2020 in Masaka and April 15th 2020 in Buikwe on farmers' fields. For each season a new site was used to avoid carry over effects for on-station experiments and on-farm, each farmer acted as a replicate.

2.4. Data Collection

Soil samples before treatment and after harvest were collected from 0 - 15 cm from each experimental plot as described by [15] [16]. Before treatment, soil samples were collected to establish the initial soil physical (texture) and chemical (pH, CEC, OC, N, P, K, Ca, Mg, Na, Al, Mn) properties. Soil samples after harvest were collected to understand the effect of the treatments on soil parameters. For on-farm, data was collected from promising treatments which had been evaluated at on-station for two consecutive seasons of 2019.

2.5. Soil Laboratory Testing Procedures

The pH was determined potentiometrically in a soil suspension of 1:2 (soil:water) using Water Proof Tester pH Meter Model HI2211 by Hanna Instruments. Soil P, Na, K, Ca, Mg, Mn, Al were determined after extraction with Mehlich 3 using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) Thermo model ICAP 6300. Soil N was digested using the Kjeldahl digester (Gerhardt model) which converts organic N compounds into the ammonium form, and then determined calorimetrically using UV (Shimadzu make UV-1900 model) at 655 nanometer (nm). Base saturation was determined by calculation:

$$\text{Percent Base Saturation} = \left(\text{Ca} + \text{Mg} + \text{K} + \text{Na}\left(\text{meq/100g soil}\right)/\text{CEC}\left(\text{meq/100g soil}\right)\right) \times 100 \quad (1)$$

Chicken manure cations were determined using ICP-OES Thermo model ICAP 6300 in closed vessel digestion with acid. Organic Matter was determined calorimetrically on the UV at about 600 nm using the Walkley-Black chromic acid wet oxidation method. Calcium and Mg from agricultural lime was determined using ICP-OES Thermo model ICAP 6300.

2.6. Data Analysis

Since location results differed greatly, data from each location were analyzed separately. Data to assess changes in soil chemical properties were entered in excel from which pre-planting and after harvest soil data changes in soil properties were calculated using the following equation:

$$\Delta y = x - a \quad (2)$$

where Δy = changes in concentration of a soil property

x is the final concentration of a soil property after bean harvest

a is the initial soil concentration of a soil property before planting. The selected soil properties that were investigated included; pH, CEC, P, N, K, BS, Mn and Al. The Δy was then analyzed using Genstat 12th edition to establish whether there were significant differences in terms of lime, chicken manure as main effects and their interactions fixed as factors using the F-tests at a significance level of $p < 0.05$. To test the level of influence of agricultural lime, chicken manure and their interactions linear regression was carried out using excel.

3. Results and Discussions

3.1. Characteristics of the Soil at on Station and on Farm before Treatment, Agricultural Lime and Chicken Manure Used in the Experiment

The pH of the soil for both on-farm (5.06 to 5.20) and on-station (5.65 to 5.79) was low to slightly acidic. On-farm CEC values were between 4.43 to 4.66 meq 100 g^{-1} and 9.28 to 11.75 meq 100 g^{-1} at on station. Likewise, the on-farm C levels were between 1.97% to 2.15% and 1.61% to 1.85% at on-station. Levels of P were between 2.12 to 8.89 ppm for both Mukono and Masaka on-farm and on-station. Total N was low ranging between 0.14% to 0.17%. Similarly, K levels were low at both on station and on-farm. The BS ranged from 50.54% to 72.81%. Exchangeable Al levels were generally high for on-farm ranging between 0.78 - 0.85 meq 100 g^{-1} and low for on-station ranging between 0.11 to 0.12 meq 100 g^{-1}. The soil texture was clay for both on-station and on-farm experimental sites (**Table 1**).

Agricultural lime used in the experiment had Ca and Mg content of 35.20% and 0.34%, respectively. In purity, CCE was 84.97% and ECCE was 60.13%. Its fineness was 22.1% (0.3 to 2 mm) and 48.67% (<0.3 millimeters (mm)) (**Table 2**).

Table 1. Selected chemical and physical properties of Ferralsols in the Lake Victoria Crescent at on-station and on-farm before treatment (0 - 15 cm).

