

Original Research Article

EFFECTS OF LIME AND NITROGEN RATES ON SOIL PROPERTIES OF AN ACIDIC SOIL AND NUTRIENT CONTENT OF SUGARCANE – SOYBEAN INTERCROPPED ~~ON ACIDIFIED SOILS OF KIBOS,~~ KISUMU COUNTY IN KENYA

ABSTRACT

~~Acidified soils are a constraint to crop production due to imbalance in availability of essential plant nutrients. Liming is known to increase soil pH, however, efficient use is critical to ensure cost effective use. Therefore, determination of efficient lime application method including lime rates and nitrogen rates was the basis of the study.~~ A field study was conducted to investigate whether lime placement methods (LPM), lime rates (LR) and nitrogen rates (NR) for intercropped sugarcane with soybean under acid soils leads to increased soil pH and also soil and sugarcane leaf nutrient status. ~~Acidified soils are a constraint to crop production due to imbalance in availability of essential plant nutrients. Liming is known to increase soil pH, however, efficient use is critical to ensure cost effective use. Therefore, determination of efficient lime application method including lime rates and nitrogen rates was the basis of the study.~~ Split – split plot randomized complete block arrangements was employed. The main plots were; LPM (lime broadcasted [L-BC], lime shallow banded, 0 – 15 cm [L-SB] and lime deep banded, 15 – 30 cm [L-DB]); ~~Sub plots were,~~ lime rates (0, 1 and 2 t ha⁻¹) and sub – sub plots ~~were N rates~~ (0, 50 and 100 kg N ha⁻¹). Lime rates significantly affected soil pH for both ~~the~~ 0 – 15 cm and 15 – 30 cm soil depth. Lime rate, 2 t ha⁻¹ led to the highest soil pH. Lime placement methods (LPM) and also nitrogen rates (NR) did not affect the soil acidity. ~~Preceding statement is not true?~~ See Lines 195, and a also Line 198 to 202, indicating effects of LPM and their interaction?

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Please modify the statement. Some soil chemical properties, specifically, exchangeable calcium (Ca), extractable manganese (Mn), zinc (Zn) and soil OC were affected by the LR but not the LPM. LPM affected sugarcane leaf total K, Ca, Mn and Zn while the LR affected total N and Mg. Lime shallow banded and lime broadcasted led to highest content of these nutrients in sugarcane leaves. Lime rate 2 t ha^{-1} is recommended for use to ameliorate soil acidity for acidified Cambisols soils of Kibos, Kisumu County, Kenya. Lime broadcasting or lime banding at shallow 0 – 15 cm soil depth should be used as a lime placement method.

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Keywords: Lime placement methods, lime rates, nitrogen rates, soil properties, nutrient content, sugarcane leaves yields **(yield data is not reported in Results and Discussion)**

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1. INTRODUCTION

Soil acidity causes detrimental effects to plants and soil organisms [1]. Nitrogen (N), a primary nutrient for crop production, is affected by soil acidity. Nitrogen is the most important plant nutrient for crop production because of its role as a constituent of the building blocks of almost all plant structures. For example, it is an essential component of chlorophyll, enzymes and proteins [2]. Apart from affecting N, soil acidity also affects availability of other macronutrients and micronutrients [3, 4]. Nitrogen use for crop production is mainly provided through inorganic and organic fertilization, through biological nitrogen fixation (BNF) and, to some extent, through atmospheric deposition [5]. Inorganic fertilization input involves application of mineral fertilizers such as urea (46 % N). The relatively simple and less costly synthesis of urea and its high N content has made it the most commonly used N fertilizer in the world. Organic N sources are either from plant or animal sources. Freshly cut green manure Plant material (catch or cover crops, legumes) is often added freshly cut (green manure) to the soil, and with crop nutrients available for the next crop ranging from less than 20 % to more than 50 % of what is applied. Legumes and manure can release quite high amounts of N in a rather short time. Biological Nnitrogen fixation occurs when Rhizobium species living in symbiotic relationship in root nodules of legumes (e.g. soybean) converts atmospheric N₂ gas to NH₃, which is further converted to amino acids and proteins. In exchange, the legumes provide the Rhizobium species with the energy they need to grow and to fix N₂. The process is depressed when other sources of N are abundant, and is also reduced in acid soils and in soils with low P availability [5].

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30 According to [6], acidity governs the type, number and activity of microorganisms, regulates the rate of
31 organic matter decomposition, thereby reducing the number of simple organic molecules available for
32 further decomposition and eventually rendering N and other constituent elements (P and S) soluble.
33 Acidity has a deleterious effect on the symbiotic relationship between rhizobia and legumes, and
34 generally in soils with pH below 6, poor nodulation and N₂ fixation result in. The inhibitory effect of
35 acidity on biological N₂ fixation has also been attributed to the poor supply of Mo and Ca, which are
36 essential for N₂ fixation. Thus, when nutrient deficiencies, especially Ca and Mo are overcome in acid
37 soils, biological N₂ fixation can be improved [7, 1].

