

Original Research Article

EFFECTS OF LIME AND NITROGEN ~~RATES~~ ON SOIL PROPERTIES OF AN ACIDIC SOIL AND NUTRIENT CONTENT OF SUGARCANE LEAVES UNDER SUGARCANE – SOYBEAN ~~INTERCROPPED~~ INTERCROPPING ~~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.

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Lime placement methods interaction with LR significantly affected soil pH, N, P, Fe, OC and CEC for 0 – 15 cm depth. This interaction also affected soil pH, N, Mg and OC for 15 – 30 cm depth. LPM alone did not affect soil chemical properties for 0 – 15 cm depth but affected soil pH and N for 15 – 30 cm depth.

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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.~~ 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 on~~ plants and soil organisms [1]. ~~Nitrogen (N), a primary nutrient for crop production, is affected by soil acidity.~~ Nitrogen (N) 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 %

26 of what is applied. Legumes and manure can release quite high amounts of N in a rather short time.

27 Biological ~~N~~nitrogen ~~f~~Fixation occurs when *Rhizobium* species living in symbiotic relationship in root
28 nodules of legumes (e.g. soybean) converts atmospheric N_2 gas to NH_3 , which is further converted to
29 amino acids and proteins. ~~In exchange, the legumes provide the Rhizobium species with the energy~~
30 ~~they need to grow and to fix N_2 .~~ The process is depressed when other sources of N are abundant,
31 and is also reduced in acid soils and in soils with low P availability [5]. ~~Legumes use in are used in~~
32 ~~sugarcane production is possible through intercropping system. Intercropping of sugarcane refers to~~
33 ~~either growing cultivating alternative crops between crops of along with sugarcane, or between the~~
34 ~~rows of existing sugarcane fields [38]. Sugarcane intercropping is practiced on small - holder farms of~~
35 ~~less than 2 ha in western Kenya with an aim of food security and household income [39, 40, 41 39-~~
36 ~~41]. The benefits of sugarcane soybean intercropping are diverse crops yield, increased income,~~
37 ~~nutrition and also biological nitrogen fixation (BNF) which cut costs on the use of N fertilizers and~~
38 ~~therefore reduce soil N mining [42].~~

39 According to Alexander [6], acidity governs the type, number and activity of microorganisms, regulates
40 the rate of organic matter decomposition, - thereby reducing the number of simple organic molecules
41 available for further decomposition and eventually rendering N and other constituent elements (P and
42 S) soluble. Acidity has a deleterious effect on the symbiotic relationship between rhizobia and
43 legumes, and generally in soils with pH below 6, poor nodulation and N_2 fixation result in. The
44 inhibitory effect of acidity on biological N_2 fixation has also been attributed to the poor supply of Mo
45 and Ca , which are essential for N_2 fixation. Thus, when nutrient deficiencies, especially Ca and Mo
46 are overcome in acid soils, biological N_2 fixation can be improved [7, 1].

47 In Kenya, most of the soils ~~of the under~~ sugarcane ~~growing areas cultivation~~ are low in soil nitrogen
48 ~~(N)~~ [8]. The low soil N coupled with long - term monocropping as a consequence of its perennality,
49 ability of the sugarcane to ratoon severally after harvesting, and land scarcity justifies continued use
50 of ~~nitrogen N~~ fertilizer ~~in the same field~~ for sugarcane production. ~~Also~~ Further, sugarcane is also
51 capable of rapidly depleting the soil of ~~nutrients~~ mineral elements, particularly N and potassium if
52 sufficient N is not applied. On average, one tonne of sugarcane removes 1.16 kg N in a given crop
53 cycle [9].

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54 Liming is a management practice to reduce the soil acidity and therefore one of the soil fertility
55 management practices [10]. Most plants grow well at a pH range of 5.5 – 6.5 and liming is aimed to
56 increase the pH to this range. The benefits of liming include: enhanced ~~soil~~-physical, chemical and
57 biological conditions ~~of soil~~. The indirect benefits include mobilization of plant nutrients, immobilization
58 of toxic heavy metals, and improvements in soil structure. Liming also ~~createscauses-an~~ optimal
59 conditions that ~~favours~~ biological activities ~~that-includinge~~ N₂ fixation and mineralization of N, P and S
60 in soils [11, 12].

