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Lime, manure and Inorganic Fertilizer Effects on Soil Chemical Properties, Maize Yield and Profitability in Acidic Soils in Central Highlands of Kenya

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Authors' contribution

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In Sub-Saharan Africa (SSA), acidic soil covers 29% of the total area. About 13% of the Kenyan total land area has acidic soils, widely distributed in croplands of the central and western Kenyan regions. The high soil acidity, coupled with soil nutrient depletion, negatively affects crop productivity in the region. We conducted an on-farm experiment to determine the effect of lime, manure, and phosphatic fertilizer application, either solely or combined, on soil chemical properties, maize yield, and profitability in acidic soils of Tharaka Nithi County, Kenya. The treatments were different rates of manure, lime, and P fertilizer. The experiment was designed as a randomized complete block design replicated ten times in farmer's fields. Soil sampling was done at a depth of 0-20 cm prior to the start of the experiment, after crop harvest of SR2016 and LR2017 seasons. The samples were

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analyzed in the laboratory following standard methods. Results showed that lime significantly increased soil pH by 10.6% during the SR2016 and by 17.7% during the LR2017. Similarly, treatments with lime reduced exchangeable acidity and increased soil available P. Treatments with inorganic fertilizers had significantly higher maize grain yield in comparison with treatments with the sole application of lime, manure, and lime + manure. Lime + fertilizer + manure treatment gave the highest average maize grain yield (5.1 t ha^{-1}), while control gave the lowest (1.5 t ha^{-1}) during the LR2017 season. Economic returns were low due to the prevailing low rainfall experienced during the study period during the SR2016 season. Lime combined with inorganic fertilizer treatment recorded the highest returns (128.75 USD ha^{-1}) followed by sole inorganic fertilizer (105.94 USD ha^{-1}) during the LR2017 season. The study recommends a combination of both lime and inorganic fertilizer for enhanced maize production and profitability in Tharaka-Nithi County, Kenya.

Keywords: Soil pH; organic fertilizers; crop production; soil management.

1 INTRODUCTION

Soil acidity is one of the major problems contributing to low crop production globally [1]. About 30% of the land worldwide, which is estimated to be 4 billion hectares, faces challenges of acidity [2]. Africa is one of the continents where most of these soils with high acidity caused by extensive leaching and weathering are found [3]. In the Sub-Saharan Africa, acidic soils occupy 29% of the total area, which is attributed to low nutrients availability and fertility depletion [4]. In Kenya, acidic soils occupy approximately 13% of the agricultural area, which is estimated to be 7.5 million hectares of land in the central highlands and western part of Kenya [5] [3] Given the extent of soil acidification and decreasing crop productivity in the Central Highlands of Kenya, there is an urgent need to correct these constraints and enhance maize yield production.

In the study site, the predominant soils are *Humic Nitisols* with moderate to high acidity [4]. High soil acidity is associated with the build-up of high toxic levels of aluminum (Al), manganese (Mn), Hydrogen (H) and iron (Fe) that corresponds to deficiencies in magnesium (Mg), calcium (Ca), potassium (K) and molybdenum (Mo) [6-7]. Acidification is a slow process that can be accelerated by agricultural activities such as the use of certain fertilizers, disturbance of soil structure, and growing high yielding crops [8]. Soil acidity limits crop growth, soil productivity in highly weathered soils, and thus the most significant source of low yield for several crops [9-10].

Leaching of crop nutrient bases (K, Mg, and Ca) and replacement by H, Al and Mn cations contribute to acid-related stresses on crop production [6-7]. Thus, problems caused by soil acidity needs to be addressed by different strategies. It can be resolved by the application of lime [5]. The correction of soil acidity through the use of lime is imperative as it reduces the levels of exchangeable Al^{3+}, $Fe^{3+,}$ and Mn^{4+} in acidic soils and thus reduces P sorption [11]. This makes both the native soil P and the applied P fertilizers available for plant uptake. In addition, lime is also known to have longer residual effects on acidic soils [3]. Hence, it results in increased soil pH and available P [12-13]. The use of manure is also considered as an ameliorating material that is a cheaper input used as a strategy for acidic soil management [14-17]. The presence of calcium and magnesium element in the manure tends to reduce the pH due to its buffer capacity forming complexes with Al and Fe in acidic soils (Wong & Swift, 2003; Tejada *et al.,* 2006; Tang *et al.,* 2007) hence perceived for a long time to lower the soil pH [17]. Therefore, there is a need to intensify agricultural production to meet the growing demand for food to feed the consistently increasing world's population while concurrently coping with the degrading soils [18].

The application of lime and organic manure has the potential to address soil acidity problems [5]. Verde *et al*. [19] reported manure applied at the rate of 5 t ha^{-1} or 10 t ha^{-1} combined with lime or mineral P fertilizer improved soil conditions and soybean grain yields by 114.9 to 145.6% above the control treatment. The correction of soil acidity through the use of lime is imperative as it reduces the levels of exchangeable Al^{3+}, $Fe^{3+,}$ and Mn^{4+} in acidic soils and thus reduces P sorption [11]. This makes both the native soil P and the applied P fertilizers available for plant uptake. In addition, lime is also known to have longer residual effects on acidic soils [20]. It is thus necessary to practice improved and sustainable strategies to guarantee improvements in crop productivity and enhance food security.