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38 In Kenya, most of the soils of the sugarcane growing areas are low in soil nitrogen (N) [8]. The low soil
39 N coupled with long - term monocropping as a consequence of its perennality, ability of the sugarcane
40 to ratoon severally after harvesting, and land scarcity justifies continued use of nitrogen fertilizer in the
41 same field. Also, sugarcane is capable of rapidly depleting the soil of ~~nutrients~~ mineral elements,
42 particularly N and potassium if sufficient N is not applied. On average, one tonne of sugarcane
43 removes 1.16 kg N in a given crop cycle [9].

44 Liming is a management practice to reduce the soil acidity and therefore one of the soil fertility
45 management practices [10]. Most plants grow well at a pH range of 5.5 – 6.5 and liming is aimed to
46 increase the pH to this range. The benefits of liming include: enhanced soil physical, chemical and
47 biological conditions of soil. The indirect benefits include mobilization of plant nutrients, immobilization
48 of toxic heavy metals, and improvements in soil structure. Liming also ~~creates~~ causes an optimal
49 conditions that favours biological activities ~~that include~~ N₂ fixation and mineralization of N, P and S
50 in soils [11, 12].

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51 Enhancing the activities of beneficial microbes such as rhizobia, diazotrophic bacteria, and mycorrhizae
52 in the rhizosphere has improved root growth by the fixation of atmospheric nitrogen, suppressing
53 pathogens, and producing phytohormones, enhancing root surface area to facilitate uptake of less
54 mobile nutrients such as P and micronutrients and mobilizing and solubilizing unavailable nutrients
55 [13]. Literature provides ample evidence that low soil pH adversely affects activities of rhizobium,
56 including a loss of its ability to fix nitrogen [14], ~~and~~ ~~[-15] showed that low soil pH~~ reduced the activity
57 and their ability to multiply [15]. ~~[16] earlier demonstrated that~~ low soil pH increased the number of

ineffective rhizobia in soil [16]. ~~[14] reported that s~~Soil pH decline below 5.5 reduced rhizobial populations, and rhizobia that survive such a pH lack the capacity to fix atmospheric nitrogen [14]. ~~[17] showed that p~~Plants grown in an unamended control soil with low pH often exhibited low rates of nitrogen fixation, ~~while showed. [17] also reported~~ high rates of nitrogen fixation when high concentrations of heavy metals were present, but soil pH was nearly neutral [17]. ~~[18] found that d~~Decreasing the pH of nutrient solutions from 5.5 to 5.0 decreased the number of nodules formed by common bean (*Scientific name??*) [18].

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Lime ameliorates the harmful effects of soil acidity [19]. Studies on bacteria suggest that the success of liming may be due not only to an effect on the soil pH but also to a direct effect of increased Calcium ~~foren~~ the bacteria themselves [20].

In Kenya, the common sugarcane production practice is continuous sugarcane monoculture and use of acidifying fertilizers such as urea and diammonium phosphate [21]. These fertilizers are favoured due to their cost and levels of ~~n~~ nutrients ~~element~~ per weight compared to other nutrient fertilizer sources. The advantage of these fertilizers means their use will continue. This therefore calls for integrated use of these fertilizers with other soil improvement strategies that will mitigate ~~against~~ soil acidification, improve soil fertility and increase sugarcane nutrient uptake. Alternative strategies such as placement of lime allow low rates of lime to be used to reduce soil acidity. This, coupled with intercropped sugarcane and soybean, could decrease rates of ~~Nitrogen~~ use hence improve ~~Nitrogen~~ use efficiency, other nutrients availability, yields and quality of sugarcane.

This study investigated ~~s~~ whether lime and N fertilizer use ~~and intercropped sugarcane and soybeans~~ leads to amelioration of soil pH, improve soil nutrient status and nutrient content of sugarcane leaves under intercropped sugarcane and soybeans. It was hypothesized that lime placement methods, lime rates and nitrogen rates does influence~~improve~~ soil chemical properties and sugarcane leaf nutrient content in acid soils of Kibos, Kisumu County in Kenya.

2. MATERIAL AND METHODS

2.1 STUDY SITE

The field experiment was conducted at field 6, experimental plots of Kibos (35°13 E, 0°06 S), under Kenya Agricultural and Livestock Research Organization – Sugar Research Institute. The elevation of

the site was 1268 m above sea level and the agro – ecological zone was sub humid, marginal sugarcane zone. The soil type for the site was a Eutric Cambisol, characterized as dark reddish brown, friable sandy clay loam underlain by gravely red loam to light clay [8]. Soil test for the study site was carried out prior to establishment of the field experiment. ~~The soil test involved soil sampling, soil preparation and laboratory analysis for soil chemical properties.~~ The methods used to analyse the soil chemical properties are shown in Table 1. The soil test results and respective rating are also shown in Table 1.

