Vol. 18(12), pp. 1110-1120, December, 2022
DOI: 10.5897/AJAR2022.16176
Article Number: 0EAC07F70110
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effect of applying low rates of lime and manure on bean growth and yield on *Ferralsols* of Lake Victoria crescent agro-ecological Zone-Central Uganda

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Received 14 August, 2022; Accepted, 16 November, 2022

An experiment was conducted to determine the effect of applying low rates of lime and chicken manure on bean (var. NABE 15) growth and yield on *Ferralsols*. Using split plot factorial randomized complete block design, lime (0.0, 0.5, 1.0, 1.5 and 2.0 t ha^{-1}) as the main plot and chicken manure (0.0, 1.0, 2.0 and 3.0 t ha^{-1}) as sub plot, were replicated three times. The experiment was conducted for three rainy seasons, two seasons' on-station and one season on-farm using promising combinations from the on-station experiments. In Mukono, increased grain yield of 117% over the control was observed at 2.0 t ha^{-1} lime with 1.0 t ha^{-1} manure. Applying 1.5 t ha^{-1} lime with 2.0 or 3.0 t ha^{-1} manure resulted in a yield increase of 81.1 and 103.6% over the control respectively. Applying 0.5 t ha^{-1} lime or 1.0 and 2.0 t ha^{-1} manure alone caused minimal yields. In Masaka 0.5 t ha^{-1} lime with 3.0 t ha^{-1} manure, resulted in 95% yield increase over the control. The control and 0.5 t ha^{-1} lime yielded the least. All the BCRs were less than one; there was net gain in nutrients (N.P.K) for the subsequent crop.

Key words: Agricultural lime, chicken manure, bean growth and yield, benefit cost ratio (BCR).

INTRODUCTION

Common bean (*Phaseolus vulgaris L.)* is one of the most important legumes grown worldwide. About 31.8 million tonnes of beans are produced annually from 41,712, 000 ha (FAO, 2019). Globally the common bean crop is ranked third after soybean and groundnut (Myers and Kimiecik, 2017). It is an important source of high protein, fiber, complex carbohydrate, vitamins like B, Ca, antioxidants, micronutrients like Fe and Zn, and household income (MAAIF, 2018). Uganda is Africa's second largest bean producer after Tanzania (Mashamba et al., 2021). Bean is ranked fifth among the priority crops in Uganda (Sibiko et al., 2013). Uganda produced

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0.9 million tonnes from 0.67 million hectares obtaining a share of 2.9% of the world production between 2012 and 2014 (FAO, 2019). The increased bean production in the country from 1998 has been due to expansion in area under cultivation and introduction of improved varieties (FAO, 2011). However, the strategy of increasing bean production through extensification processes has come under serious scrutiny. For example, ecosystems have been tampered with like the country's forests cover continues to be reduced (Sibiko et al., 2013) and fragile areas have been seriously degraded in search of fertile cultivatable land for increased crop production. It is therefore, important to increase land productivity as cultivatable land continues to become scarce over time (Piya et al., 2011).

In Uganda, the bean crop is preferentially grown on black (*Phaeozem*) soil but because of its small area coverage coupled with competing production needs, they are also grown on red *Ferralsols* (Goettsch et al., 2017) which are inherently deficient of nutrients. On such soil, the productivity of bean gets constrained by low and declining soil fertility emanating from low available N, P, low pH, aluminum and Mn toxicity and deficiency of Ca and Mg among others (Mowrer et al., 2019). Previous liming studies have recommended application of 15 to 19 t ha^{-1} agricultural lime (Goettsch et al., 2017; Bulyaba et al., 2020). However, such rates are often too high for the smallholder farmer. Such constraints can be addressed by use of small quantities of lime with chicken manure that is affordable by the small holder farmers. However, there is a paucity of information on the optimum quantities to be applied to obtain optimum yields. Therefore, the objective of this study was to determine optimum rates of lime and chicken manure for bean production on *Ferralsols* of Lake Victoria agro-ecological zone, Central Uganda.

MATERIALS AND METHODS

Site description

On-station experiments were set up at two research centres under the Mukono Zonal Agricultural Research and Development Institute (Figure 1). The first on-station experiment in Masaka region was established at Kamenyamiggo in Lwengo district situated at 0°18'45.4"S 31°39'61.4"E, 1280 m above sea level. The soil at this station is a *Rhodic Ferralsol* with the pH range between 4.4 to 4.8, OM 2.9 to 4.1%, Bray-P is trace-0.2 ppm, Ca 1.79 to 3.94 cmol(+)/kg soil, Mg 0.17 to 0.52 cmol(+)/kg soil, K 0.02 to 0.11 cmol(+)/kg soil, CEC 18.5 to 26.1 cmol(+)/kg soil, base saturation (BS) 15.6 to 18.1% and the textural class is clay (Sustainable Land Management Uganda, 2020). Prior to the experiment, the field was under cassava, then maize followed by fallow for four months. No fertilizer had been applied in 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. Previously this site had been under sweet potato for 3 years with no fertilizer applied. The common weeds were *Digitaria scalarum*, *Bidens pilosa* and *Commelina benghalensis*.