In terms of profitability, smallholder farmers adopt any new technology taking into account financial benefits, especially with the addition of labor in the technology establishment and management. According to Kimani *et al*. [21] farmers are likely to adopt integrated soil fertility management technologies if assured returns to investment in crop production. They will mostly compare costs and returns associated with the adoption of new agricultural technological practices, and if the returns outweigh the costs, they will opt to use it. Therefore, it is important to consider economically viable technology for adoption by the smallholder farmers' that can assist them in making crop production decisions [16].

It would be vital to adopt soil fertility management strategies, which involve a combination of organic and inorganic fertilizers considering economic returns as recommended by Mucheru-Muna *et al*. [16]. The addition of lime can be beneficial in soil fertility improvement, soil organic matter maintenance, and high crop yield [6]. This study was therefore carried out to determine the effects of lime, manure and P fertilizer application sole and combined on selected soil properties (soil pH, exchangeable Al, Mn, Ca, Mg, and available P), maize grain yield and profitability in the acidic soils of the Central Highlands of Kenya.

2. MATERIALS AND METHODS

2.1 Study Site

The experiment was carried out at Kirege Ward, Meru South Sub-county in Tharaka-Nithi County. Meru South sub-county is located in Upper Midland 2 (UM2), and Upper Midland 3 (UM3) agro-ecological zones (AEZ) [22]. It lies at an altitude of approximately 1,500 m above sea level with an annual mean temperature of about 20 ^{0}C. The annual rainfall is about 1,200 -1,400 mm, which is received in a bimodal pattern. Long rains (LR) last from March to May and short rains (SR) last from October to December. The predominant soil type is *Humic Nitisols,* which are deep, well-weathered with moderate to high inherent fertility [22].

The soils have low levels of nitrogen (≤0.2%), soil organic carbon (≤2.0%), phosphorus (≤10 ppm), and moderately to strongly acidic soils with a pH range of 4.6-5.4, a condition that leads to declining crop productivity [23]. The sub-county has small landholdings, ranging from 0.1 to 1.5 ha per household [23]. Maize (*Zea mays* L.) is the main staple food grown while beans (*Phaseolus vulgaris* L.*)* are mostly grown as an intercrop. Other food crops include banana (*Musa spp.*), cassava (*Manihot esculenta* Crantz*),* and vegetables mostly grown for domestic consumption. Tea (*Camellia sinensis* (L.) Kuntze) and coffee (*Coffea arabica* L.) are the main cash crops. Dairy farming is a foremost enterprise, particularly dairy cattle breed's improvement. Poultry, goats, and sheep are other livestock kept in the area.

2.2 Experimental Design and Field Management

We designed a farmer-managed experiment, which was laid down in a randomized complete block design (RCBD) with eight treatments replicated ten times in farmers' fields (Table 1). The farms were selected within the same locality with relatively similar land characteristics that include enough land to accommodate eight treatments, soil type, topography, and an environment free from ditches, paths, and large trees to avoid biased results. The experiment was conducted during the short rains 2016 season and long rains 2017 season. The plots measured 4.5 m by 4 m and were established after plowing, maintaining guard zones of 1 m from one plot to another. Two weeks before planting, manure and lime were broadcasted and then incorporated at a depth of 15cm using a hand hoe. At planting, TSP was applied as a source of P and well mixed with the soil. Maize hybrid H516 was the test crop. Three seeds were sown per hole and then thinning done two weeks after germination to leave two plants per hole hence a population density of 53,333 plants ha^{-1}. Planting was done with an inter-row spacing of 0.75 m and intra-row spacing of 0.50 m.

A sample of manure applied in the treatments was analyzed to determine the N content (2.1%) and the amount of manure to be applied calculated from the results. Nitrogen fertilizer was applied as a top dress four weeks after planting (33.3%) and the rest (66.6%) 4 weeks later. Stem borers in maize were controlled by the preventive spraying of BuldockTM pesticide. No diseases were observed on the maize during the experimental period.

Table 1. Treatments implemented at Kirege site during the SR2016 and LR2017 seasons

Treatment	Description
Control	No inputs
Lime	2 t ha^{-1} $CaCO_3$
Manure	10 t ha^{-1} manure
Inorganic fertilizer	60 kg N ha^{-1} + 60 kg P ha^{-1}
Lime + manure	2 t ha^{-1} $CaCO_3$ + 10 t ha^{-1} manure
Manure + inorganic fertilizer	5 t ha^{-1} manure + 30 kg N ha^{-1} + 30 kg P ha^{-1}
Lime + inorganic fertilizer	2 t ha^{-1} $CaCO_3$ + 60 kg N ha^{-1} + 60 kg P ha^{-1}
Lime + inorganic fertilizer + manure	2 t ha^{-1} $CaCO_3$ + 5 t ha^{-1} manure + 30 kg N ha^{-1} + 30 P kg ha^{-1}

2.3 Soil Sampling and Laboratory Analysis

Soil sampling was done using Edelman auger at a depth of 0-0.20 m at five different points in a plot using the zigzag method [24] and bulked to make a composite sample. The composite samples from all plots were labeled, packed, and taken to the laboratory for analysis. This initial sampling was done before setting up the experiment (July 2016) to assess the initial status of the soil chemical properties (Table 2). To assess the changes in soil nutrients, soil samples from each plot were also collected at the end of each cropping season (SR2016 and LR2017). Soil pH was determined using a pH meter [25] exchangeable acidity by titration method, exchangeable cations (Mg, Ca and K) by Mehlich 1 (a mixture of 0.025M H_2SO_4 and 0.1M HCl); available P by spectrophotometer (1 mL of ammonium vanadate and ammonium molybdate) and Sodium (Na), Calcium (Ca) and Potassium (K) by flame photometry.