Parameter	Unit	Masaka		Mukono	
		On-station	On-farm	On-station	On-farm
pH		5.79	5.06	5.65	5.20
C.E.C	meq 100 g^{-1}	11.75	4.43	9.28	4.66
Organic C	%	1.85	2.15	1.61	1.97
Total N	%	0.17	0.14	0.14	0.15
P	ppm	4.22	2.12	8.89	5.94
K	ppm	154.00	40.90	60.85	57.27
Ca	ppm	1200.00	319.00	827.50	374.33
Mg	ppm	250.00	58.50	170.00	56.87
Na	ppm	12.70	11.85	11.84	10.58
Mn	ppm	396.00	70.90	86.40	237.70
Exchangeable Al	meq 100 g^{-1}	0.12	0.78	0.11	0.85
BS	%	72.81	50.54	66.78	54.47
Particle size distribution					
Sand	%	43.0		39.7	
Silt	%	7.7		9.0	
Clay	%	49.3		51.3	
Soil texture		Clay		Clay	

Chicken manure used in the experiment had a Total N of 2.26% and 2.28% in Masaka and Mukono, respectively. In Masaka and Mukono, the P content was 1.43% and 1.10% whereas the pH was slightly alkaline at 7.81 and 7.84, respectively. In Masaka and Mukono, the K content was 1.75% and 1.83%, while Ca was 6.01% and 4.44%, respectively. Magnesium content in Masaka and Mukono was 0.72% and 0.74% whereas; Na was 0.38% and 0.32%, respectively. The Al content was 2537 and 2917 parts per million (ppm) whereas Mn was 305.67 and 731.67 ppm for chicken manure at Masaka and Mukono respectively (Table 3).

Table 2. Chemical characteristics of agricultural lime used in the experiment.

Grade	Parameter	Agricultural lime contents	
Alkalinity and acidity	pH	pH	10.63
Ca and Mg content	Ca	Ca (%)	35.20
	Mg	Mg (%)	0.34
Purity	Calcium Carbonate Equivalent	CCE (%)	84.97
	Effective Calcium Carbonate Equivalent	ECCE (%)	60.13
Fineness	Particle size (0.3 - 2 mm)	PSRE2 (%)	22.10
	Particle size (<0.3 mm)	PSRE (%)	48.67

PSRE is Particle Size Relative Effectiveness.

Table 3. Average chemical composition of chicken manure used in the experiment.

Composition	Masaka	Mukono	Mean
Macronutrients (%)			
Total N	2 .26	2.28	2.27
P	1.43	1.10	1.27
K	1.75	1.83	1.79
Ca	6.01	4.44	5.23
Mg	0.72	0.75	0.74
Na	0.38	0.32	0.35
S	0.32	0.26	0.29
C	34.97	40.03	37.50
Dry matter	91.80	91.40	91.60
Micronutrients (ppm)			
Mn	305.67	731.67	518.67
Fe	4966.67	8553.33	6760.00
Zn	256.33	179.00	217.67
B	22.40	20.13	21.27
Cu	58.37	43.97	51.17
Al	2536.67	2916.67	2726.67
Chemical properties			
EC(S) - 'mS·cm^{-1}	12.13	10.50	11.32
pH	7.81	7.84	7.83
C:N	15.50	17.57	16.54

3.2. Effect of Agricultural Lime and Chicken Manure on pH

Application of lime alone at Mukono on station significantly ($p < 0.05$) affected pH, CEC, P, N, K, BS, Mn and not Al changes (Table 4). Regression analysis indicated an increase in pH changes with increased agricultural lime rates (r^2 = 0.889). Similarly, [7] observed increased pH with increased limestone application rate (r^2 = 0.885) in the 0 to 15 cm depth in an Alfisol. The lowest pH change was observed with the control and at 0.5 t·ha^{-1} lime application rate and the highest pH change of 1.31 was obtained at 2.0 t·ha^{-1} lime application rate.