A similar on-station experiment was established at Ntawo in 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 a *Rhodic Ferralsol* with pH range between 4.9 to 5.7, OM 3.8 to 7.7%, Bray-P, trace-1.6 ppm, Ca 1.35 to 15.69 cmol(+)/kg soil, Mg 1.94 to 7.27 cmol(+)/kg soil, K trace-0.07 cmol(+)/kg soil, CEC 9.6 to 32.2 cmol(+)/kg soil, BS 26.1 to 80.1% and the textural class is sandy clay loam and clay (Sustainable Land Management Uganda, 2020). Previously the site was cropped to maize with no fertiliser applied. For season 2019A site, the common weeds were *Digitaria scalarum* and *Brachiaria* sp. For season 2019B another site was used situated on the same farm and was under a short four-month fallow during the previous season. The common weeds were *Digitaria scalarum* and *Brachiaria* sp.

During the third season (2020A), experiments were conducted at farmers' fields. Promising on-station combinations of lime and chicken manure were 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 kg^{-1}, Ca 4.31 to 6.77 mg kg^{-1}, Mg 0.93 to 1.09 mg kg^{-1}, K 0.27 to 1.61 mg kg^{-1}, CEC 13.7 to 22.01 meq 100 g^{-1}, BS 25.0 to 69% (Sustainable Land Management Uganda, 2020). 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 under Mukono region, three farmers from Najja sub-county situated at 0°17'44.4"N 33°05'39.0"E, 1240 m above mean sea level were selected. The soil at Buikwe on-farm is a *Rhodic Ferralsol* with the pH range between 4.5 to 5.3, OM 0.7 to 2.7%, Bray-P, trace-0.4 mg kg^{-1}, Ca 3.84 to 6.47 mg kg^{-1}, Mg 1.37 to 6.31 mg 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 (Sustainable Land Management Uganda, 2020). 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 also under a short fallow. The common weeds were *Digitaria scalarum* and *H. contortus*. The third farmer's field was also under a short fallow. The common weeds were *D. scalarum* and *Bidens pilosa.*

Both Masaka and Mukono regions receive bimodal rainfall in the MAM (March-April-May) and SON (September-October-November) with average of 1000 to 1300 mm annually (Masaka DDP, 2011; Mukono DDP, 2015). Before any treatment of agricultural lime and chicken manure, soil samples were collected from 0 to 15 cm from all the sites and analyzed for pH, CEC, C, N, P, K, Ca, Mg, Na, Mn, Exch. Al, base saturation (BS) and soil texture at Crop Nutrition Laboratory Service Ltd (CropNuts) in Nairobi, Kenya.

Experimental design

The experiment used a Split Plot Factorial Randomized Complete Block Design on each site of study with three replications done over three seasons in two years of 2019 and 2020. Treatments included five rates of agricultural lime applied once to the main plots at 0.0, 0.5, 1.0, 1.5 and 2.0 t ha^{-1}. 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 and 3.0 t ha^{-1}. Agricultural lime and chicken manure samples were similarly sent to Crop-Nuts, Nairobi, Kenya for analyses.