Table 2. Initial soil chemical characteristics at 0-0.20 m cm depth (July 2016) at Kirege, Tharaka Nithi County, Kenya

Parameter	Baseline Value
Soil Ph.	4.64
Exchangeable acidity (cmol kg^{-1})	0.39
Total nitrogen (%)	0.17
Total organic carbon (%)	1.80
Phosphorus (ppm)	11.56
Potassium (cmol kg^{-1})	0.42
Calcium (cmol kg^{-1})	3.25
Magnesium (cmol kg^{-1})	0.92
Manganese (cmol kg^{-1})	0.52
Copper ppm	5.81
Iron ppm	31.27
Zinc (ppm)	7.20
Sodium (cmol kg^{-1})	0.27

2.4 Maize Grain and Stover Yields

Maize grain and stover were harvested from a net area of 13.725 m^2 after leaving out one row from each side of the plot and the first and last maize plants on each row to minimize the edge effect. After harvesting, cobs in each plot were separated from the maize stover, and weight determined. Maize grains were hand shelled and the weight determined for cobs and the grains. Moisture content of the maize grains was determined using the Dickey-John MiniGAC® moisture meter. Maize grains were dried at 12.5% equivalence moisture content and weight corrected based on the moisture content and extrapolated to per hectare basis. Maize stover was taken, weighed and dried under shade until constant weight was determined and further converted to per hectare basis.

2.5 Economic Analysis

Data on labor was collected every season during each field operation (land preparation, planting, fertilizer application, thinning, weeding, pest control, and harvest). The time taken to perform every activity was recorded and valued at the local wage rate in Kenyan shilling (KShs) 200 (USD $2.0) per working day (8 hours) (Table 3). Maize stover, which is commonly used as cattle feed in the area, was accounted for as an additional benefit (with an approximate market value of USD 22.1 t^{-1}). Other inputs and output prices used in the economic analysis were derived from the farm gate prices of the area (Table 3).

The net benefit was calculated by subtracting total costs from gross benefits. The benefit cost ratio (BCR) was calculated as net benefits divided by costs. The return to labour was calculated as net benefit divided by labour costs.

The economic analysis was performed on cumulated costs and benefits over the experimental period using equations 1, 2 and 3.

Table 3. Parameters used in the profitability analysis

Parameter	Cost (USD)
Cost of maize seed (kg^{-1})	1.90
Cost of TSP fertilizer ((P kg^{-1})	5.60
Cost of NPK fertilizer (kg^{-1})	5.00
Cost of CAN fertilizer (kg^{-1})	4.00
Labour cost (day^{-1})	2.00
Price of maize grains (kg^{-1})	0.44
Price of maize stover (t^{-1})	30.00

Exchange rate (September 2016) USD1 = Kshs 100

Net Profit= Gross Income - Gross Cost (including the imputed value of family labor)
Benefit-Cost Ratio= Net Profit/Gross Cost
BCR**=** Net Return / Cost of cultivation

2.6 Rainfall Amount and Distribution

Daily rainfall data was collected using a manual rain gauge. Variation in rainfall distribution was observed during the study period (Fig. 1). The total rainfall recorded during SR2016 season and LR2017 season was 426 mm and 1136 mm, respectively (Fig. 1).

Cumulatively, a higher rainfall amount was recorded during the LR2017 season compared to SR2016 season. There was soil moisture deficit for most of the growing season during the SR2016 season, with more than 80% of the rain being received in the first month followed by a prolonged dry season. Sufficient and well-distributed rainfall was received during the LR2017 season. On the 30-day and 45-day after planting, 500 mm and 700 mm rainfall was received; this is in line with crop water requirements [26] that is adequate to thus preventing water shortage during the reproductive phase [27]. The well-distributed rainfall across the season is often more important than total rainfall, as soil moisture is retained at the desired level for crop growth [28].

2.7 Data Analysis

We did diagnostic checks such as normality and homogeneity of variance on the maize yield, soil properties, and economic returns data using studentized residual as the first step in data analysis. It was followed by an analysis of variance (ANOVA) using SAS 9.3 software [29], then means separation using Duncan's Multiple Range Test (DMRT) at p = 0.05). We determined the changes in soil chemical properties between the start and the end of the study period using the student's t-test pairwise comparison.