The ~~weather data showing~~ rainfall and temperature ~~amount~~ during the experiment period (2012 to 2014) are shown in Figure 1. The study area experiences bimodal rainfall, characterized by two rainy seasons per year known as long and short rains. Annually, long rains occur in March to May while short rains are observed in September to October. This weather pattern is in agreement with [8], who recorded bimodal rainfall for lake regions in western Kenya.

Table 1. Chemical properties of experimental soil

Soil properties	Method of analysis	0 – 15 cm depth	Rating	15 – 30 cm depth	Rating
pH (H ₂ O)	1: 2.5 soil / water. Potentiometrically	6.19	Slightly acid	5.93	Medium acid
pH (KCl)	1 : 2.5 soil / 1 N KCl. Potentiometrically	5.04	Very strongly acid	4.73	Very strongly acid
Org. C (%)	Dichromate Wet Oxidation	1.30	Medium	1.23	Low
O.M (%)	Convert using factor 1.72 x Org. C	2.24	Medium	2.11	Medium
Total N (%)	Kjeldhal Method	0.10	Low	0.1	Low
Avail. P (mg kg ⁻¹)	Bray 1	20.52	High	11.91	Medium
Ex. Cu mg kg ⁻¹	Extracted using DTPA* and measured using AAS ¹	1.53	High	1.60	High
Ex. Zn mg kg ⁻¹	DTPA	1.79	High	1.52	High
Ex. Fe mg kg ⁻¹	DTPA	147.9	High	137.2	High
Ex. Mn mg kg ⁻¹	DTPA	206.2	High	193.7	High

*DTPA – diethylenetriaminepenta acetic acid; ¹AAS – Atomic absorption spectrophotometer. Ratings are according to Landon (1984), Estefan (2013)

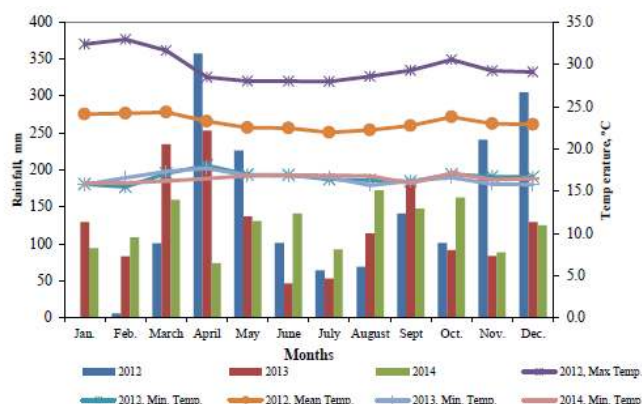


Fig. 1. Rainfall and temperature for the study site during the period of field experiment

2.2 TREATMENTS AND EXPERIMENTAL DESIGN

The experiment design was split – split plot in randomized complete block design. The main plots were 3 lime placement methods (LPM), with three levels namely: lime broadcasted (L-BC); lime shallow banded (L-SB) at depth 0 – 15 cm, and lime deep banded (L-DB) at depth 15 – 30 cm. The sub plots were 3 lime rates, with three levels namely 0, 1 and 2 t ha⁻¹. The sub – sub plots were 3 nitrogen rates with three levels, namely 0, 50 and 100 kg N ha⁻¹. This gave a total of 27 treatments, which were then replicated three times to give 81 plots. The experiment unit was gross plot, which measured [5 m x 5 rows each 1.2 m apart]. Data were collected from the net plots, i.e. the three inner rows with the one row on each side referred as guard rows.

2.3 EXPERIMENT MANAGEMENT

The field experiment was established in 2012 and managed up to 2014. The field research period coincided with sugarcane crop cycle namely plant crop (0 – 18 months after planting sugarcane setts) and ratoon one crop cycle (0 – 16 months after ratoon emergence) cycle. Soybean was intercropped and managed during the early growth stages of sugarcane which was about 0 to 60 days after soybean seeds were sowed. This early stage of sugarcane growth is referred to germination and emergence, about 45 days after planting sugarcane setts. It is then followed by tillering and canopy establishment stage usually about 2nd month to 7th month after sugarcane planting [22]. The experiment unit was plot which measured [5 m x 5 rows each 1.2 m apart] referred to as gross plot. Data was collected in the net plots described as the three inner rows with the one row in each side

119 ~~referred to guard rows.~~ Sugarcane variety used was KEN 83 – 737 referred ~~aste~~ medium maturity (0 –
120 18 months and 0 – 16 months for plant crop and ratoon crop cycle, respectively).