On the other hand, the application of chicken manure alone at Mukono on-station significantly ($p < 0.05$) affected pH, CEC, K and BS changes (Table 4). Chicken manures improve the chemical properties of soils by supplying N, P, K, Mn, Cu, Zn, Cl, B, Fe, and Mo which originate from the feed, bedding material, supplements, medications, and water the birds consume [17] [18]. Regression analysis indicated an increase in pH changes with increased chicken manure rates (r^2 = 0.981) in the 0 to 15 cm depth. The lowest pH change with chicken manure application was observed with the control and the highest of 0.61 at 3.0 t·ha^{-1}, although it was not significantly different from 0.50 obtained at 2.0 t·ha^{-1} chicken manure application. Applying small quantities of lime with chicken manure significantly affected pH, CEC, P, N, K, BS and Mn changes at Mukono on station (Table 4). Regression analysis showed an increase in pH changes with lime at 0.5 t·ha^{-1} and chicken manure (r^2 = 0.987). However, the lowest pH change of −0.77 was obtained with the control and the highest change of 1.50 with lime at 2.0 t·ha^{-1} combined with 3.0 t·ha^{-1} chicken manure (Table 4).

It can be concluded for pH that much as single application of lime and chicken manure brings about significant changes, their application when combined at 2.0 t·ha^{-1} lime with 3.0 t·ha^{-1} chicken manure brings about a bigger change compared to what is obtained from lime or chicken manure applied singly. High pH of 2.28 over the control at 5 t·ha^{-1} lime with 10 t·ha^{-1} manure was observed as compared to 1.33 and 2.19 when manure and lime were applied singly respectively [19]. This can be explained by the combined effects of both lime and chicken manure. When lime is applied to soil it supplies significant amounts of Ca^{2+} and Mg^{2+} ions (Table 2) which displace H^+, Fe^{2+}, Al^{3+}, Mn^{4+} and Cu^{2+} ions from soil adsorption sites resulting in increased soil pH [20] [21]. On the other hand, chicken manure raises soil pH due to the presence of Ca and Mg elements in it (Table 3) and its buffer capacity because of forming complexes with Al, Mn and Fe in acid soils [22] [23].

3.3. Effect of Lime and Chicken Manure on CEC

The application of agricultural lime influenced CEC (Table 4). Regression analysis showed that CEC change decreased with increased agricultural application rates in the 0 - 15 cm depth (r^2 = 0.776). CEC change was high at 4.617 meq 100 g^{-1} when 0.5 t·ha^{-1} lime was applied and decreased to its lowest of −0.324 meq 100 g^{-1} when lime was increased to 1.5 t·ha^{-1} (Table 4). On the contrary, [7] [24] while working on a *Ferralsol* of Masaka, reported increased CEC by 11.1 meq 100 g^{-1}

Table 4. Effect of applying different rates of agricultural lime and chicken manure on soil properties in the 0 - 15 cm at Mukono on station.