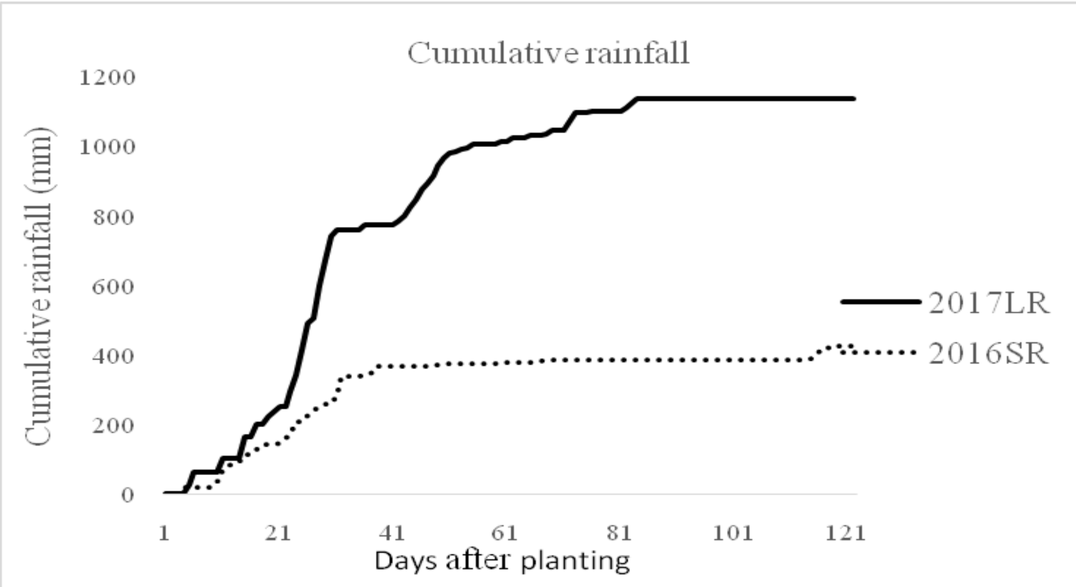

Fig. 1. Rainfall distribution during short rains 2016 season and long rains 2017 season (March to May 2017) at Kirege

3. RESULTS AND DISCUSSION

3.1 Soil pH and Exchangeable Acidity

Soil pH significantly increased ($p \leq 0.05$) in all treatments except the control during the study period (Table 4). The greatest change was in three treatments; lime + manure (14.97%), lime + manure + fertilizer (15.3%), and sole lime treatments with over 17.07% increase at the end of SR2016 season. At the end LR2017 season, the same treatments recorded the highest increase in pH of more than 14% increase at $p \leq 0.001$).

Exchangeable acidity significantly reduced at $p \leq 0.05$ in all treatments apart from the control and fertilizer treatments during both seasons. During the SR2016 season, lime + fertilizer, manure + fertilizer, manure, and lime + manure treatments gave the highest percentage change with over 20% reduction in exchangeable acidity. Similar results were observed in the same treatments in the LR2017 season, with over 24% reduction in exchangeable acidity (Table 5). There was no significant in sole fertilizer application on exchangeable acidity.

Treatments with manure, sole lime or combined significantly increased the soil pH and reduced exchangeable acidity. This could be due to calcium carbonate in lime that reacts with soil moisture releasing Ca^{2+} and OH^-. The Ca^{2+} produced exchange Al^{3+} and H^+ and the OH^- reacts with Al^{3+} and H^+ to form aluminium hydroxide and water, respectively [30]. Excess OH^- raises the soil pH hence reduction in exchangeable acidity [31] [32]. On the other hand, manure has the ability to reduce H^+ due to presence of Mg^{2+} and Ca^{2+} ions hence reduction in Al toxicity. In the control treatment there was continuous depletion of nutrients thus low soil pH. This could have caused increase in exchangeable acidity due to increased Al^{3+} toxicity and presence of H^+ concentration in the soil solution. Rajneesh *et al.* [33] reported significant decrease in different forms of soil acidity with continuous application of lime and balanced fertilizers during cropping. The effect of phosphorus fertilizer application was not significant this is contrary with other studies that have reported reduction in exchangeable acidity [34].

3.2 Maize Grain and Stover Yields

During LR17 season, Lime + Manure + Fertilizer had significantly ($p \leq 0.001$) higher maize grain yields by 1.96% compared to Lime + Fertilizer. Soil fertility inputs significantly influenced grain yields during the trials period in the study sites. Grain yields increased significantly ($p \leq 0.001$) increased in lime + Manure + Fertilizer, Lime + Fertilizer, Fertilizer, and Manure + Fertilizer by 71, 70, 63 and 61% compared with the control during SR17. Increased grain yields under sole manure inputs were 32% higher compared with control. Also, sole lime had higher grain yields by 17% compared to control in the LR17 season. No grains were harvested during SR16 (Table 6).

Table 4. Changes in soil pH (0-0.20 m depth) in the different treatments during SR2016 and LR2017 seasons at Kirege, Tharaka Nithi County, Kenya

Treatments	SR2016				LR2017		
	Start*	**End****	**Change (%)**	***t*-test, *p***	**End****	**Change (%)**	***t*-test, *p***
Control	4.70a	4.71a	0.21	0.92	4.64b	-1.28	0.61
Lime	4.51a	4.99a	10.64	0.009	5.28a	17.07	<0.001
Manure	4.71a	4.98a	5.73	0.003	5.20a	10.4	<0.001
Fertilizer	4.71a	4.96a	5.31	0.04	4.95ab	5.1	0.05
Lime + manure	4.61a	5.21a	13.02	<0.001	5.30a	14.97	<0.001
Manure + fertilizer	4.61a	5.07a	9.98	0.003	5.13a	11.28	0.002
Lime + fertilizer	4.63a	5.01a	8.21	0.002	5.26a	13.61	<0.001
Lime + fertilizer + manure	4.64a	5.23a	12.72	0.01	5.35a	15.3	<0.001
P-value	0.98	0.55			0.02		
LSD	0.446	0.490			0.421		