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61 Enhancing the activities of beneficial microbes such as rhizobia, diazotrophic bacteria, and mycorrhizae
62 in the rhizosphere has improved ~~root-plant~~ growth by the fixation of atmospheric nitrogen, suppressing
63 pathogens, and producing phytohormones, enhancing root surface area to facilitate uptake of less
64 mobile nutrients such as P and micronutrients and mobilizing and solubilizing unavailable nutrients
65 [13]. ~~Literature-Previous studies~~ provides ample evidence that low soil pH adversely affects activities
66 of rhizobium, including a loss of its ability to fix ~~nitrogen-N~~ [14], ~~and -~~ [15] showed that low soil pH
67 reduced the activity and their ability to multiply [15]. [16] earlier demonstrated that ~~low~~ soil pH
68 increased the number of ineffective rhizobia in soil [16]. [14] reported that ~~soil pH decline~~ below 5.5
69 reduces rhizobial populations, and rhizobia that survive such a pH lack the capacity to fix
70 atmospheric ~~nitrogen-N~~ [14]. [17] showed that ~~p~~ plants grown in ~~growing an-unamended-control-soil in~~
71 ~~acidic soils with low pH~~ often exhibited ~~low rates of nitrogen low N₂ fixation, while showed~~ [17] also
72 reported high rates of ~~nitrogen-N₂ fixation even under when~~ high concentrations of heavy metals ~~were~~
73 ~~are reported under near neutral pH present, but soil pH was nearly neutral~~ [17]. [18] found that
74 ~~dDecreasing-theA drop in~~ pH of nutrient solutions from 5.5 to 5.0 decreases the number of nodules
75 formed by common bean (*Phaseolus vulgaris*) [18] [22]. ~~Scientific name??~~ [18].

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

79 In Kenya, ~~the-common-sugarcane production-practice-is~~ cultivated under continuous sugarcane
80 monoculture ~~and-along-with-the~~ use of acidifying fertilizers such as urea and diammonium phosphate
81 [21]. These fertilizers are favoured due to their cost and levels of ~~in~~ 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 fertilization ~~er use and intercropped sugarcane and soybeans~~ leads to amelioration of soil pH~~Acidity~~, improve soil nutrient status and nutrient content of sugarcane leaves under intercropped sugarcane and when intercropped with 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~~is~~ 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-between March ~~to~~ and May while short rains are observed in-during September to October. This weather pattern is in agreement with Jaetzold et al. [8], who recorded bimodal rainfall for lake regions in western Kenya.

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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	148	High	137	High
Ex. Mn (mg kg ⁻¹)	DTPA	206	High	194	High

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

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- Comment [b22]: Rounded off to whole number Fe and Mn results
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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)

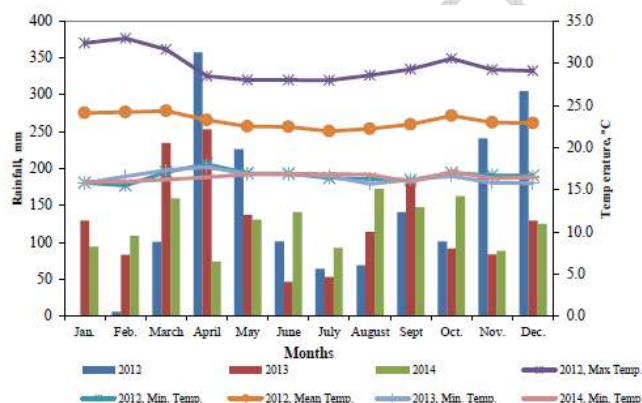


Fig. 1. Rainfall and temperature for the study site during the period of field experiment

2.2 TREATMENTS AND EXPERIMENTAL DESCRIPTION

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

127 whereas 3 nitrogen rates ~~with three levels~~, namely 0, 50 and 100 kg N ha⁻¹. This gave a total of 27
128 treatments, which were ~~then~~ replicated three times ~~to give 81 plots~~. The experiment unit was gross
129 plot, which measured [5 m x 5 rows each 1.2 m apart]. Data were collected from the net plots, i.e. the
130 three inner rows with the one row on each side referred as guard rows.

