

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

ABSTRACT

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 [nutrient](#) 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 ~~were~~as 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~~ [nitrogen rates](#) (0, 50 and 100 kg N ha⁻¹). Lime rates significantly affected soil pH for both 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. Some soil chemical properties, specifically, exchangeable calcium (Ca), extractable manganese (Mn), zinc (Zn) and soil [organic carbon \(OC\)](#) 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. Lime rate [at](#) 2 t ha⁻¹ is recommended for ~~the use to~~ameliorate ~~teion~~

of soil acidity in fer-acidified Cambisols soils of Kibos, Kisumu County, Kenya. Lime broadcasting or lime banding at shallow depth (0 – 15 cm) soil depth should be used as a lime placement method.

Keywords: Lime placement methods, lime rates, nitrogen rates, nutrient content, sugarcane yields

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. 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 Nitrogen Fixation occurs when Rhizobium species living in symbiotic relationship in root nodules of legumes (e.g. soybean) converts atmospheric N_2 gas to NH_3 , 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 N_2 . 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].

According to [6], acidity governs the type, number and activity of microorganisms, regulates the rate of organic matter decomposition, thereby reducing the number of simple organic molecules available for further decomposition and eventually rendering N and other constituent elements (P and S) soluble. Acidity has a deleterious effect on the symbiotic relationship between rhizobia and legumes, and generally in soils with pH below 6, as poor nodulation and N_2 fixation result in. The inhibitory effect of acidity on biological N_2 fixation has also been attributed to the poor supply of Mo and Ca which are essential for N_2 fixation. Thus, when nutrient deficiencies, especially Ca and Mo are overcome in acid

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36 | soils, biological N₂ fixation can be improved [7, 1]. In Kenya, most of the soils of the sugarcane
37 | growing areas are low in soil nitrogen (N) [8]. The low soil N coupled with long - term monocropping
38 | as a consequence of its perenniality, ability of the sugarcane to ratoon severally after harvesting and
39 | land scarcity justifies continued use of nitrogen fertilizer in the same field. Also, sugarcane is capable
40 | of rapidly depleting the soil of mineral elements, particularly N and potassium if sufficient N is not
41 | applied. On average, one tonne of sugarcane removes 1.16 kg N in a given crop cycle [9].

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

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48 | Enhancing the activities of beneficial microbes such as rhizobia, diazotrophic bacteria, and mycorrhizae
49 | in the rhizosphere has improved root growth by the fixation of atmospheric nitrogen, suppressing
50 | pathogens, and producing phytohormones, enhancing root surface area to facilitate uptake of less
51 | mobile nutrients such as P and micronutrients and mobilizing and solubilizing unavailable nutrients
52 | [13]. Literature provides ample evidence that low soil pH adversely affects activities of rhizobium,
53 | including a loss of its ability to fix nitrogen [14]. It has been shown [15] ~~showed~~ that low soil pH
54 | reduced the activity of rhizobia and their ability to multiply. It has also been [16] ~~earlier demonstrated~~
55 | [16] that low soil pH increased the number of ineffective rhizobia in soil. [14] ~~reported that soil pH~~
56 | decline below 5.5 reduced rhizobial populations, and rhizobia that survive such a pH lack the capacity
57 | to fix atmospheric nitrogen. [17] showed that plants grown in an unamended control soil with low pH
58 | often exhibited low rates of nitrogen fixation. [17] also reported high rates of nitrogen fixation when
59 | high concentrations of heavy metals were present, but soil pH was nearly neutral. [18] found that
60 | decreasing the pH of nutrient solutions from 5.5 to 5.0 decreased the number of nodules formed by
61 | common bean. Lime ameliorates the harmful effects of soil acidity [19]. Studies on bacteria suggest
62 | that the success of liming may be due not only to an effect on the soil pH but also to a direct effect of
63 | increased Cacalcium on the bacteria themselves [20].