**Start of the experiment, ** at the end of the experimental period*
Means with the same letter(s) are not significantly different from each other at 5% level of significance, LSD-Least Significant Difference

Table 5. Changes in Exchangeable acidity (0-0.20 m depth) in the different treatments during SR2016 and LR2017 seasons in Kirege, Tharaka Nithi County, Kenya

Treatments	SR2016				LR2017		
	Beginning of Experiment	End	% Change	*t*-test, *p*	End	% Change	*t*-test, *p*
Control	0.37a	0.38a	2.7	0.7263	0.39a	5.4	0.3434
Lime	0.42a	0.34a	-19	0.0002	0.33ab	-21.4	≤.0001
Manure	0.36a	0.28a	-22.2	0.0002	0.27ab	-25	0.01
Fertilizer	0.39a	0.36a	-7.7	0.3938	0.38ab	-2.6	0.3434
Lime + manure	0.41a	0.32a	-22	≤.0001	0.31ab	-24.4	≤.0001
Manure + fertilizer	0.37a	0.27a	-27	≤.0001	0.26ab	-29.7	≤.0001
Lime + fertilizer	0.36a	0.26a	-27.8	≤.0001	0.25b	-30.6	≤.0001
Lime + fertilizer + manure	0.41a	0.38a	-7.3	0.2789	0.32ab	-22	0.0294
P-value	0.95	0.27			0.16		
LSD	0.126	0.122			0.119		

Means with the same letter(s) are not significantly different from each other at 5% level of significance, LSD-Least Significant Difference

Table 6. Stover yields and maize yields (t ha–1) in the different treatments during the SR2016 and the LR2017 seasons in Kirege, Tharaka Nithi County, Kenya

Treatment	Stover yield (t ha^{-1})		Grain yield (t ha^{-1})
	SR16	LR17	LR17
Control	0.8c	5.9c	1.5c
Lime	0.8c	6.5bc	1.8c
Manure	1.3bc	6.1bc	2.2c
Fertilizer	2.4ab	8.9abc	4.0a
Lime + manure	1.5abc	8.2abc	2.5bc
Manure + fertilizer	2.7ab	8.3abc	3.8ab
Lime + fertilizer	2.8a	10.6ab	5.0a
Lime + fertilizer + manure	3.0a	11.2a	5.1a
p-value	≤.0001	0.0439	≤.0001
LSD	1.354	3.724	1.354

Means with the same letter(s) are not significantly different from each other at 5% level of significance, LSD-Least Significant Difference

In SR16 season, stover yields significantly ($p \leq 0.001$) increased under Lime + manure + Fertilizer, Lime + Fertilizer, Manure + Fertilizer and Fertilizer by 73, 71, 70 and 67% compared with the control. In LR17, stover yields had significantly (p=0.0439) increased under Fertilizer, Lime + manure + Fertilizer, Lime + Fertilizer, Manure + Fertilizer and by 50.8%, 47.3%, 44.3% and 32.5% compared with the control. Soil fertility inputs significantly influenced stover yields during the trial period in the study sites. Increased stover yields under sole manure inputs were 11% higher compared with control in LR17. Sole lime had higher grain yields by 9% compared to control in the LR17 season. In the SR16 season, sole manure input was higher by 38% compared to control.

On Average, grain yields were highest under the combination of fertilizer and organic inputs, followed by the use of sole mineral fertilizer compared with the control during the LR17 season (Table 6). In LR17, grain yields were highest under lime + Fertilizer + manure compared with the control. On average, during the SR16 and SR17 seasons, the stover yields were highest under the application of lime + fertilizer + manure compared with the control (Table 6). Increased maize and stover yields under sole organic inputs were also observed during the two seasons.

The combination of lime, manure, and fertilizers gave higher crop yields compared to the application of sole fertilizer, lime, and manure in both seasons. Similarly, Nyamangara *et al. [35]*, Mtambanengwe *et al.* [36], and Bekele *et al*. [37] reported crop yield increment in a combination of inorganic fertilizer and manure compared to the sole application of P fertilizer and sole manure. The increase was as a result of the inorganic fertilizer that supplies readily available nutrients from the early stage of crop growth, thus promoting sufficient water and nutrient uptake. This corroborates with the findings of Mugwe *et al.* [23], Mucheru-Muna *et al.* [38] Kimetu *et al.* [39] and Nziguheba *et al.* [40] who similarly observed increased maize grain yields as a result of organic manure application with combined with P fertilizer in comparison to sole application of organic manure and sole mineral fertilizers. The positive effect observed as a result of increased soil pH due to the lime application was, therefore, likely due to an increased availability of most nutrients for plant uptake.

Higher yields in lime combined with manure and mineral fertilizer could be attributed to the supply of nutrients from manure and fertilizer, thus achieving a positive rise in recorded grain yield. This is similar to a study by Pan *et al*. [41] who reported increased uptake of nutrients such as N, Ca, P, K, and Mg by crops that resulted in high yields of sweet potato and canola seeds with amelioration of soil acidity. Most nutrients are more available at higher soil pH and consequently lead to high grain yields [19]. The application of manure provides the essential nutrients to the soil, such as P, N, and K, which are crucial for maize growth [42].