131 2.3 EXPERIMENT MANAGEMENT

132 The field experiment was established in 2012 and managed up to 2014. The field research period
133 coincided with sugarcane ~~crop cycle namely~~ plant crop (0 – 18 months after planting sugarcane setts)
134 and ratoon one crop ~~cycle~~ (0 – 16 months after ratoon emergence) cycle. ~~Soybean was intercropped~~
135 ~~and managed during the early growth stages of sugarcane which was about 0 to 60 days after~~
136 ~~soybean seeds were sowed~~. This early stage of sugarcane growth is referred to germination and
137 emergence, about 45 days after planting sugarcane setts. It is then followed by tillering and canopy
138 establishment stage usually about ~~2nd ed month to 7th th~~ month after sugarcane planting [22]. ~~The~~
139 ~~experiment unit was plot which measured [5 m x 5 rows each 1.2 m apart] referred to as gross plot~~.
140 ~~Data was collected in the net plots described as the three inner rows with the one row in each side~~
141 ~~referred to guard rows~~. Sugarcane variety used was KEN 83 – 737 referred aste medium maturity (0 –
142 18 months and 0 – 16 months for plant crop and ratoon crop cycle, respectively).

143 Soybean variety SB 19 was used as intercrop, which was ~~seeded~~sowed in between sugarcane rows.
144 Soybean seeds were sowed in the 30th day after sugarcane setts were planted. In this period,
145 sugarcane setts had germinated and the shoots emerged. The soybean was inoculated with rhizobial
146 (Biofix ®) inoculant. Soybean intercrop was managed for 6 months and the pods harvested upon
147 maturity. The above ground biomass residue was then incorporated into the soil during manual weed
148 control using hoes.

149 ~~When was soybean crop seeded?~~ Soybean was intercropped and managed during the early growth
150 ~~stages of sugarcane pant crop, which was about 0 to 60 days after soybean seeds were sowed.~~
151 ~~Soybean intercrop was managed for 6 months and the pods harvested upon maturity. The soybean~~
152 ~~was inoculated with rhizobial (Biofix ®) inoculant.~~

153 Agricultural lime (20 % CaO) mined in Koru, Kisumu County, was used as the liming material. The raw
154 material limestone is carbonanite which is volcanic in origin. The lime as per treatment was applied 48
155 days (on 29th June 2016) prior to planting of sugarcane setts which was carried out on 15th August

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2012. 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 as 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].

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

2.4 MEASUREMENTS AND PARAMETERS

2.4.1 Soil chemical properties

Soil was sampled in each of the experimental plot referred to the sampling units. In every unit, diagonal pattern was used to mark the sampling points. Soil auger was then used to collect soil 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 Landon Booker [27] and Estefan et al. [28].

2.4.2 Sugarcane nutrient content

Sugarcane ~~leaves were~~ leaf was sampled at 18th month of sugarcane age after planting 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