Parameter		ΔpH	ΔCEC (meq 100 g^{-1})	ΔP (ppm)	ΔN (%)	ΔK (ppm)	ΔBS (%)	ΔMn (ppm)	ΔAl (meq 100 g^{-1})
Lime (t·ha^{-1})									
0.0		-0.6600^{a}	3.607^{bc}	6.11^{a}	-0.011^{a}	6.8^{a}	-16.87^{a}	395.5^{d}	-0.005^{ns}
0.5		-0.2612^{b}	4.617^{c}	5.74^{a}	-0.005^{a}	7.4^{a}	-6.76^{b}	363.2^{c}	-0.023^{ns}
1.0		0.5350^{c}	2.909^{b}	33.14^{b}	0.028^{b}	135.2^{b}	14.63^{c}	334.8^{b}	0.009^{ns}
1.5		1.0700^{d}	-0.324^{a}	51.54^{c}	0.053^{c}	234.4^{c}	31.22^{d}	276.6^{a}	0.058^{ns}
2.0		1.3104^{e}	-0.253^{a}	52.66^{c}	0.055^{c}	222.6^{c}	35.81^{e}	275.0^{a}	0.019^{ns}
Significance		*	*	*	*	*	*	*	ns
Manure (t·ha^{-1})									
0.0		0.2383^{a}	2.785^{b}	27.1^{ns}	0.024^{ns}	106.7^{a}	7.37^{a}	334.9^{ns}	0.012^{ns}
1.0		0.2397^{a}	2.755^{b}	24.2^{ns}	0.0173^{ns}	91.8^{a}	7.11^{a}	338.1^{ns}	-0.002^{ns}
2.0		0.5033^{b}	1.408^{a}	31.5^{ns}	0.029^{ns}	135.8^{b}	14.63^{b}	318.3^{ns}	0.031^{ns}
3.0		0.6140^{b}	1.497^{a}	36.5^{ns}	0.026^{ns}	150.8^{b}	17.31^{b}	324.8^{ns}	0.006^{ns}
Significance		*	*	ns	ns	*	*	ns	ns
Lime × Manure (t·ha^{-1})									
Lime	Manure								
0.0	0.0	-0.7667^{a}	3.572^{bc}	5.33^{a}	-0.012^{ab}	12.1^{a}	-20.26^{a}	393.5^{d}	0.045^{ns}
0.0	1.0	-0.7250^{a}	4.032^{bcd}	11.63^{a}	-0.00333^{b}	7.7^{a}	-18.89^{ab}	401.5^{d}	-0.018^{ns}
0.0	2.0	-0.6567^{ab}	3.513^{bc}	4.78^{a}	-0.00333^{b}	-0.4^{a}	-16.61^{ab}	392.7^{d}	-0.019^{ns}
0.0	3.0	-0.4917^{abc}	3.313^{b}	2.72^{a}	-0.027^{a}	7.8^{a}	-11.71^{bc}	394.3^{d}	-0.026^{ns}
0.5	0.0	−0.3517bc	5.432^{bcd}	10.80^{a}	-0.00500^{ab}	13.4^{a}	-8.88^{c}	354.5^{c}	-0.028^{ns}
0.5	1.0	-0.3033^{bc}	3.967^{bcd}	4.50^{a}	-0.013^{ab}	4.4^{a}	-7.26^{cd}	353.2^{c}	-0.018^{ns}
0.5	2.0	-0.2217^{cd}	4.417^{bcd}	3.42^{a}	0.00167^{b}	4.9^{a}	-6.67^{cde}	375.8^{cd}	-0.02^{ns}
0.5	3.0	-0.1683^{cd}	4.655^{bcd}	4.25^{a}	-0.00167^{b}	6.9^{a}	-4.24^{cde}	369.5^{cd}	-0.025^{ns}
1.0	0.0	0.0600^{d}	5.643^{cd}	15.81^{a}	-0.00333^{b}	52.7^{a}	0.68^{e}	383.5^{cd}	-0.044^{ns}
1.0	1.0	0.0867^{d}	6.118^{c}	3.39^{a}	0.00333^{b}	10.1^{a}	-0.77^{de}	364.7^{cd}	-0.048^{ns}
1.0	2.0	0.9117^{e}	-0.283^{a}	44.11^{b}	0.06167^{def}	223.7^{b}	27.24^{f}	303.3^{b}	0.087^{ns}
1.0	3.0	1.0817^{ef}	0.157^{a}	69.24^{c}	0.05167^{cdef}	254.5^{b}	31.35^{fghi}	287.6^{ab}	0.042^{ns}
1.5	0.0	0.9683^{ef}	0.100^{a}	53.36^{bc}	0.07167^{f}	249.0^{b}	29.72^{fgh}	281.6^{ab}	0.052^{ns}
1.5	1.0	0.9117^{e}	-0.033^{a}	50.53^{bc}	0.04167^{cd}	212.0^{b}	27.87^{fg}	280.3^{ab}	0.029^{ns}
1.5	2.0	1.2483^{efg}	-1.005^{a}	52.31^{bc}	0.04667^{cde}	241.8^{b}	34.97^{ghi}	257.4^{a}	0.103^{ns}
1.5	3.0	1.1517^{efg}	-0.358^{a}	49.96^{bc}	0.05167^{cdef}	234.8^{b}	32.33^{fghi}	287.3^{ab}	0.047^{ns}
2.0	0.0	1.2817^{fg}	-0.822^{a}	50.24^{bc}	0.06833^{ef}	206.5^{b}	35.57^{hi}	261.6^{a}	0.035^{ns}
2.0	1.0	1.2283^{efg}	-0.308^{a}	51.06^{bc}	0.05833^{cdef}	224.8^{b}	34.61^{fghi}	290.8^{ab}	0.045^{ns}
2.0	2.0	1.2350^{efg}	0.400^{a}	53.03^{bc}	0.03833^{c}	209.2^{b}	34.24^{fghi}	262.1^{a}	0.004^{ns}
2.0	3.0	1.4967^{g}	-0.283^{a}	56.29^{bc}	0.05500^{cdef}	249.8^{b}	38.80^{i}	285.4^{ab}	-0.006^{ns}
Significance		*	*	*	*	*	*	*	ns