Site management

Before planting, all the selected sites were sprayed with glyphosate

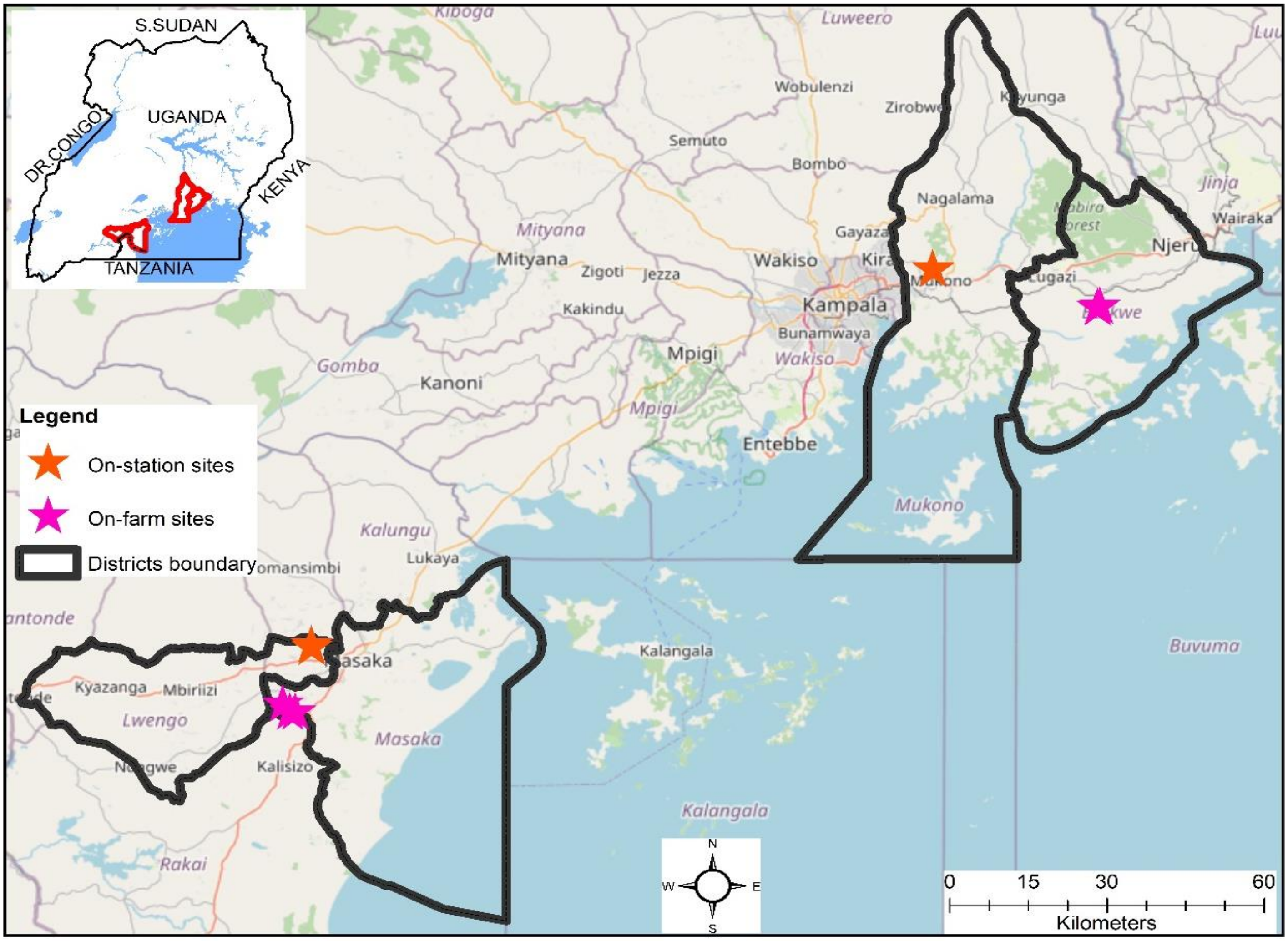


Figure 1. Map showing the location of on-station and on-farm study areas in Mukono and Masaka regions.
Source: Authors

herbicide (480 g L^{-1} SL) mixed with 2-4 D Amine at a rate of 80 ml with 50 ml respectively in 16-L knapsack to eliminate stubborn weeds notably *D. scalarum*, *P. clandestinum* and *C. 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 the main block, five main plots were demarcated each measuring 2×13 m from which 4 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 broadcast and incorporated at a depth of 8 to 10 cm using a garden rake at the time of planting (Kyebogola, 2018). Two bean seeds of NABE15 variety were planted per hole at a spacing of 50×20 cm at a depth of 3 to 5 cm (Amongi et al., 2014). Spacing was followed using the string and stake technique (Bulyaba et al., 2020) and each individual plot had 5 rows with 55 planting stations. The first season of the experiment (2019A) was planted on 1st and 2nd April for Mukono ZARDI and Kamenyamiggo, respectively. In the 2nd season of 2019 planting was done on 22nd September at Kamenyamiggo and 5th October at Mukono ZARDI. In the 3rd season that is the long rainy season (MAM) of 2020, planting was done on 1st April in Masaka and 15th April in Buikwe on-farmers' fields. For each season a new site was used to avoid carry over effects for on-station experiments; on-farm, each farmer acted as a replicate.

Data collection

Data was collected from individual plots from the plants in the three middle rows, leaving aside plants in the border rows and those at both ends of each row.

Leaf area index (LAI)

Data on LAI was collected using an electronic device (Accupar LP-80 Ceptometer (Model LP-80 Version 2014, Meter Group, Inc., Pullman, WA, USA)) which assesses the light intercepted by the canopies (Gonsamo et al., 2018; Fang et al., 2019). Measurements were done in each plot at 50% flowering stage (R1 or 7 weeks after planting-WAP) under the canopy of the bean plants as described by Fang et al. (2019). In each plot at least three positions were used to get consistent readings.

Biomass (kg ha^{-1})

Three plants from each plot at 50% flowering stage were randomly cut at ground level, their fresh weight taken, and then oven-dried at 60°C for three days (72 hours), and weighed.