121 Soybean variety SB 19 was used as intercrop, which was ~~seeded~~sowed in between sugarcane rows.

122 When was soybean crop seeded? Soybean was intercropped and managed during the early growth
123 stages of sugarcane plant crop, which was about 0 to 60 days after soybean seeds were sowed.

124 Soybean intercrop was managed for 6 months and the pods harvested upon maturity. The soybean
125 was inoculated with rhizobial (Biofix ®) inoculant.

126 Agricultural lime (20 % CaO) mined in Koru, Kisumu County, was used as the liming material. The raw
127 material limestone is carbonanite which is volcanic in origin. The lime as per treatment was applied
128 prior to planting of sugarcane setts. ~~Lime placement methods used were broadcasting, banding at 0 –~~
129 ~~15 cm and also 15 – 30 cm.~~ Germination was observed at 30 to 45 days after planting. At this time,
130 soybean was ~~seeded~~sowed as intercrop, in between the sugarcane rows. Soybean was inoculated
131 with rhizobial (Biofix ®) inoculants. The sugarcane was managed for 18 months and harvested as the
132 plant crop. It was also managed for the ratoon one crop for 16 months and harvested.

133 ~~Nitrogen was applied as treatment rates of 0, 50 and 100 kg N ha⁻¹.~~ Fertilizer used was urea 46 % N.
134 ~~Time when urea was~~ applied was 4 months after planting sugarcane setts for plant crop cycle and 3
135 months after ratoon emergence for the ~~case of~~ ratoon crop cycle. The method of application was side
136 dressing along the sugarcane rows [23].

137 Ratoon crop establishment involved ~~trash~~ alignment of the sugarcane trash in between sugarcane
138 rows following green sugarcane harvest of plant crop cycle. ~~Soybean intercrop was managed for 6~~
139 ~~months and the pods harvested upon maturity.~~ The above ground biomass residue was then
140 incorporated into the soil during manual weed control using hoes. Weed control and other
141 management practices were undertaken according to KESREF recommendations [24].

142 **2.4 MEASUREMENTS AND PARAMETERS**

143 **2.4.1 Soil chemical properties**

144 Soil was sampled in each of the experimental plot referred to the sampling units. In every unit,
145 diagonal pattern was used to mark the sampling points. Soil auger was then used to collect soil
146 sample at depth 0 – 15 cm (top soil) and 15 – 30 cm (sub soil). The sampled soil was then prepared

and analysed for soil chemical properties, as given in Table 1. The parameters analysed included soil pH in water and 1 N KCL, total N, available P, extractable K, Ca, Mg, Mn, Fe, Zn, Cu and also OC, Na and cation exchange capacity (CEC) according to standard methods of soil analysis [25, 26]. The soil chemical results were interpreted according to ratings by [27] and [28].

2.4.2 Sugarcane nutrient content

Sugarcane ~~leaves were~~leaf was sampled at 18th month of sugarcane age after plant~~ing~~ed for plant crop cycle and also at 9th and 12th month ~~sugarcane age~~ after ratoon ~~crop one~~ emergence. The sampling unit was sugarcane shoot / stool per experimental plot. Four sugarcane shoots were randomly selected within the net plots and marked. Third dew lap leaf from the tip was chosen and cut using scateur. The leaves were then placed in labelled brown bags ~~well labelled~~. The leaves sampled were then taken to the laboratory and prepared. ~~The parameters analysed included total nitrogen, phosphorus, potassium, calcium, magnesium, manganese and zinc according to standard methods by [26].~~ In the laboratory, the leaf samples were gently cleaned using distilled water to remove soil and debris ~~/ dirt removed~~. Using a sharp knife, the leaf midrib was removed, leaving only the leaf sheath. This~~ese were~~as then placed in brown bags which were then placed in the oven to dry at 72°C to constant weight. The dried leaf samples were ground to fine texture using a plant mill. The parameters analysed included total nitrogen, phosphorus, potassium, calcium, magnesium, manganese and zinc according to standard methods [26]. The ground leaf samples were subjected to dry ashing and also wet digestion. For dry ashing, 0.5 grams of the leaf samples was weighed in crucibles. The crucibles were then placed in a muffle furnace and heated for 3 hours at 600°C. Ten ml of 6 N HCl and 10 ml of distilled water were added into the crucible to dissolve the ash, and the solution was filtered using Whatman number 42 filter paper. The amount of filtrate collected was then put into 25 ml volumetric flask and then topped up to mark using distilled water. The extract following dry ashing was used for determining Mn, Fe, Zn and Cu using respective wavelengths in an atomic adsorption spectrophotometer (AAS). One ml of extract was diluted and used for determining Ca and Mg in AAS and for K using a flame photometer. The amount of P in the extract was determined using the ascorbic acid molybdate blue method. Total N in the plant samples was determined by the Kjeldahl method. One gram of the plant samples was put in digestion tube, followed by addition of 10 ml 98 % H₂SO₄ and a scoop of mixed catalyst. This mixture was then digested in a digestion block for 1 hour and at 360°C. The digest was then distilled after adding 25 ml of 40 % NaOH followed by titration with

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0.05 N H₂SO₄ and boric acid indicator. The titre value was used to compute total N. Results of the sugarcane leaf nutrient content were interpreted against the critical levels according to [29] and [30].