*Significant at $p < 0.05$, Means with the same letter within a column means not significant from each other at $p < 0.05$, ns-Non significant.

with increased lime application rates of 20 t·ha^{-1}. They attributed the direct relationship of CEC with soil pH to the presence of pH dependent negative charges and enhanced concentration of Ca^{2+} which could have led to the replacement of H^+ and Al^{3+} from the soil solution and soil exchange complex. Similarly, with the application of chicken manure at Mukono, the trend showed a decreased CEC change with an increased chicken manure application rate (**Table 4**).

CEC change was significantly high with the control and at 1.0 t·ha^{-1} chicken manure compared to 2.0 and 3.0 t·ha^{-1} chicken manure and decreased with increased chicken manure rates. On the contrary, [25] reported a significant increase of CEC at 10%, 20% and 40% chicken manure in *Luvic Calcisol*, *Ferralic Arenosol* and *Vertic Luvisol*. They attributed the increase in CEC to the humus contained in chicken manure.

Combining lime with chicken manure showed a similar decreasing trend of CEC with an increased application rate at Mukono. Applying 1.0 t·ha^{-1} lime with an equal amount of chicken manure resulted in high change in CEC of 6.118 meq 100 g^{-1} which was not significantly different from values obtained at 0.5 t·ha^{-1} lime with the four chicken manure rates; the control and chicken manure at 1.0 and 2.0 t·ha^{-1} without lime (**Table 4**). Applying lime with chicken manure beyond 1.0 t·ha^{-1} lime with 1.0 t·ha^{-1} chicken manure resulted in decreased CEC change.

3.4. Effect of Lime and Chicken Manure on P

Application of agricultural lime in Mukono influenced P in the 0 - 15 cm soil depth (**Table 4**). The trend indicates increased P changes with increased lime rates. The lowest P was obtained at 0.5 t·ha^{-1} and the highest of 52.66 ppm at 2.0 t·ha^{-1} in Mukono. In Masaka, no significant change in P was observed with lime application rates. This is contrary to what [6] observed when they applied 15.9 t·ha^{-1} lime and obtained an available P change of 15 ppm on a *Ferralsol* of Masaka. This can be explained by the low lime rates that were used in the experiment compared to what [6] applied.

Application of chicken manure alone, on the other hand, did not cause any significant effect on P change at Mukono on-station, but when lime was combined with chicken manure, a significant increase was observed. The trend showed increased P change with increased lime with chicken manure rate (**Table 4**). The highest P change of 69.24 ppm was obtained when 1.0 t·ha^{-1} of lime was combined with 3.0 t·ha^{-1} chicken manure which was not significantly different from the values obtained at 1.5 t·ha^{-1} and 2.0 t·ha^{-1} lime with the four chicken manure rates (**Table 4**). This means that if the aim is to increase P which is always a limiting factor in *Ferralsol*, application of lime at 1.0 t·ha^{-1} with 3.0 t·ha^{-1} chicken manure may suffice. The study further indicates that lime alone caused a significant increase in P changes of 33.1 ppm at 1.0 t·ha^{-1} compared to the control and 0.5 t·ha^{-1}. As lime increased to 1.0 t·ha^{-1} P changes (51.5 ppm) increased significantly and on further increment to 2.0 t·ha^{-1}, the P change (52.7 ppm) did not significantly differ from that obtained with 1.0 t·ha^{-1} lime. When chicken manure was used alone it did not cause a significant increase at Mukono on-station. This means that combining lime with chicken manure can be beneficial in P availability on a *Ferralsol*.