Grain yield (kg ha^{-1})

Bean plants were counted separately, pods and grain from each removed by hand, counted, and grain weighed. A sample of known weight was oven dried at 60°C for three days (72 h) to 13% moisture content, then weighed. Oven drying of samples for both biomass and grain yield were processed at the National Agricultural Research Laboratories, Kawanda.

Data analysis

Data for LAI, biomass and grain yield were analyzed using Genstat 12th edition. Data for 1st and 2nd season was analysed together using Analysis of Variance to establish whether there were significant differences in terms of lime and chicken manure as main effects and their interactions were fixed as factors using the F-tests at significance level of ($p < 0.05$). Due to significant differences in locations, each of Mukono and Masaka data were analysed separately. For treatment comparisons where significant differences were observed, mean separation was used (Gomez and Gomez, 1984; Ott and Longnecker, 2010) using Duncan multi range test. To test the level of influence of agricultural lime, chicken manure and their interactions, linear regression was carried out using excel. To further determine interaction of low lime and manure rates for optimal bean grain yield, 3-D analysis using R studio was used using the following model:

$$f\ (\text{bean grain yield})\ ax+by+cx^2+dy^2+c \quad (1)$$

Where; x is agricultural lime rates; y is chicken manure rates; a, b and c are constants

Optimum and minimum yield combinations and their corresponding BCRs and the associated financial implications were established using excel for the optimized combinations. The optimized lime and manure combinations were then taken on-farm for further validation by farmers.

RESULTS AND DISCUSSION

Characteristics of the soil at on-station and on-farm before treatment, plus agricultural lime and chicken manure used in the experiment

The pH of the soil for both on-farm (5.06-5.20) and on-station (5.65 to 5.79) were 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 100g^{-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 available 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 to 0.85 meq 100g^{-1} and low for on-station ranging between 0.11 to 0.12 meq 100g^{-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 mm) (Table 2).

Chicken manure used in the experiment had 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 ppm whereas Mn was 305.67 and 731.67 ppm for chicken manure at Masaka and Mukono respectively (Table 3).

Effect of low levels of lime and chicken manure on bean growth and grain yield in Mukono and Masaka on-station

There was a significant ($p<0.05$) main effect of lime on both biomass and grain yield at Mukono on-station (Table 4). Regression analysis showed significant (r^2=0.953 and 0.942) increase in biomass and grain yield respectively with increased lime rate (Table 6). The least biomass yield of 714 kg ha^{-1} was obtained with the control and the highest of 2143 kg ha^{-1} was obtained with 2.0 t ha^{-1} of lime application representing a 3-fold increase in crop biomass (Table 4). The increase in biomass yield with increasing lime rates was also corroborated by Lauricella et al. (2020) and Effa et al. (2019). Such rates could have therefore, provided better a soil environment in terms of pH and nutrient supply necessary for proper crop growth. This has an implication on eventual grain yield but also on nutrient recycling which is very crucial in sustainability of *Ferralsol* (IUSS Working Group WRB (2014). Application of chicken manure in Mukono significantly affected LAI but not biomass and grain yield (Table 4). The highest LAI of 2.2 was obtained at 2.0 t ha^{-1} manure and the lowest of 1.5 with the control. Combining lime with chicken manure in Mukono significantly increased biomass yield but not LAI and grain yield (Table 4). This study showed that the best combination would be 1.0 t ha^{-1} lime with 1.0 t ha^{-1} manure which yielded 1990 kg ha^{-1}, however biomass which was not significantly different from 1.5 and 2.0 t ha^{-1} lime with the four manure combinations (Table 4).

On the other hand, in Masaka manure significantly affected grain yield but not LAI and biomass (Table 5). The highest grain yield of 1445 kg ha^{-1} was obtained at 3.0 t ha^{-1} manure (Table 4). Regression analysis indicated increasing grain yield with increased manure rates (r^2=0.999) (Table 6). According to Bohara et al.

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	

Source: Authors' experiment

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.
Source: Authors' experiment

(2019), application of chicken manure as a complementary pH improvement source increased the biomass and grain yield of beans.

Optimisation of bean grain yield with low levels of lime and chicken manure in Mukono and Masaka on-station

Optimisation of grain yield on the *Ferralsol* showed varying promising combinations at both stations (Figures 2 and 3). Maximum bean yields were obtained at optimized rates of 2.0 t ha^{-1} lime with 1.0 t ha^{-1} manure for Mukono (Figure 2), and 0.5 t ha^{-1} lime with 3.0 t ha^{-1} manure for Masaka (Figure 3). This indicates that for beans, 1.5 t ha^{-1} lime may be applied at Mukono given the economic implications of its use (Table 8). Furthermore, the study found that all the optimized combinations at Mukono had BCR less than 1.0 although the increment in yield was over 100% for options 1, 2 and 3 (Table 7). This means that although the yields obtained were optimal, the associated revenue was not enough to

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

Source: Authors' experiment

Table 4. Effect of lime and chicken manure on bean growth and grain yield in Mukono on-station.