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64 | In Kenya, the common sugarcane production practice is continuous sugarcane monoculture and [the](#)
65 | use of acidifying fertilizers such as urea and diammonium phosphate [21]. These fertilizers are
66 | favoured due to their cost and levels [onof](#) nutrient element per weight compared to other nutrient
67 | fertilizer sources. The advantage of these fertilizers means their use will continue. This therefore calls
68 | for integrated use of these fertilizers with other soil improvement strategies that will mitigate against
69 | soil acidification, improve soil fertility and sugarcane nutrient uptake. Alternative strategies such as
70 | [method of lime](#) placement [of lime and appropriate -allow low-rates](#) of lime to be used [in to-reduceing](#)
71 | soil acidity. [TheseThis](#), coupled with intercropped sugarcane and soybean, could decrease rates of
72 | [Nnitrogen](#) use hence improve [Nnitrogen](#) use efficiency, nutrients availability, yields and quality of
73 | sugarcane.

74 | This study investigates whether lime use and intercropped sugarcane and soybeans [could](#) leads to
75 | amelioration of soil pH, improved [d](#) soil nutrient status and nutrient content of sugarcane leaves. It was
76 | hypothesized that lime placement methods, lime rates and nitrogen rates [does](#) improve soil chemical
77 | properties and sugarcane leaf nutrient content in acid soils of Kibos, Kisumu County in Kenya.

78 | 2. MATERIAL AND METHODS

79 | 2.1 STUDY SITE

80 | The field experiment was conducted at field 6, experimental plots of Kibos ($35^{\circ}13'$ E, $0^{\circ}06'$ S), under
81 | Kenya Agricultural and Livestock Research Organization – Sugar Research Institute. The elevation of
82 | the site [wasis](#) 1268 m above sea level and the agro – ecological zone [wasis](#) sub humid, marginal
83 | sugarcane zone. The soil type for the site [iswas](#) Eutric Cambisol characterized as dark reddish brown,
84 | friable sandy clay loam underlain by gravely red loam to light clay [8]. Soil test for the study site was
85 | carried out prior to establishment of the field experiment. The soil test involved soil sampling, soil
86 | preparation and laboratory analysis for soil chemical properties. The methods used to [analyseanalyze](#)
87 | the soil chemical properties are shown in Table 1. The soil test results and respective ratings [s](#) are
88 | shown in Table 1. The weather data showing rainfall and temperature amount during the experiment
89 | period (2012 to 2014) is shown in Figure 1. The study area experiences bimodal rainfall characterized
90 | by two rainy seasons per year known as long and short rains. Annually, long rains occur in March to
91 | May while short rains are observed in September to October. This weather pattern is in agreement
92 | 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)

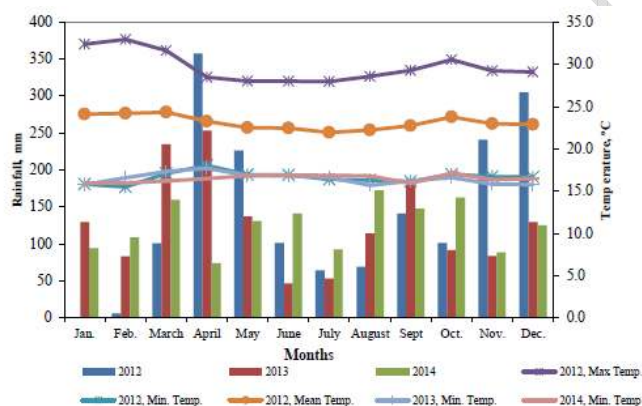


Fig. 1. Rainfall and temperature for the study site during the period of field experiment

2.2 EXPERIMENTAL DESIGN AND TREATMENTS DESCRIPTION

The experimental design used was split – split plot in randomized complete block design. The main plot was 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 plot was lime rates with three levels namely 0, 1 and 2 t ha⁻¹. The sub – sub plots was 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.