3.5. Effect of Lime and Chicken Manure on N

Application of lime at Mukono on station resulted in significant ($p < 0.05$) N change. The N changes obtained with the control and application of 0.5 $t \cdot ha^{-1}$ of lime were significantly lower than those obtained with the application of 1.0 - 2.0 $t \cdot ha^{-1}$ of lime (**Table 4**). Increasing lime to 1.5 $t \cdot ha^{-1}$ caused 0.053% N change which was not significantly different from 0.055% obtained with 2.0 $t \cdot ha^{-1}$. The trend indicates increased N changes with an increase in lime application rates (**Table 4**). A strong positive significant ($r^2 = 0.932$) relationship between lime application rates and N changes was obtained indicating increased N changes with the increased lime rate (**Table 5**).

Short-term impact of liming increases N availability due to improved pH conditions which in turn enhances soil biological process such as N cycling [26]. Application of chicken manure alone did not significantly affect N at Mukono on station however, combining small rates of lime with chicken manure caused a significant effect (**Table 4**). Use of slightly high rate of 1.5 $t \cdot ha^{-1}$ lime alone resulted in N change of 0.072% which was not significantly different from 0.062 and 0.052% obtained when 1.0 $t \cdot ha^{-1}$ lime with either 2.0 or 3.0 $t \cdot ha^{-1}$ was applied respectively.

3.6. Effect of Lime and Chicken Manure on K

Lime application at Mukono on-station significantly affected K changes (**Table 4**). There was increased K change with increased lime rates. A high K change of 234.4 ppm was obtained with 1.5 $t \cdot ha^{-1}$ lime and this was not significantly different from 222.6 ppm obtained with 2.0 $t \cdot ha^{-1}$ lime. A slight increment in exchangeable K was reported when lime ($CaCO_3$) was applied to acidic soils [27]. It was explained that availability of K was associated with the impact of pH on the release of K from interlayer spaces in clays [26].

Table 5. Linear functions for agricultural lime and chicken manure rates predicting selected soil properties at Mukono on-station.

Parameter	Treatment	Function	r^2
ΔpH	l	0.1400x - 0.2442	0.889
	m	0.0361x - 0.1584	0.981
	$m \times l_{0.0}$	0.0893x - 0.7942	0.862
	$m \times l_{0.5}$	0.0633x - 0.3562	0.987
ΔCEC (meq 100 g^{-1})	l	−2.5320x + 4.6460	0.776
ΔN (%)	l	0.0380x - 0.0140	0.932
ΔK (ppm)	m	131.7200x - 10.4400	0.839
ΔBS (%)	l	28.6680x -17.1000	0.954

l-agricultural lime; m-chicken manure.

Application of chicken manure, on the other hand, significantly affected K changes in Mukono on station. Regression analysis indicated an increase in K changes with increased agricultural lime rates ($r^2 = 0.839$) as presented in **Table 5**. The highest K change of 150.8 ppm was obtained with 3.0 t·ha^{-1} chicken manure (**Table 4**). This increased K change when chicken manure was applied was attributed to the release of K from the manure [27].

When lime was combined with chicken manure a similar trend of increased K changes with increased lime with chicken manure rates was obtained. The highest K change of 254.5 ppm was obtained when 1.0 t·ha^{-1} lime was applied with 3.0 t·ha^{-1} chicken manure (**Table 4**). However, this was not significantly different from 223.7 ppm obtained with 1.0 t·ha^{-1} lime with 2.0 t·ha^{-1} chicken manure and 1.5 and 2.0 t·ha^{-1} lime with the four chicken manure rates. That means that K content can be substantially increased by lime application at 1.0 t·ha^{-1} with either 2.0 or 3.0 t·ha^{-1} chicken manure. The change in K is much higher than when lime or chicken manure is applied separately. At a rate of 1.0 t·ha^{-1} when lime is applied singly 135.2 ppm is obtained and if chicken manure is applied singly at 2.0 t·ha^{-1} 135.8 ppm and at 3.0 t·ha^{-1} 150.8 ppm is obtained.