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2.5 STATISTICAL ANALYSIS

The statistical significance was determined using ANOVA to test treatment effects on soil chemical properties, sugarcane leaf nutrient content, sugarcane yield and quality. GENSTAT statistical package was used for the statistical analysis [31]. Comparisons of means were carried out using least significance difference (LSD) at the 5% probability level. GENSTAT statistical package was used for the above statistical analysis [31].

3. RESULTS AND DISCUSSION

3.1 ~~Effects of lime placement methods (LPM), lime rates (LR) and nitrogen rates (NR)~~ on Soil chemical properties for 0 – 15 cm and 15 – 30 cm depth

~~The influence of LPM, LR and NR and their interactions on soil pH, macro and micro nutrients and also OC, Na and CEC for 0 – 15 cm soil depth is shown in Table 2 and 3 while for 15 – 30 cm depth is shown in Table 4 and 5.~~ Lime rates significantly affected soil pH, Ca, Mn and OC for the 0 – 15 cm depth (Table 2 and 3). Similarly, lime rates treatment significantly affected influenced soil pH (in water and KCl), OC, extractable Mn, Fe and Zn for the 15 – 30 cm depth (Table 4 and 5).

Increased lime rate led to increased soil pH and exchangeable Ca as given in (Table 6 and 7). Plots that received 2 t ha⁻¹ lime rate, 2 t ha⁻¹ showed the highest soil pH and Ca while the lowest soil pH and Ca werewas in control plots (no lime) plots. This trend was noted for both depths, 0 – 15 cm and also 15 – 30 cm, and also when pH was determined in water and KCl solution (Table 6). The least amount of soil extractable Mn, Zn and OC was recorded in plots that received 2 t ha⁻¹ of lime compared to the control and 1 t ha⁻¹ (Table 7).

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The increase in pH was due to the increase in basic cation calcium and neutralization of H⁺ at the exchange complex [32]. The reaction of CaO component of lime dissolves in the soil, then Ca generated moves to the surface of exchange site replacing the acidity. Meanwhile, the acidity reacts with the carbonate to forms CO₂ and water [32]. This finding is consistent with findings by [33], and [34].

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The concentration of soil extractable Mn and Zn decreased in the soil solution as lime rate increased (Table 7). These findings are in agreement in citation by [35], and [1]. [35] reported an expected decrease in Mn with increased liming. According to [36], the gradual decrease in Zn activity with increasing pH is attributed to increasing CEC. Similar observation was noted by [37] who reported that increasing surface charge due to liming increased Zn retention.

Lime placement methods did not significantly affect the soil chemical properties for 0 – 15 cm depth (Table 2 and 3) but it affected the soil pH (in KCl), total N and OC for 15 – 30 cm depth (Table 4). Nitrogen rate affected only the soil available P for the 15 – 30 cm depth (Table 4). There was no significant influence of nitrogen rates on all the soil chemical properties for the 0 – 15 cm depth.

Interaction effects of the LPM_{main} treatments were recorded for both the 0 – 15 cm and 15 – 30 cm depth. Interaction between LPM and LR significantly affected ($P < 0.05$) the soil pH (both in water and KCl), soil total N, available P, exchangeable Mg, OC, CEC and extractable Fe for 0 – 15 cm depth (Table 2 and 3). Similarly, LPM by LR_{the same} interactions significantly affected soil pH, total N, extractable Mg and OC for 15 – 30 cm depth (Table 4 and 5).

Table 2. F – test probabilities for effects of LPM, LR and N rates on soil pH and macronutrients at 0 – 15 cm soil depth

	F Test probabilities						
	Soil pH (H ₂ O)	Soil pH (KCl)	Total N, %	Avail. P,	Ex. K, cmol (+) / kg	Ex. Ca, cmol (+) / kg	Ex. Mg, cmol (+) / kg
LPM	0.492	0.474	0.39	0.158	0.563	0.323	0.426
LR	< 0.001	< 0.001	0.084	0.073	0.238	0.003	0.446
NR	0.796	0.989	0.575	0.092	0.193	0.467	0.182
LPM x LR	< 0.001	< 0.001	0.005	< 0.001	0.187	0.263	0.017
LPM x NR	0.018	0.28	0.357	0.807	0.134	0.415	0.562
LR x NR	0.228	0.092	0.447	0.874	0.113	0.291	0.161
LPM x LR x NR	0.368	0.73	0.112	0.181	0.06	0.99	0.806

LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Avail. – Available; Ex. – extractable; N – nitrogen; P – phosphorus; K – potassium; Ca – calcium; Mg – magnesium

Table 3. F – test probabilities for effects of soil micronutrients, OC, Na and CEC at 0 – 15 cm depth

	F test probabilities						
	Ex. Mn	Ex. Fe	Ex. Zn	Ex. Cu	OC, %	Na	CEC
LPM	0.208	0.792	0.696	0.770	0.541	0.583	0.431
LR	< 0.001	0.949	0.005	0.630	0.043	0.45	0.101
NR	0.928	0.717	0.242	0.700	0.544	0.789	0.812
LPM x LR	0.056	< 0.001	0.257	0.561	< 0.001	0.978	0.021
LPM x NR	0.633	0.149	0.769	0.250	0.789	0.013	0.163
LR x NR	< 0.001	0.07	0.325	0.657	0.048	0.906	0.260
LPM x LR x NR	0.549	0.489	0.075	0.965	0.876	0.803	0.329

Significance tested at $P \leq 0.05$. LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Ex. – extractable; Mn – manganese; Fe – iron; Zn – zinc; Cu – copper; OC – organic carbon; Na – sodium; CEC – cation exchange capacity

Table 4. F – test probabilities for effects of LPM, LR and N rates on soil pH and macronutrients at 15 – 30 cm soil depth

	F test probabilities						
	Soil pH (H ₂ O)	Soil pH (KCl)	Total N, %	Avail. P, /kg	Ex. K, cmol (+) /kg	Ex. Ca, cmol (+) /kg	Ex. Mg, cmol (+) /kg
LPM	0.340	0.041	0.04	0.081	0.758	0.958	0.155
LR	0.006	< 0.001	0.113	0.136	0.062	0.117	0.54
NR	0.380	0.301	0.72	0.049	0.362	0.118	0.167
LPM x LR	0.003	< 0.001	0.018	0.346	0.161	0.512	0.007
LPM x NR	0.160	0.366	0.292	0.359	0.784	0.065	0.538
LR x NR	0.349	0.006	0.734	0.089	0.366	0.276	0.291
LPM x LR x NR	0.539	0.276	0.238	0.385	0.969	0.61	0.133

Significance tested at $P \leq 0.05$. LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Avail. – Available; Ex. – extractable; N – nitrogen; P – phosphorus; K – potassium; Ca – calcium; Mg – magnesium

Table 5. F – test probabilities for effects of soil micronutrients, OC, Na and CEC at depth, 15 – 30 cm

	F – Test probabilities						
	Ex. Mn	Ex. Fe	Ex. Zn	Ex. Cu	OC, %	Na	CEC
LPM	0.393	0.756	0.651	0.193	0.023	0.181	0.662
LR	0.027	0.006	0.006	0.243	< 0.001	0.784	0.17
NR	0.79	0.920	0.289	0.158	0.115	0.368	0.682
LPM x LR	0.325	0.120	0.339	0.107	< 0.001	0.164	0.481
LPM x NR	0.703	0.233	0.809	0.749	0.259	0.442	0.717
LR x NR	0.09	0.442	0.594	0.927	0.524	0.71	0.09
LPM x LR x NR	0.243	0.599	0.955	0.516	0.817	0.088	0.75

Significance tested at $P \leq 0.05$. LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Ex. – extractable; Mn – manganese; Fe – iron; Zn – zinc; Cu – copper; OC – organic carbon; Na – sodium; CEC – cation exchange capacity

Table 6. Effects of lime rates of soil pH for depths of 0 – 15 and 15 – 30cm

Lime rates, t ha ⁻¹	0 – 15 cm soil depth			15 – 30 cm soil depth		
	Soil pH (water)	Soil pH (KCl)	CEC cmol(+)/kg soil	Soil pH (water)	Soil pH (KCl)	CEC cmol(+)/kg soil
0	6.06b	6.01b	15.77	4.81c	4.70b	17.06
1	6.28a	6.12a	16.53	5.07b	4.88a	16.41
2	6.34a	6.15a	16.63	5.23a	4.89a	15.61
LSD (P ≤ 0.05)	0.10	0.09	0.856	0.11	0.07	1.523
CV (%)	3.0	2.8	9.6	4.3	2.9	17

Means in the same column followed by the same letter(s) are not significantly different at 0.05 level of significance. Key: CEC – cation exchange capacity

Need to include soil depth in Table 7 (below)

Table 7. Effects of lime rates on soil exchangeable Calcium, Manganese, Zinc and Organic carbon

Lime rates, t ha ⁻¹	Soil chemical properties			
	Ex. Ca, cmol (+)/kg	Ex. Mn, ppm	Ex. Zn, ppm	OC, %
0	20.43b	214a	1.57b	1.38ab
1	23.42a	199a	1.84a	1.45a
2	23.74a	178b	1.44b	1.30b
LSD (P ≤ 0.05)	2.06	15.8	0.24	0.11
CV (%)	16.7	14.7	27.1	15.2