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). 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 referred to as guard rows. Sugarcane variety used was KEN 83 – 737 referred to as medium maturity (0 – 18 months and 0 – 16 months for plant crop and ratoon crop cycle respectively). Soybean variety SB 19 was used as intercrop which was sowed in between sugarcane rows. The soybean was inoculated with rhizobial (Biofix ®) inoculant.

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

Nitrogen was applied ~~asat~~ treatment rates of 0, 50 and 100 kg N ha⁻¹. Fertilizer used was urea 46 % N. Time when urea was applied was 4 months after planting sugarcane setts for plant crop cycle and 3 months after ratoon emergence for the case of ratoon crop cycle. The method of application was side dressing along the sugarcane rows [23]. The sugarcane was managed for 18 months and harvested as the plant crop. It was also managed for the ratoon one crop for 16 months and harvested.

129

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

135 **2.4 MEASURED PARAMETERS**

136 **2.4.1 Soil chemical properties**

137 Soil was sampled in each of the experimental plot referred to the sampling units. In every unit,
138 diagonal pattern was used to mark the sampling points. Soil auger was then used to collect soil
139 sample at depth 0 – 15 cm (top soil) and 15 – 30 cm (sub soil). The sampled soil was then prepared
140 and ~~analysed~~analyzed for soil chemical properties as given in Table 1. The parameters
141 ~~analysed~~analyzed included soil pH in water and ~~in~~ 1 N KCL, total N, available P, extractable K, Ca,
142 Mg, Mn, Fe, Zn, Cu and also OC, Na and cation exchange capacity (CEC) according to standard
143 methods of soil analysis [25, 26]. The soil chemical results were interpreted according to ratings by
144 [27] and [28].

145 **2.4.2 Sugarcane nutrient content**

146 Sugarcane leaf was sampled at 18th months ~~s after planting of sugarcane age after planted~~ for plant
147 crop cycle and also at 9th and 12th months ~~s sugarcane age~~ after ratoon one emergences. The
148 sampling unit was sugarcane shoot / stool per experimental plot. Four sugarcane shoots were
149 randomly selected within the net plots and marked. Third dew lap leaf from the tip was chosen and cut
150 using scateur. The leaves were then placed in brown bags well labelled. The leaves sampled were
151 then taken to the laboratory and prepared. The parameters ~~analysed~~analyzed included total nitrogen,
152 phosphorus, potassium, calcium, magnesium, manganese and zinc according to standard methods
153 by [26]. In the laboratory, the leaf samples were gently cleaned using distilled water and debris / dirt
154 removed. Using a sharp knife, the leaf midrib was removed, leaving only the leaf sheath. This was
155 then placed in brown bags which were then placed in the oven to dry at 72°C to constant weight. The
156 dried leaf samples were ground to fine texture using a plant mill. The ground leaf samples were
157 subjected to dry ashing and also wet digestion. For dry ashing, 0.5 grams of the leaf samples was

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weighed in crucibles. The crucibles were then placed in a muffle furnace and heated for 3 hours at 600°C. Ten ~~ml~~ ^{millilitres} 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 ~~millilitre~~ ^{millilitre} 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 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. 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 depths

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 Tables 2 and 3 while ~~that for~~ ^{for} 15 – 30 cm depth is shown in Tables 4 and 5. Lime rates significantly affected soil pH, Ca, Mn and OC for 0 – 15 cm depth (Tables 2 and 3). Similarly, lime rates treatment significantly affected ~~influenced~~ ^{influenced} soil pH (in water and KCl), OC, extractable Mn, Fe and Zn for 15 – 30 cm depth (Tables 4 and 5).

Increased lime rate led to increased soil pH and exchangeable Ca as given in Tables 6 and 7. Plots that received lime ~~rate at~~ ^{at} 2 t ha⁻¹ showed the highest soil pH and Ca while the lowest soil pH and Ca

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187 | was in control plots (no lime). This trend was noted for both depths, (0 – 15 cm, ~~and also~~ 15 – 30 cm)
188 | and also when pH was determined in water and KCl solution (Table 6). The least amount of soil
189 | extractable Mn, Zn and OC was recorded in plots that received 2 t ha⁻¹ of lime compared to the control
190 | and 1 t ha⁻¹ (Table 7).