3.7. Effect of Lime and Chicken Manure on BS

In Mukono, lime significantly ($p < 0.001$) increased BS changes (**Table 4**). Regression analysis indicated that BS increased with an increased lime application rate ($r^2 = 0.954$). The highest BS change of 35.81% was obtained at 2.0 t·ha^{-1} lime application rate which was significantly higher than the BS change that was obtained with the lime rates applied and the control (**Table 4**). The BS increment was a result of Ca and Mg contained in lime [28] as also observed in **Table 2**. An increment of 29% and 69% BS over the control in the level of Ca and Mg were reported when 2 t·ha^{-1} of lime were applied to a sandy loam Leptosol [29]. Application of chicken manure significantly affected BS as well. Generally, BS changes increased with increased chicken manure rates (**Table 4**). The highest BS change of 17.31% was obtained at 3.0 t·ha^{-1} chicken manure rate though it was not significantly different from 14.63% obtained at 2.0 t·ha^{-1} chicken manure. Kyebogola (2018) [12] attributed the BS increase to the basic ions found in chicken manure. In this study the chicken manure that was used in the Mukono experiment contained Ca 4.44%, Mg 0.75%, K 1.83% and Na 0.32% on a dry weight basis (**Table 3**). The combined application of lime with chicken manure significantly affected BS changes. The highest change in BS of 38.80% was obtained when 2.0 t·ha^{-1} lime was applied with 3.0 t·ha^{-1} chicken manure however, this was not significantly different from what was obtained when lower rate of 1.5 t·ha^{-1} lime was applied with either 2.0 or 3.0 t·ha^{-1} chicken manure or when lime was maintained at 2.0 t·ha^{-1} without chicken manure or with chicken manure at 1.0 or 2.0 t·ha^{-1} chicken manure (**Table 4**).

3.8. Effect of Lime and Chicken Manure on Mn

At Mukono on station Mn changes decreased significantly ($p < 0.001$) with increased lime application rates. The highest change in Mn content of 395.5 ppm was at the control and the lowest of 275.0 ppm with 2.0 t·ha^{-1} lime application rate (**Table 4**). Application of lime with chicken manure significantly affected Mn changes in Mukono. The trend indicated a decreasing trend with increased lime rates at the four chicken manure rates (**Table 4**). The lowest Mn change of 257.4 ppm was obtained when lime at 1.5 t·ha^{-1} was applied with 2.0 t·ha^{-1} chicken manure and this was not significantly different from the four manure rates at the same lime rate of 1.5 t·ha^{-1} and 2.0 t·ha^{-1} with the four chicken manure rates but significantly lower than the control, lime rates at 0.5 and 1.0 t·ha^{-1} with the four chicken manure rates (**Table 4**). When lime was used alone at the rate of 1.5 t·ha^{-1}, Mn change was 276.6 ppm and application of chicken manure alone did not significantly affect Mn changes. However, the reduction obtained when small quantities of lime at 1.5 t·ha^{-1} with chicken manure at 2.0 t·ha^{-1} indicates the importance of combining these two in Mn toxicity reduction on *Ferralsols*.

3.9. Effect of Lime and Chicken Manure on Al

The application of lime or chicken manure alone or their interaction did not significantly affect Al changes in Mukono (**Table 4**). At both stations (Mukono and Masaka), the exchangeable Al was below the critical level of 0.6 meq 100 g^{-1}. At low pH less than 5.5 dissolution of toxic free Al^{3+}, Mn^{2+} and high concentration of H^+ thrives, and with liming the soil precipitates Al and Fe as $Al(OH)_3$ and $Fe(OH)_3$ [30] [31] [32]. At both stations the soil contained 0.11 meq 100 g^{-1} and 0.12 meq 100 g^{-1} in Mukono and Masaka respectively which were below the critical value of 0.6 meq 100 g^{-1} (**Table 1**) and the average Al composition in the chicken manure that was applied was only 2726.67 ppm (**Table 3**).

3.10. Effect of Lime and Chicken Manure at on Farm

The third season study was carried out at farmers' fields using promising combinations of low rates of lime with chicken manure (**Table 6**). Validation of promising technologies at on-station resulted in varied results. In Mukono pH improved by 0.007, Mn and Al concentrations reduced by 55.7 ppm and 0.287 meq 100 g^{-1} respectively by application of 2.0 t·ha^{-1} chicken manure (**Table 6**). The other option was 1.5 t·ha^{-1} of lime with 2.0 t·ha^{-1} chicken manure. This improved the pH by 0.013, reduced Mn by 50.3 ppm and Al by 0.48 meq 100 g^{-1}. Alternatively, the application of equal amounts of 2.0 t·ha^{-1} for lime with chicken manure also resulted in pH increase of 0.057 and Mn reduction by 51.7 ppm and Al by 0.617 meq 100 g^{-1}. With those options the CEC, P, N, K, BS were enhanced as well (**Table 6**).