Means in the same column followed by the same letter(s) are not significantly different at 0.05 level of significance. Key: Ex – exchangeable; Ca – Calcium; Mn – Manganese; Zn – Zinc; OC – Organic Carbon

Comments:

- F-test probabilities (Table 2 to 5) provide useful information to readers on statistics for different treatments on measured parameters.
- However, very little data is presented in the form of Lime Rate effects on some measured parameters.
- The LPM treatments had significant effects on some soil properties for the 15-30 cm soil depth, and LPM x LR interactions are significant effects on soil properties.
- In my view more data needs to be presented, even when effects of some treatments may not be significant for all measurements.
- Because N rate did not influence any soil property, it is suggested to present the LPM by LR interaction data plus the MPM and LR means data for all the soil measurements. These data will provide useful information to readers.
- To minimize the number of Tables, the actual data can be included in the table used for F-test probabilities, example given below:

Table ?. F-test probabilities for main effects and interaction effects of the treatments.

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data on the main effects of LPM and LR and their interactions for the ?, ?, and ?.									
?	?	?	?	?	?	?	?	?	?
F-test probabilities									
LPM x LR interaction, LPM means and LR means									

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3.2 ~~Effects of lime placement methods, lime rates and nitrogen rates on n~~Nutrient content of sugarcane leaf for plant crop and ratoon one cycles

Effects of lime placement methods, lime rates and nitrogen rates on sugarcane leaf nutrients; nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn) and zinc (Zn) for the 3 sampling times are plant crop cycle is given in Table 8₁. ~~The same treatment effects on the sugarcane leaf nutrients for sugarcane aged 9 months after ratoon emergence and 12 months after ratoon emergence is given in Table 9 and 10 respectively.~~ Lime placement methods (LPM), LR, NR and interactions did not affect nutrient content in sugarcane for the plant crop cycle₁ except total Mn in sugarcane leaves under interaction, LPM x LR x NR treatment (Table 8). Lime placement methods, interaction LR x NR and interaction LPM x LR x NR significantly affected the sugarcane leaf K content for leaves sampled at 9th month of ratoon one cycle₁. ~~(Table 9).~~ ~~while~~ ~~Other~~ nutrients such as sugarcane leaf N, P, Ca, Mg, Mn and Zn were not significantly affected by the treatments. (Table 9). For sugarcane leaf sampled at 12 months after ratoon emergence, ~~LPM~~lime placement methods significantly affected sugarcane leaf K, Ca, Mg, Mn and Zn content, ~~LR~~ (Table 10). ~~Lime rates~~ significantly affected sugarcane leaf N and Mg content₁. Interaction LPM x LR significantly affected sugarcane leaf K content, ~~and~~. While interaction LPM x NR significantly affected sugarcane leaf N content (Table 10). Highest amount of ~~sugarcane leaf~~ K, Ca, Mg, Mn and Zn in sugarcane leaf was recorded for ~~sugarcane leaves sampled in plots that were lime shallow banded (L-SB)~~ while the lowest was in ~~plots that were lime deep banded, L-DB~~ plots (Table 11). With exception of sugarcane

leaf K content, all other nutrients were in adequate amount above critical levels according to [29] and [30]. The more sugarcane leaf nutrients content noted in L-SB sugarcane plots shallow banded with lime plots was perhaps due to enhanced uptake of the nutrients from the at 0 – 15 cm depth. However, this could not be related to the soil chemical properties investigated since lime placement methods did not influence the soil chemical properties. Though not closely related, the findings are in agreement with [34] who reported high sugarcane leaf K content in plots where lime was integrated with mineral fertilizer and compost in ratoon one crop cycle, season 2.

Table 8. F – test probabilities for effects of LPM, LR and NR on nutrient content of sugarcane leaves for plant crop cycle

	F – test probabilities						
	N	P	K	Ca	Mg	Mn	Zn
LPM	0.217	0.137	0.655	0.067	0.666	0.873	0.728
LR	0.654	0.722	0.728	0.365	0.423	0.344	0.930
NR	0.162	0.608	0.510	0.92	0.972	0.706	0.616
LPM x LR	0.698	0.859	0.887	0.945	0.900	0.085	0.124
LPM x NR	0.636	0.546	1.000	0.244	0.162	0.303	0.837
LR x NR	0.920	0.294	0.994	0.425	0.255	0.536	0.821
LPM x LR x NR	0.113	0.276	0.932	0.699	0.606	0.048	0.934

Significance tested at $P \leq 0.05$. N – nitrogen, P – phosphorus, K – potassium, Ca – calcium, Mg – magnesium, Mn – manganese, Zn – zinc