Treatment	Biomass (kg ha^{-1})	Grain (kg ha^{-1})	LAI	Lime × Manure (t ha^{-1})		Biomass (kg ha^{-1})	Lime × Manure (t ha^{-1})		Biomass (kg ha^{-1})
	Lime (t ha^{-1})								
0.0	714^{a}	505^{a}	2.1^{a}	0.0	0.0	679^{a}	1.0	3.0	1001^{a}
0.5	834^{a}	580^{ab}	1.8^{a}	0.0	1.0	598^{a}	1.5	0.0	2061^{bcd}
1.0	1410^{b}	741^{b}	1.7^{a}	0.0	2.0	639^{a}	1.5	1.0	1808^{bc}
1.5	2021^{c}	961^{c}	1.8^{a}	0.0	3.0	942^{a}	1.5	2.0	1942^{bcd}
2.0	2143^{c}	1029^{c}	1.9^{a}	0.5	0.0	881^{a}	1.5	3.0	2273^{cd}
Significance	*	*	ns	0.5	1.0	1033^{a}	2.0	0.0	2300^{d}
	Manure (t ha^{-1})			0.5	2.0	631^{a}	2.0	1.0	1909^{bcd}
0.0	1526^{a}	748^{a}	1.5^{a}	0.5	3.0	790^{a}	2.0	2.0	2273^{cd}
1.0	1468^{a}	797^{a}	1.9^{ab}	1.0	0.0	1708^{b}	2.0	3.0	2091^{bcd}
2.0	1285^{a}	716^{a}	2.2^{b}	1.0	1.0	1990^{bcd}			
3.0	1420^{a}	792^{a}	1.8^{ab}	1.0	2.0	941^{a}			
	ns	ns	*			*			*

* = Significant (p<0.05), ns = non-significant.
Source: Authors' experiment

cover the costs involved given the price of grain during the study period. However, there was net gain in terms of nutrients (N, P and K) for the subsequent crop (Table 8). Failure to use any amendment or application of chicken manure at 2.0 t ha^{-1} alone led to negative N and K in the soil profile (0-15 cm) and the farmer would lose $ 52 and

Table 5. Effect of lime and chicken manure on bean growth and grain yield in Masaka on-station,

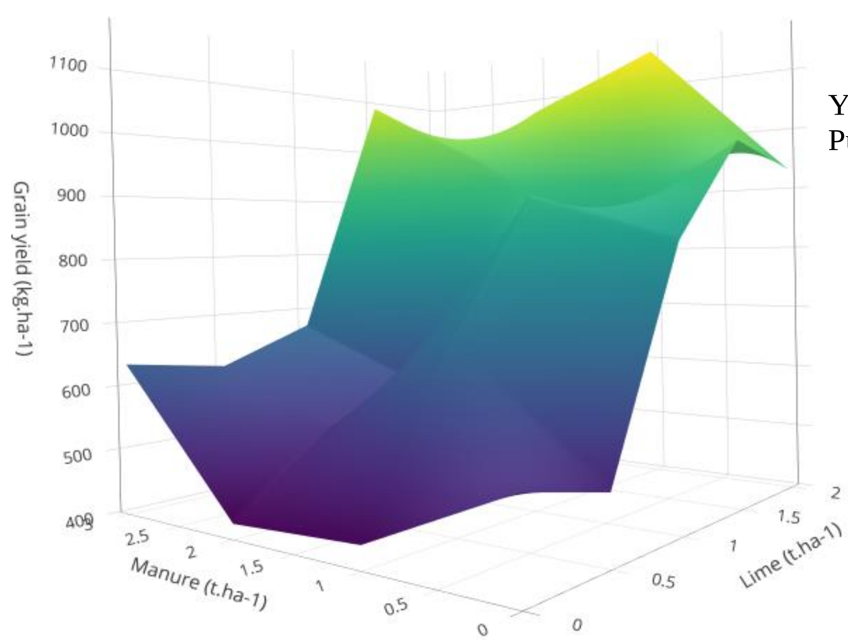
Treatment	Biomass (kg ha^{-1})	Grain (kg ha^{-1})	LAI	Lime × Manure (t ha^{-1})		Biomass (kg ha^{-1})	Lime × Manure (t ha^{-1})		Biomass (kg ha^{-1})
Lime (t ha^{-1})									
0.0	965[a]	1172.51[a]	1.5[a]	0.0	0.0	1519[a]	1.0	3.0	1933[abc]
0.5	2014[a]	1111.3[a]	1.7[a]	0.0	1.0	1653[a]	1.5	0.0	1807[ab]
1.0	2052[a]	1259.38[a]	1.7[a]	0.0	2.0	2791[c]	1.5	1.0	2096[abc]
1.5	2094[a]	1280.64[a]	1.6[a]	0.0	3.0	2091[abc]	1.5	2.0	1756[ab]
2.0	2164[a]	1347.6[a]	1.6[a]	0.5	0.0	1881[ab]	1.5	3.0	2202[abc]
Significance	ns	ns	ns	0.5	1.0	1763[ab]	2.0	0.0	1887[ab]
Manure (t ha^{-1})				0.5	2.0	2192[abc]	2.0	1.0	2303[abc]
0.0	1846[a]	1024[a]	1.7[a]	0.5	3.0	2539[bc]	2.0	2.0	2171[abc]
1.0	1949[a]	1157[a]	1.6[a]	1.0	0.0	2134[abc]	2.0	3.0	2294[abc]
2.0	2212[a]	1311bc	1.6[a]	1.0	1.0	1928[ab]			
3.0	2224[a]	1445c	1.6[a]	1.0	2.0	2211[abc]			
	ns	*	ns			ns			ns