In Masaka, with the aim of reducing Mn and Al concentration, the options are to use 1.0 t·ha^{-1} lime with 3.0 t·ha^{-1} chicken manure. This reduced Mn by 11.0 ppm and Al by 0.013 meq 100 g^{-1}. It however, resulted in reduced pH by 0.117, N by 0.017% and BS by 3.4% but enhanced CEC, P and K (**Table 6**). Another

Table 6. Validation of best optimum lime and chicken manure on selected soil properties in Mukono and Masaka on-farm.

Location	Lime ($t \cdot ha^{-1}$)	Manure ($t \cdot ha^{-1}$)	ΔpH	ΔCEC (meq 100 g^{-1})	ΔP (ppm)	ΔN (%)	K (ppm)	ΔBS (%)	ΔMn (ppm)	ΔAl (meq 100 g^{-1})
Mukono	0.0	0.0	−0.423	0.93	−0.02	0.013	−3.5	−11.41	−88.7	0.373
	0.0	2.0	0.007	3.04	3.16	0.007	5.6	0.19	−55.7	−0.287
	1.0	3.0	−0.010	3.83	3.65	0.000	9.9	−0.25	−64.7	−0.543
	1.5	2.0	0.013	6.05	6.04	0.007	13.0	0.44	−50.3	−0.483
	1.5	3.0	−0.093	2.87	3.53	0.020	14.0	−3.04	−66	−0.213
	2.0	1.0	−0.097	6.27	4.61	0.023	11.4	−2.76	−66.7	−0.600
	2.0	2.0	0.057	8.61	11.40	0.020	10.0	1.77	−51.7	−0.617
Masaka	0.0	0.0	−0.177	0.43	1.33	−0.037	1.2	−4.20	−3.1	0.150
	0.0	1.0	−0.243	2.40	1.07	0.000	19.3	−6.20	18.3	−0.160
	0.0	2.0	−0.213	0.86	2.41	−0.010	25.2	−4.90	3.9	0.160
	0.0	3.0	−0.03	0.47	3.24	−0.027	44.7	−0.20	4.0	−0.097
	0.5	3.0	−0.14	0.92	3.19	−0.045	21.4	−3.70	−1.9	−0.020
	1.0	3.0	−0.117	0.63	0.99	−0.017	27.2	−3.40	−11.0	−0.013
	2.0	3.0	−0.027	4.84	5.02	−0.013	22.6	0.60	16.5	−0.257

option was the application of 0.5 $t \cdot ha^{-1}$ lime with 3.0 $t \cdot ha^{-1}$ chicken manure. This reduced Mn by 1.9 ppm and Al by 0.02 meq 100 g^{-1}. However, it also resulted in reduced pH by 0.14, and N by 0.045% but similarly enhanced CEC, P, and K.

4. Conclusion

In acid soil, results from this study had varied results in Mukono applying lime alone significantly affected pH, CEC, P, N, K, BS, Mn and not Al changes, whereas chicken manure caused a significant increase in pH, CEC, K, and BS. A strong positive relationship was obtained between lime rate and pH, CEC, N, and BS, whereas for chicken manure, the strong relationship was between chicken manure rate and pH and K. Applying low rates of lime with chicken manure significantly affected pH, CEC, P, N, K, BS and Mn changes. The strong positive relationship with the combination was with pH only at Mukono. It can be concluded from the study that a big pH change can be obtained at 2.0 $t \cdot ha^{-1}$ lime with 3.0 $t \cdot ha^{-1}$ chicken manure when compared to what is obtained from lime or chicken manure applied singly. At that rate P, N, K, and BS will also be significantly available for the subsequent season crop and Mn will decrease significantly. It was further evidence that applying small quantities of lime alone at a rate of 0.5 $t \cdot ha^{-1}$ or no input at all did not improve the soil fertility situation but led to a reduction in pH, P, K, BS and least gain in N after the cropping season implying unsustainable production systems. It is therefore, recommended that for sustainable production systems, it is important to apply lime at a rate higher than 0.5 $t \cdot ha^{-1}$ with chicken manure. Cultivation without any input leads to soil nutrient mining and subsequent soil degradation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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