The combination of organic and inorganic fertilizer practices are better options, which can be considered in increasing the efficient use of fertilizer since they ensure the availability of more balanced nutrients supply and other agro-ecological multiple benefits [16] [43]. The organic and inorganic fertilizer has shown improved synchronization of nutrient release, proper uptake by plants and synergetic effects that result to higher yields [44] particularly in a case where smallholder farmers use relatively low levels of inorganic fertilizers in tropical farming systems [45]. Additionally, fertilizers are able to supply enough nutrients for the management of soil fertility and to increase crop yields, while organic sources are able to restore less responsive soils and make them responsive to fertilizers [46] [47]. Lime alone did not increase yields since it does not contain any nutrients. Zhang *et al*. [48] indicated that heavy liming does not overcome the growth limiting factors in crops hence results to low yields. Liming can only be viable in yield increment when combined with organic and/or inorganic fertilizer [48] [49].

3.3 Economic Returns

The net benefit, BCR, and return to labor were all negative during the SR2016 season. The control treatment gave the highest net benefit of -88.5 and also the highest return to the labor of -1.7 (Table 7). This was followed by fertilizer treatment with -170.6 and -3.0, respectively. During the LR2017 season, treatments with inorganic fertilizer gave significantly higher net benefits, BCR, and return to labor compared with organic and sole lime treatments. Lime+ fertilizer, fertilizer, manure + fertilizer, and lime + fertilizer + manure gave the highest net benefit though not significantly different from the control (Table 7).

Table 7. Profitability (USD) of maize under different treatments during SR2016 and LR2017 seasons in Kirege, Tharaka Nithi County, Kenya

Treatment	SR2016			LR2017		
	Net Benefit (USD)	Benefit-Cost Ratio	Return to Labour	Net Benefit (USD)	Benefit-Cost Ratio	Return to Labour
Control	-88.05a	0.78ab	-1.7a	96.10a	0.67a	1.6abc
Lime	-213.75c	-0.90b	-3.9c	-33.89abc	-0.12bcd	0.5bcd
Manure	-319.33de	-0.89b	-6.2e	-186.20c	-0.23cd	-0.6cd
Fertilizer	-170.60b	-0.68a	-3.0b	105.94a	0.34ab	3.3ab
Lime + manure	-434.21f	-0.91b	-8.1f	-108.01bc	-0.34d	-1.5d
Manure + fertilizer	-228.16c	0.76ab	-4.1c	60.70a	0.18bc	2.4abc
Lime + fertilizer	-287.77d	0.77ab	-4.9d	128.75a	0.30ab	3.8a
Lime + fertilizer + manure	-339.98e	0.79ab	-5.7e	48.38ab	0.10bcd	2.3abc
p-value	≤.0001	0.1471	≤.0001	0.0006	0.0006	0.0042
LSD	-42.25	0.1806	-0.799	150.99	0.446	2.82

Means with the same letter(s) are not significantly different from each other at 5% level of significance, LSD-Least Significant Difference

The combination of lime and fertilizer was higher in net benefits compared to the sole application of lime, fertilizer, and over the control. The high economic returns could be associated with low labor input in the farm, adequate rainfall during LR2017 season, and the fact that these treatments had relatively higher yields with improved soil properties recorded. Therefore, the optimum fertilizer combined with lime is important to obtain maximum net benefit returns. This is in agreement with Sodo [50] who reported maximum net profits in lime combined with fertilizer treatment. This is also in agreement with Manpreet & Dixit [51-52], who established that incorporation of lime along with a recommended level of fertilizers every year is economical, practicable, and effective. Mucheru-Muna *et al*. [16] also reported a higher return to labor under the integration of organic and inorganic compared to the sole applications. However, on average, the net benefit, benefit-cost ratio, and return to labor were lower during the short rains compared to the long rains season. This could be due to inadequate rainfall experienced during the SR2016 season, which adversely affected the maize yields.

4. CONCLUSIONS

Soil analysis in the study area showed high soil acidity of 4.64. Treatments with the application of lime and/or manure showed a significant increase in soil pH and reduction in exchangeable acidity. A combination of lime + fertilizer + manure was found to have good synergy as it consistently gave higher yields than when the inputs were applied solely.

In terms of profitability, smallholder farmers adopt any new technology taking into account financial benefits, especially with the addition of labor in the technology establishment and management. Farmers are likely to adopt integrated soil fertility management technologies if assured returns to investment in crop production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO. Global climate change, food supply and livestock production systems: A bioeconomic analysis. Incomplete, no publisher and no page numbers; 2015.
2. Sumner ME, Noble AD. Soil acidification: the world story. Handbook of soil acidity. Marcel Dekker, New York. 2003;1-28.
3. Kisinyo PO, Opala PA, Gudu SO, Othieno CO, Okalebo JR, Palapala V, Otinga AN. Recent advances towards understanding and managing Kenyan acid soils for improved crop production. African Journal of Agricultural Research. 2014;9(31):2397-2408.
4. Muindi EM. Phosphorus retention and the interactive effects of phosphorus, lime and tillage on maize in acid soils of the Kenya Highlands (Doctoral dissertation, Sokoine University of Agriculture); 2016.
5. Kanyanjua SM, Ireri L, Wambua S, Nandwa SM. Acid soils in Kenya: Constraints and remedial options. KARI Technical Note. 2002;11.
6. Okalebo JR, Othieno CO, Nekesa AO, Ndungu-Magiroi KW, Kifuko-Koech MN. Potential for agricultural lime on improved soil health and agricultural production in Kenya. In African Crop Science Conference Proceedings. 2009;9:339 -341.
7. Havlin JL, Tisdale SL, Nelson WL, Beaton JD. Soil fertility and fertilizers. Pearson Education India; 2016.
8. Fageria NK, Baligar VC. Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. Advances in agronomy. 2008;99:345-399.
9. Mugai EN. Salinity characterization of the Kenyan saline soils. Soil Science and Plant Nutrition. 2004;50(2):181-188.
10. Akinrinade EA, Iroh I, Obigbesan GO, Hilger T, Romheld V, Neumann G. Response of cowpea varieties to phosphorus supply on an acidic alumi-haplic-Acrisol from Brazil. Nigerian Journey of Soil Science. 2006;16:115-120.
11. Goulding KWT. Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom. Soil use and management. 2016;32(3):390-399.
12. Barasa JN, Omami EN, Okalebo JR, Othieno CO. Effect of lime and phosphorus fertilizer applications on performance of french beans in Uasin Kishu district, Kenya. Global Journal of Biology, Agriculture & Health Sciences. 2013;3:35-41.
13. Kisinyo PO, Othieno CO, Okalebo JR, Kipsat MJ, Serem AK, Obiero DO. Effects of lime and phosphorus application on early growth of Leucaena in acid soils. In