*Significance (p<0.05), ns non-significant.
Source: Authors' experiment

Table 6. Linear functions for agricultural lime and manure rates predicting bean growth and grain yield at on-station.

Description	Parameter	Mukono		Masaka	
		Function	r^2	Function	r^2
Agricultural lime	Biomass	762.68x + 710.52	0.953*	34.2x + 2023.6	0.127[ns]
	Grain yield	298.34x + 473.74	0.942*	104x + 1130.4	0.781[ns]
Chicken manure	Grain yield	-0.86x + 773.39	0.001[ns]	141.7x + 1021.7	0.999*

*Significant at p<0.05, ns-Non significant.
Source: Authors



Yellow zone: Area of optimization
Purple zone: Area of minimization

Figure 2. Grain yield optimization for on-station low levels of lime application with manure in Mukono
Source: Authors

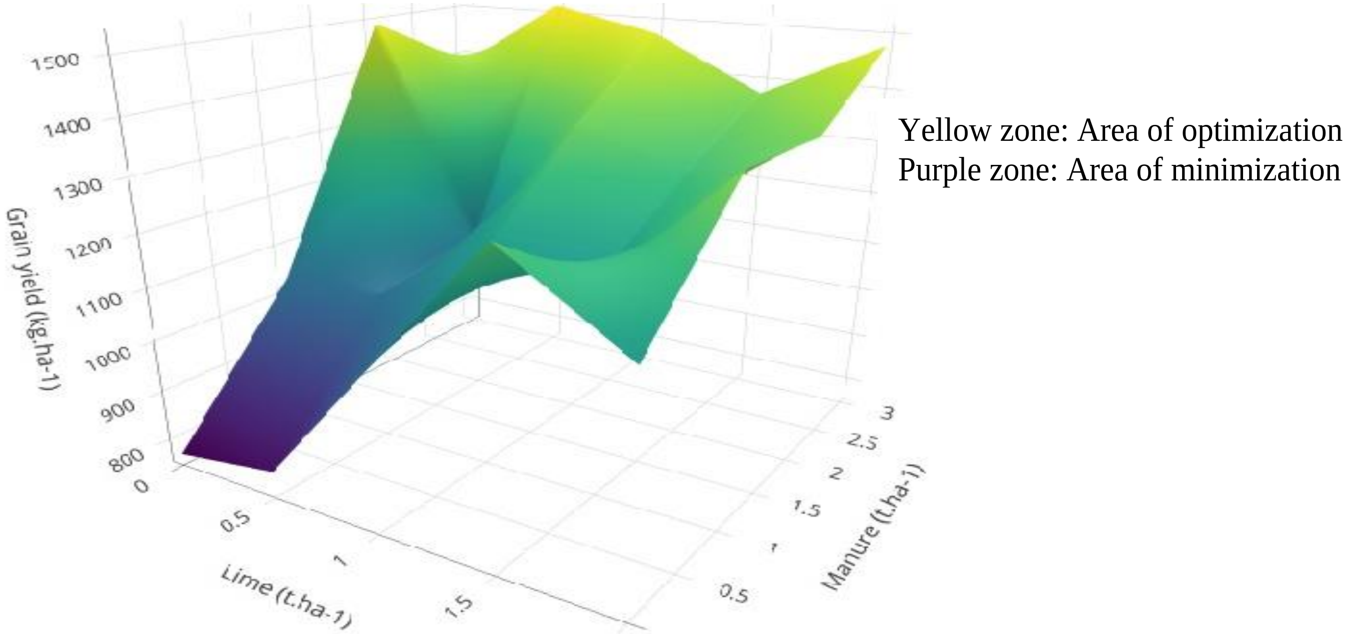


Figure 3. Grain yield optimization for on-station low levels of lime application with manure in Masaka.
Source: Authors

Table 7. Grain yield optimization for on-station lime application with manure in Mukono and Masaka.