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

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

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

204 | Interaction effects of the main treatments were recorded for both 0 – 15 cm and 15 – 30 cm depths.
205 | Interaction between LPM and LR significantly affected (P < 0.05) the soil pH (both in water and KCl),
206 | soil total N, available P, exchangeable Mg, OC, CEC and extractable Fe for 0 – 15 cm depth (Tables
207 | 2 and 3). Similarly, the same interactions significantly affected soil pH, total N, extractable Mg and OC
208 | for 15 – 30 cm depth (Tables 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,	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 ($P \leq 0.05$)	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

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 ($P \leq 0.05$)	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

Comment [D2]: Where you have LSD values you do not need to attach letters in comparing

Comment [D3]: Where you have LSD values you do not need to attach letters in comparing

3.2 Effects of lime placement methods, lime rates and nitrogen rates on 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 plant crop cycle [isare](#) given in Table 8. The same treatment effects on the sugarcane leaf nutrients for sugarcane aged 9 months after ratoon emergence and 12 months after ratoon emergence [isare](#) given in Tables [9](#) and [10](#) respectively. Lime placement methods, LR, NR and interactions did not affect nutrient content in sugarcane for the plant crop cycle except total Mn in sugarcane leaves under

223 interaction, LPM x LR x NR treatment (Table 8). Lime placement methods, interaction LR x NR and
 224 interaction LPM x LR x NR significantly affected the sugarcane leaf K content for leaves sampled at
 225 9th months of ratoon one cycle (Table 9). Other nutrients such as sugarcane leaf N, P, Ca, Mg, Mn
 226 and Zn were not significantly affected by the treatments. For sugarcane leaf sampled at 12 months
 227 after ratoon emergence, lime placement methods significantly affected sugarcane leaf K, Ca, Mg, Mn
 228 and Zn contents (Table 10). Lime rates significantly affected sugarcane leaf N and Mg contents.
 229 Interaction LPM x LR significantly affected sugarcane leaf K content. While interaction LPM x NR
 230 significantly affected sugarcane leaf N content (Table 10). Highest amount of sugarcane leaf K, Ca,
 231 Mg, Mn and Zn was recorded for sugarcane leaves sampled in plots that were lime shallow banded
 232 (L-SB) while the lowest was in plots that were lime deep banded, L-DB (Table 11). With exception of
 233 sugarcane leaf K content, all other nutrients were in adequate amount above critical levels according
 234 to [29] and [30]. The more sugarcane leaf nutrients content noted in sugarcane plots shallow banded
 235 with lime was perhaps due to enhanced uptake of the nutrients at 0 – 15 cm depth. However, this
 236 could not be related to the soil chemical properties investigated since lime placement methods did not
 237 influence the soil chemical properties. Though not closely related, the findings are in agreement with
 238 [34] who reported high sugarcane leaf K content in plots where lime was integrated with mineral
 239 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

Source of variation	F test probabilities						
	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

Comment [D4]: Where you have LSD values you do not need to attach letters in comparing

4. CONCLUSION

Liming with reference to lime rates affected the soil pH forin both 0 – 15 cm and 15 – 30 cm soil depths. Lime placement methods (LPM) and also nitrogen rates (NR) did not affect the soil acidity. 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 in both between depths, 0 – 15 cm and 15 – 30 cm. Lime rate, at 2 t ha⁻¹ led to the highest soil pH. Significant effects of the

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sugarcane nutrient content as affected by the treatments ~~was~~^{were} noted for ratoon crop ~~aged~~^{at} 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 lime placement methods, lime rates and also nitrogen rates. In view of the findings, 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 depth, 0 – 15 cm, should be used as a lime placement method.

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257 **CONSENT (WHERE EVER APPLICABLE)**

258 Not applicable

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

260 Not applicable

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