African Crop Science Conference Proceedings. 2005;7(pt. 03 of 03):1233-1236.

14. Fageria NK, Dos Santos AB, Moraes MF. Influence of urea and ammonium sulfate on soil acidity indices in lowland rice production. Communications in soil science and plant analysis. 2010;41(13):1565-1575.
15. Onwonga RN, Lelei JJ, Mochoge BB. Mineral nitrogen and microbial biomass dynamics under different acid soil management practices for maize production. Journal of Agricultural Science. 2010;2(1):16.
16. Mucheru-Muna MW, Mugendi D, Pypers P, Mugwe J, Kung'u J, Vanlauwe B, Merckx R. Enhancing maize productivity and profitability using organic inputs and Mineral Fertilizer in central Kenya small-hold farms. Experimental Agriculture. 2014;50:250-269.
17. Zhang H, Schroder J. Animal manure production and utilization in the US. In Applied manure and nutrient chemistry for sustainable agriculture and environment. Springer, Dordrecht. 2014;1-21.
18. Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Toulmin C. Food security: the challenge of feeding 9 billion people. Science. 2010;327(5967):812-818.
19. Verde BS, Danga BO, Mugwe JN. Effects of manure, lime and mineral P fertilizer on soybean yields and soil fertility in a humic nitisol in the Central Highlands of Kenya. International journal of Agricultural science research. 2013;2(9):283-291.
20. Rheinheimer DS, Tiecher T, Gonzatto R, Zafar M, Brunetto G. Residual effect of surface-applied lime on soil acidity properties in a long-term experiment under no-till in a Southern Brazilian sandy Ultisol. Geoderma. 2018;313:7-16.
21. Kimani SK, Macharia JM, Gachengo C, Palm CA, Delve RJ. Maize production in the central highlands of Kenya using cattle manures combined with modest amounts of mineral fertilizer. Uganda Journal of Agricultural Sciences. 2004;9:480–490.
22. Jaetzold R, Schmidt H, Hornet ZB, Shisanya CA. Farm Management Handbook of Kenya. Natural Conditions and Farm Information C Eastern Province. Ministry of Agriculture/GTZ, Nairobi, Kenya. 2007;11.
23. Mugwe J, Mugendi D, Mucheru- Muna M, Odee D, Mairura F. Effect of selected organic materials and inorganic Fertilizer on the soil fertility of a Humic Nitisol in the central highlands of Kenya. Soil Use and Management. 2009;25(4):434-440.
24. Santos EODJ, Gontijo I, Silva MBD, Partelli FL. Sampling Design of Soil Physical Properties in a Conilon Coffee Field. Revista Brasileira de Ciência do Solo. 2017;41.
25. Ryan J, Estefan G, Rashid A. Soil and Plant Analysis Laboratory Manual (2nd ed.). International Center for Agricultural Research in the Dry Areas (ICARDA) and the National Agricultural Research Center (NARC); 2011.
26. FAO. Land and water division, FAO AGLw, Water, News, Contacts Agriculture. 2001;21 Available: http://www.fao.arg/ag/agl/.Accessed .
27. Omoyo NN, Wakhungu J, Oteng'i S. Effects of climate variability on maize yield in the arid and semi-arid lands of lower eastern Kenya. Agriculture & Food Security. 2015;4(1):8.
28. Fischer RA. Definitions and determination of crop yield, yield gaps, and of rates of change. Field Crops Research. 2015;182:9-18.
29. SAS Institute. SAS/STAT 9.3 User's Guide. SAS Institute Inc., Cary, NC, USA; 2011.
30. Brown TT, Koenig RT, Huggins DR, Harsh JB, Rossi RE. Lime effects on soil acidity, crop yield, and aluminum chemistry in direct-seeded cropping systems. Soil Science Society of America Journal. 2008;72(3):634-640.
31. Ardestani MM, Van Gestel CA. Sorption and pH determine the long-term partitioning of cadmium in natural soils. Environmental Science and Pollution Research. 2016;23(18):18492-18501.
32. Onwonga RN, Lelei JJ, Freyer B, Friedel JK, Mwonga SM, Wandhawa P. Low cost technologies for enhance N and P availability and maize (*Zea mays* L.) performance on acid soils. World Journal Agricultural Science. 2008;4(5):862-873.
33. Rajneesh RP, Sharma NK. Sankhyan, Rameshwar Kumar & Swapana Sepehya. Effect of a four-decade long application of fertilizers, farmyard manure and lime, on forms of soil acidity and their relationship with yield of wheat and maize in an acid