Table 9. F – test probabilities for effects of lime placement methods, lime rates and nitrogen rates on nutrient content of sugarcane leaves for ratoon crop cycle at 9 months after ratoon emergence

Source of variation	F test probabilities						
	N	P	K	Ca	Mg	Mn	Zn
LPM	0.746	0.960	0.035	0.953	0.870	0.400	0.801
LR	0.747	0.929	0.096	0.075	0.155	0.097	0.266
NR	0.636	0.470	0.071	0.827	0.929	0.996	0.572
LPM x LR	0.970	0.442	0.201	0.960	0.308	0.397	0.615
LPM x NR	0.418	0.915	0.227	0.799	0.379	0.992	0.990
LR x NR	0.840	0.718	0.011	0.981	0.570	0.871	0.747
LPM x LR x NR	0.379	0.638	0.024	0.985	0.969	0.698	0.840

Significance tested at $P \leq 0.05$. N – nitrogen, P – phosphorus, K – potassium, Ca – calcium, Mg – magnesium, Mn – manganese, Zn – zinc

Table 10. F - test probabilities for effects of lime placement methods, lime rates and nitrogen rates on nutrient content of sugarcane leaves for ratoon crop cycle at 12 months after planting

	F test probabilities						
Source of variation	N	P	K	Ca	Mg	Mn	Zn
LPM	0.330	0.478	< 0.001	0.024	0.049	0.027	0.034
LR	0.029	0.218	0.26	0.076	0.014	0.429	0.16
NR	0.491	0.680	0.169	0.416	0.532	0.160	0.866
LPM x LR	0.124	0.809	< 0.001	0.728	0.385	0.936	0.979
LPM x NR	0.035	0.889	0.823	0.395	0.516	0.308	0.596
LR x NR	0.230	0.711	0.077	0.168	0.813	0.054	0.063
LPM x LR x NR	0.238	0.32	0.053	0.662	0.609	0.667	0.972

Significance tested at $P \leq 0.05$. N – nitrogen, P – phosphorus, K – potassium, Ca – calcium, Mg – magnesium, Mn – manganese, Zn – zinc

Table 11. Effects of lime placement methods on nutrient content of sugarcane leaves at 12 months after ratoon emergence

Lime placement methods	Sugarcane leaf nutrient content				
	K, %	Ca, %	Mg, %	Mn, ppm	Zn, ppm
Lime Broadcasted	0.47b	0.70a	0.23ab	57b	17.8a
Lime deep banded	0.47b	0.53b	0.15b	52b	13.4b
Lime shallow banded	0.57a	0.68a	0.25a	60a	18.4a
LSD ($P \leq 0.05$)	0.05	0.13	0.07	6.1	4.0
CV %	19	37	30	19	44

Means in the same column followed by the same letter(s) are not significantly different at 0.05 level Key: CV – coefficient of variation; K- potassium; Ca – calcium; Mg – magnesium, Mn – manganese; Zn – Zinc

Comments: Present more actual sugarcane leaf nutrients concentrations data in addition to F-test probabilities, as suggested for soil properties.

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4. CONCLUSIONS

Liming with reference to lime rates affected the soil pH for both 0 – 15 cm and 15 – 30 cm. Lime placement methods (LPM) and also nitrogen rates (NR) did not affect the soil acidity. **Preceding statement is not true? See Lines 195, and also Line 198 to 202, indicating effects of LPM and their interaction? Please modify the statement.** Increased lime rate led to increased soil pH. Some soil chemical properties, specifically, Ca, Mn, Zn and OC were affected by the LR but not the LPM. These trends were similar for the between depth 0 – 15 cm and 15 – 30 cm. Lime rate, 2 t ha^{-1} led to the highest soil pH. Significant effects on the sugarcane nutrient content as affected by the treatments was noted for ratoon crop aged 12 months after ratoon emergence. LPM affected total K, Ca, Mn and Zn while the LR affected total N and Mg. Lime shallow banded and lime broadcasted led to highest uptake of these nutrients. **Sugarcane yield and quality parameters were not affected by the**

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285 ~~lime placement methods, lime rates and also nitrogen rates. **No mention of sugarcane yield in**~~
286 ~~**materials and Methods or Results and Discussion sections. So, either include the yield results**~~
287 ~~**in those sections or you cannot include this in conclusions.**~~ In view of the findings, lime rate 2 t
288 ha⁻¹ is recommended for use to ameliorate soil acidity for acidified Cambisols soils of Kibos, Kisumu
289 County, Kenya. Lime broadcasting or lime banding at shallow depth, 0 – 15 cm, should be used as a
290 lime placement method.

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291 **CONSENT (WHERE EVER APPLICABLE)**

292 Not applicable

293 **ETHICAL APPROVAL (WHERE EVER APPLICABLE)**

294 Not applicable

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