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185 were then taken to the laboratory and ~~prepared~~^{processed}. ~~The parameters analysed included total~~
 186 ~~nitrogen, phosphorus, potassium, calcium, magnesium, manganese and zinc according to standard~~
 187 ~~methods by [26].~~ In the laboratory, the leaf samples were gently ~~cleaned using~~ ^{washed with} distilled
 188 water ~~to remove soil~~ and debris ~~/ dirt removed~~. Using a sharp knife, the leaf midrib was removed ~~from~~
 189 ~~the lamina, leaving only the leaf sheath~~. ~~Thise~~^{se} ~~were~~^{as} then placed in brown bags ~~which were then~~
 190 ~~and dried~~ ^{placed in the an hot air oven to dry at (72°C)} to constant weight. The dried leaf samples
 191 were ground to fine texture using a plant mill. ~~The ground leaf samples were subjected to dry ashing~~
 192 ~~and also wet digestion. For dry ashing, 0.5 grams of the leaf sample was weighed in crucibles. The~~
 193 ~~crucibles were then placed in a muffle furnace and heated for 3 hours at 600°C. Ten ml of 6 N HCl~~
 194 ~~and 10 ml of distilled water were added into the crucible to dissolve the ash, and the solution was~~
 195 ~~filtered using Whatman number 42 filter paper. The amount of filtrate collected was then put into 25 ml~~
 196 ~~volumetric flask and then topped up to mark using distilled water. The parameters analysed included~~
 197 ~~total nitrogenN, phosphorusP, potassiumK, calciumCa, magnesiumMg, manganeseMn and zincZn~~
 198 ~~according to using standard methods procedures [26].~~ The ground leaf samples were subjected to dry
 199 ~~ashing and also wet digestion. For dry ashing, 0.5 grams of the leaf samples was weighed in~~
 200 ~~crucibles. The crucibles were then placed in a muffle furnace and heated for 3 hours at 600°C. Ten ml~~
 201 ~~of 6 N HCl and 10 ml of distilled water were added into the crucible to dissolve the ash, and the~~
 202 ~~solution was filtered using Whatman number 42 filter paper. The amount of filtrate collected was then~~
 203 ~~put into 25 ml volumetric flask and then topped up to mark using distilled water. The extract following~~
 204 ~~dry ashing was used for determining Mn, Fe, Zn and Cu~~ ^{content in leaves were measured} using
 205 respective wavelengths in an atomic adsorption spectrophotometer (AAS). One ml of extract was
 206 diluted and used for determining Ca and Mg in AAS and for K using a flame photometer. ~~The amount~~
 207 ~~of P in the extract was determined using the ascorbic acid molybdate blue method. Total N in the~~
 208 ~~plant samples was determined by the Kjeldahl method. One gram of the plant samples was put in~~
 209 ~~digestion tube, followed by addition of 10 ml 98 % H₂SO₄ and a scoop of mixed catalyst. This mixture~~
 210 ~~was then digested in a digestion block for 1 hour and at 360° C. The digest was then distilled after~~
 211 ~~adding 25 ml of 40 % NaOH followed by titration with 0.05 N H₂SO₄ and boric acid indicator. The titre~~
 212 ~~value was used to compute total N.~~ Results of the sugarcane leaf nutrient content were interpreted
 213 against the critical levels according to [Calcino et al. \[29\]](#) and [McCray and Mylavarapu \[30\]](#).

214 2.5 STATISTICAL ANALYSIS

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

220 3. RESULTS AND DISCUSSION

221 3.1 Effects of lime placement methods (LPM), lime rates (LR) and nitrogen rates (NR) 222 on sSoil chemical properties for 0 – 15 cm and 15 – 30 cm depth

223 The influence of LPM, LR and NR and their interactions on soil pH, macro and micro nutrients and
224 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
225 shown in Table 4 and 5. Lime rates significantly affected soil pH, Ca, Mn and OC for the 0 – 15 cm
226 depth (Table 2 and 3). The respective means as affected by the treatments for 0 – 15 cm depth is
227 shown in Tables 4 and 5.

228 Similarly, lime rates treatment significantly affected influenced soil pH (in water and KCl), OC,
229 extractable Mn, Fe and Zn for the 15 – 30 cm depth as shown in (Tables 6, 7, 8 and 9, 4 and 5).

230 Increased lime rate led to increased soil pH and exchangeable Ca as given in (Tables 4, 5, 8 and 9-6
231 and 7). Plots that received 2 t ha⁻¹ lime rate, 2 t ha⁻¹ showed the highest soil pH and Ca while the
232 lowest soil pH and Ca were was in control plots (no lime) plots. This trend was noted for both depths, 0
233 – 15 cm and also 15 – 30 cm, and also when pH was determined in water and KCl solution (Table 4
234 and 86). The least amount of soil extractable Mn, Zn and OC was recorded in plots that received 2 t
235 ha⁻¹ of lime compared to the control and 1 t ha⁻¹ (Tables 75 and 9).