Alfisol, Journal of Plant Nutrition. 2018;41:11:1444-1455.
DOI: 10.1080/01904167.2018.1457684
34. Yang LT, Zhou YF, Wang YY, Wu YM, Qian B, Wang H, Chen LS. Phosphorus-mediated alleviation of aluminum toxicity revealed by the iTRAQ technique in Citrus grandis roots. PloS one. 2019;14(10).
35. Nyamangara J, Piha MI, Giller KE. Effect of combined cattle manure and mineral nitrogen on maize N uptake and grain yield. African Crop Science Journal. 2003;11:289–300.
36. Mtambanengwe F, Mapfumo P, Vanlauwe B. Comparative short-term effects of different quality organic resources on maize productivity under two different environments in Zimbabwe. Nutrient Cycling Agroecosystems. 2006;76:271–284.
37. Bekele A, Kibret K, Bedadi B, Yli-Halla M, Balemi T. Effects of lime, vermicompost, and chemical p fertilizer on selected properties of acid soils of Ebantu District, Western Highlands of Ethiopia. Applied and Environmental Soil Science; 2018.
38. Mucheru-Muna MW, Mugendi D, Kung'u J, Mugwe J, Bationo A. Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. Agroforestry Systems. 2007;69:189-197.
39. Kimetu JM, Mugendi DN, Palm CA, Mutuo PK, Gachengo CN, Bationo A, Nandwa S, Kung'u J. Nitrogen fertilizer equivalences by organics of differing quantity and optimum combinations with organic nitrogen source in central Kenya. Nutrient Cycling in Agroecosystems. 2004;68:127-135.
40. Nziguheba G, Merckx R, Palm CA, Rao MR. Organic residues affect the phosphorous availability and maize yields in Nitisol of Western Kenya. Biology Fertility Soils. 2000;32:328 – 339.
41. Pan XY, Li JY, Deng KY, Xu RK, Shen RF. Four-year effects of soil acidity amelioration on the yields of canola seeds and sweet potato and N fertilizer efficiency in an ultisol. Field Crops Research. 2019;237:1-11.
42. Jing J, Christensen JT, Sørensen P, Christensen BT, Rubæk GH. Long- term effects of animal manure and mineral fertilizers on phosphorus availability and silage maize growth. Soil Use and Management. 2019;35(2):323-333.
43. Theriault V, Smale M, Haider H. Economic incentives to use fertilizer on maize under differing agro-ecological conditions in Burkina Faso. Food Security. 2018;10(5):1263-1277.
44. Palm CA, Myers RJK, Nandwa SM. Organic-inorganic nutrient interactions in soil fertility replenishment. In, Replenishing Soil Fertility in Africa. Soil Science Society of America Special Publication, (Eds R. J. Buresh, P. A. Sanchez, and F. Calhoun). Madison WI: Soil Science Society of America.1997;51:193-218.
45. Kapkiyai JJ, Karanja NK, Woomer P, Qureshi JN. Soil organic carbon fractions in a long-term experiment and the potential for their use as diagnostic assays in highland farming systems of central Kenya. African Crop Science Journal. 1998;6:19–28.
46. Vanlauwe B, Kihara J, Chivenge P, Pypers P, Coe R, Six J. Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. Plant and soil. 2011;339(1-2):35-50.
47. Kiboi MN, Ngetich KF, Fliessbach A, Muriuki A, Mugendi DN. Soil fertility inputs and tillage influence on maize crop performance and soil water content in the Central Highlands of Kenya. Agricultural Water Management. 2019;217:316-331.
48. Zhang J, Bei S, Li B, Zhang J, Christie P, Li X. Organic fertilizer, but not heavy liming, enhances banana biomass, increases soil organic carbon and modifies soil microbiota. Applied soil ecology. 2019;136:67-79.
49. Dominguez-Hernandez ME, Zepeda-Bautista R, Dominguez-Hernandez E, Valderrama-Bravo MDC, Hernández-Simón LM. Effect of lime water–manure organic fertilizers on the productivity, energy efficiency and profitability of rainfed maize production. Archives of Agronomy and Soil Science. 2019;1-16.
Available:https://doi.org/10.1016/j.fcr.2018.12.013.
50. Sodo NAW, Ethiopia S, Shirko M. Effect of Application of Lime (Caco3) Aand Phosphorus on Yield and related Traits of Maize (*Zea Mays* L.) on Nitisols at Wolaita Sodo, Southern Ethiopia. M.Sc Thesis, Haramaya, Ethiopia; 2014.

51. Manpreet S, Dixit SP. Yield, profitability and nutrient uptake of wheat under soil test crop response based fertilizer application with different levels of lime in an acid Alfisol. Journal of Pharmacognosy and Phytochemistry. 2017;6(6):1985-1988.

52. Opala PA. Influence of lime and phosphorus application rates on growth of maize in an acid soil. Advances in Agriculture; 2017.

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