Location	Description	X (Lime, t ha^{-1})	Y (Manure, t ha^{-1})	Z (Yield, kg ha^{-1})	% increase over the control	BCR
		Optimization (To consider)				
Mukono	1st option	2.0	1.0	1158	117.3	0.65
	2nd option	1.5	3.0	1085	103.6	0.64
	3rd option	2.0	2.0	1072	101.1	0.58
	4th option	1.5	2.0	965	81.1	0.67
Masaka	1st option	0.5	3.0	1515	95.0	1.28
	2nd option	0.0	2.0	1493	92.1	1.50
	3rd option	2.0	3.0	1479	90.3	0.75
	4th option	1.0	3.0	1473	89.6	0.96
		Minimization (To avoid)				
Mukono	1st option	0.0	1.0	432	-18.9	0.57
	2nd option	0.0	2.0	421	-20.9	0.52
	3rd option	0.5	0.0	497	-6.8	0.52
Masaka	1st option	0.0	0.0	776	0.0	1.00
	2nd option	0.5	0.0	806	3.9	0.80

Source: Authors

110 respectively if he/she is to replenish them for optimum bean crop production in the following season (Table 8).

For Masaka, the first and second options had BCR greater than one, with 2.0 t ha^{-1} manure alone giving highest BCR of 1.5, however, the increment in yield for all treatments was less than 100% (Table 7).

Unlike in Mukono, the combinations that gave optimal

Table 8. Nutrient gains of promising on-station options and their financial implications.

Location	Lime (t ha^{-1})	Manure (t ha^{-1})	∆N (%)	∆P (ppm)	∆K (ppm)	Net gain ($)
	2.0	1.0	0.058	51.06	206.5	232
	2.0	2.0	0.038	53.03	209.2	34
	1.5	2.0	0.047	52.31	241.8	408
Mukono	1.5	3.0	0.052	49.96	234.8	379
	0.0	0.0	-0.012	5.33	12.05	-52
	0.0	2.0	-0.003	4.78	-0.4	-110
	1.0	2.0	0.0617	44.11	223.7	677
	0.5	3.0	0.028	-14.72	-105.0	-436
	1.0	3.0	0.035	-22.57	-105.0	-609
	0.0	2.0	0.016	-4.86	-79.0	-183
Masaka	2.0	3.0	0.047	-38.22	-101.0	-824
	0.0	0.0	0.009	-1.40	-7.8	52
	0.0	1.0	0.017	-6.88	-29.4	0
	0.0	3.0	0.016	-4.86	-22.6	-81

Source: Authors

yields in Masaka resulted in negative P and K changes after harvest and therefore, negative nutrient gains in terms of finances. This means that for the subsequent season the farmer has to procure NPK however, the amount required would depend on what combination is considered (Table 8). Application of 3.0 t ha^{-1} manure would require 81 USD, while for the 2.0 t ha^{-1} manure, 183 USD is required to replace the P and K lost. Phosphorus is a big challenge in *Ferralsols*. It seems when lime was applied the P that was released got used up by the growing bean crop or fixed indicating that P of 4.22 ppm unlike at Mukono where 8.89 ppm was more limiting in the soils of Masaka than Mukono (Table 1) hence a need to replenish P for the subsequent crop. Owino et al. (2015) reported that availability of soil solution P depends on addition of P fertilizers, soil P fixing capacity, soil moisture, P mineralization and P removal by crops.

Validation of promising low levels of lime and chicken manure on bean grain yield in Mukono and Masaka on-farm

When validation of promising technologies was done at farmers' field, the results in Mukono had all the BCRs less than one similar to what was obtained at on-station. Much as the control had a good BCR of 0.72; it resulted into reduced pH, P, K and BS. Importantly, there were reduction in Mn and Al concentrations, and increased CEC, P, N, and K with all the optimized combinations implying improved soil chemical conditions and sustainable agro-ecosystems (Table 9).

Similarly, in Masaka all the BCRs were less than one except where manure at 3.0 t ha^{-1} was applied. Much as there were reduced pH, N, BS, Mn and Al the CEC, P and K increased (Table 10).

Conclusion

There was increased biomass yield when low rates of lime and manure were applied. Biomass is important because it is one of the ways systems sustainability of *Ferralsols* can be ensured due to the fact that the bulk of all cycling plant nutrients on this soil are contained in the biomass and the available nutrients are concentrated in soil organic matter. For Mukono farmers that may not afford higher rates of lime, applying 1.5 t ha^{-1} lime with 2.0 t ha^{-1} manure or 2.0 t ha^{-1} lime with 1.0 t ha^{-1} manure would suffice but would not be profitable for the short-season beans. However, application of these rates would result in a net nutrient gain of 408 and 232 respectively, which nutrients would be used by the subsequent crop. Looking at the BCR aspect it would apparently show a non-profitable venture to grow beans as a sole crop on the *Ferralsol* of Mukono thus requiring subsidized production systems to ensure food security and sustainable agro ecosystems. This indicates that bean production using agricultural lime with/or manure may not be profitable given the fact that it is a short season crop yet the benefits of lime and manure last longer than the three months that beans take to mature. In Masaka, optimum combinations were lime at 0.5with 3.0 t ha^{-1} and single application of manure at 2.0 t ha^{-1}. However, in terms of nutrient, financial gains both options resulted in net negative nutrient gains implying that N, P and K became more limiting after crop harvest. This means

Table 9. Validation of best optimum lime and manure rates on bean growth and grain yield, associated soil properties and profitability at Mukono on-farm.

Lime (t ha^{-1})	Manure (t ha^{-1})	ΔpH	ΔCEC (meq 100 g^{-1})	ΔP (ppm)	ΔN (%)	K (ppm)	ΔBS (%)	ΔMn (ppm)	ΔAl (meq 100g^{-1})	LAI	Biomass (kg ha^{-1})	Grain (kg ha^{-1})	BCR
0.0	0.0	-0.423	0.93	-0.02	0.0133	-3.5	-11.41	-88.7	0.373	1.297	1173	480	0.72
0.0	2.0	0.007	3.04	3.16	0.007	5.6	0.19	-55.7	-0.287	1.430	1159	474	0.67
1.0	3.0	-0.010	3.83	3.65	0.000	9.9	-0.25	-64.7	-0.543	1.200	769	527	0.74
1.5	2.0	0.013	6.05	6.04	0.007	13.0	0.44	-50.3	-0.483	1.280	1374	354	0.52
1.5	3.0	-0.093	2.87	3.53	0.020	14.0	-3.04	-66.0	-0.213	1.603	1618	436	0.63
2.0	1.0	-0.097	6.27	4.61	0.023	11.4	-2.76	-66.7	-0.600	1.443	1629	441	0.63
2.0	2.0	0.057	8.61	11.40	0.020	10.0	1.77	-51.7	-0.617	1.757	1905	459	0.65

Source: Authors

Table 10. Validation of best optimum lime and manure on bean growth parameters, associated properties and profitability at Masaka on-farm.

Lime (t ha^{-1})	Manure (t ha^{-1})	ΔpH	ΔCEC (meq 100 g^{-1})	ΔP (ppm)	ΔN (%)	K (ppm)	ΔBS (%)	ΔMn (ppm)	ΔAl (meq 100 g^{-1})	LAI	Biomass (kg ha^{-1})	Grain (kg ha^{-1})	BCR
0.0	0.0	-0.177	0.43	1.33	-0.037	1.2	-4.2	-3.1	0.15	0.553	1212	348	0.54
0.0	1.0	-0.243	2.40	1.07	0.000	19.3	-6.2	18.3	-0.16	0.700	992	477	0.68
0.0	2.0	-0.213	0.86	2.41	-0.010	25.2	-4.9	3.9	0.16	0.987	1638	380	0.55
0.0	3.0	-0.03	0.47	3.24	-0.027	44.7	-0.2	4.0	-0.097	1.083	1714	1022	1.35
0.5	3.0	-0.14	0.92	3.19	-0.045	21.4	-3.7	-1.9	-0.02	0.577	2542	325	0.48
1.0	3.0	-0.117	0.63	0.99	-0.017	27.2	-3.4	-11	-0.013	1.177	3042	344	0.50
2.0	3.0	-0.027	4.84	5.02	-0.013	22.6	0.6	16.5	-0.257	1.473	1481	561	0.78

Source: Authors

supplementary provision of NPK fertilisers would be required for the subsequent crop, for sustainable crop production and agro systems functioning. Combining lime with chicken manure, application of 0.0 t ha^{-1} lime with 2.0 t ha^{-1} manure had the highest BCR of 1.5 at Masaka whereas at Mukono that very combination had a BCR of 0.52 and among the combinations to avoid. This means that for sustained production systems lime and manure recommendations should be area specific based on routine soil tests. From this study we recommend application of 2.0 t ha^{-1} lime combined with 1.0 t ha^{-1} manure at Mukono, while for Masaka, apply lime at 0.5 t ha^{-1} lime combined with 3.0 t ha^{-1} of manure.

CONFLICT OF INTERESTS

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

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support from The African Centre of Excellence in Agro-ecology and Livelihood Systems (ACALISE), the Faculty of Agriculture-Uganda Martyrs University, and Masaka District Local Government.

Special thanks to Professor Andrew W Lenssen of Iowa State University for the financial support which made laboratory analyses possible. The authors would like to acknowledge the Director, Mukono Zonal Agriculture Research Institute (MUZARDI) for supporting on-station studies, National Agricultural Research Laboratories-Kawanda, and Crop Nutrition Laboratory Service Ltd (CropNuts)-Nairobi, the farmers of Masaka and Buikwe districts and all those who supported the collection and analyses of data, and the reviewers for their constructive comments**.**

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