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

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241 The concentration of soil extractable Mn and Zn decreased in the soil solution as lime rate increased
 242 (Tables 5 and 9-7). These findings are in agreement in citation by with the results of Edmeades [35],
 243 and Bolan et al. [1].

245 [35] reported Aan expected decrease in Mn with increased liming was reported by Edmeades [35].
 246 According to Shuman [36], the gradual decrease in Zn activity with increasing pH is attributed to
 247 increasing CEC. Similar observation was also noted by Stahl and James [37] who reported that
 248 increasing surface charge due to liming increased Zn retention.

249 Lime placement methods did not significantly affect the soil chemical properties for 0 – 15 cm depth
 250 (Table 4 and 52-and-3), but it affected the soil pH (in KCl), total N and OC for 15 – 30 cm depth (Table
 251 6, 7 8 and 94). Nitrogen rate affected only the soil available P for the 15 – 30 cm depth (Table 46 and
 252 8). The probable reason could be that sugarcane under plots that received 100 kg N ha⁻¹ performed
 253 well to extent that sugarcane roots extracted P better compared to sugarcane under control plots (0
 254 kg N ha⁻¹). There was no significant influence of nitrogen rates on all the soil chemical properties for
 255 the 0 – 15 cm depth.

256 Interaction effects of the LPM and LRmain treatments were recorded for both the 0 – 15 cm and 15 –
 257 30 cm depth. Interaction between LPM and LR significantly affected (P < 0.05) the soil pH (both in
 258 water and KCl), soil total N, available P, exchangeable Mg, OC, CEC and extractable Fe for 0 – 15 cm
 259 depth (Tables 2, 3, 10 and Figure 2Table-2 and-3). Similarly, LPM by LRthe same interactions
 260 significantly affected soil pH, total N, extractable Mg and OC for 15 – 30 cm depth (Tables 6, 7 and
 261 11). 4 and 5).

262 Table 2. F – test probabilities for effects of lime placement methods, lime rates and nitrogen LPM, LR and N rates on soil
 263 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

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Comment [R6]: Spellout fully. Avoid abbreviations in table and figure titles.

Comment [R7]: What does these probability values in bold represent? Significant levels??? Mention in the foot notes. This holds true for other such tables.

264 LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Avail. – Available; Ex. – extractable; N – nitrogen; P
 265 – phosphorus; K – potassium; Ca – calcium; Mg – magnesium; **bold figures indicate significant difference at level $P \leq 0.05$.**

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 267 Table 3. F – test probabilities for effects of soil micronutrients, organic carbon, sodium and cation exchange capacityOC, Na
 268 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

269 Significance tested at $P \leq 0.05$. LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Ex. – extractable; Mn
 270 – manganese; Fe – iron; Zinc – zinc; Cu – copper; OC – organic carbon; Na – sodium; CEC – cation exchange capacity.
 271 **bold figures indicate significant difference at level $P \leq 0.05$.**

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274 Table 4: Means for the effects of lime placement methods, lime rates and nitrogen ratesLPM, LR and NR on soil pH and
 275 macronutrients at 0 – 15cm soil depth

Factors	Levels	Soil pH (In H ₂ O)	Soil pH (in KCl)	Total N, %	Avail P, mg kg ⁻¹	Ex. K, cmol(+)/kg	Ex. Ca, cmol(+)/kg	Ex. Mg, cmol(+)/kg
LPM	LBC	6.27	5.08	0.11	9.04a	0.54	22.11	2.56
	LDB	6.21	5.04	0.10	7.05b	0.51	23.43	2.65
	LSB	6.23	5.00	0.11	8.08ab	0.50	22.05	2.57
	LSD ($P \leq 0.05$)	ns	ns	ns	1.82	ns	ns	ns
LR, tha ⁻¹	0	6.07b	4.81c	0.11	8.45ab	0.53	20.43b	2.60
	1	6.28a	5.07b	0.10	8.95a	0.53	23.42a	2.64
	2	6.35a	5.23a	0.10	6.78b	0.48	23.74a	2.55
	LSD ($P \leq 0.05$)	0.1	0.11	ns	1.82	ns	2.06	ns
NR, kg Nha ⁻¹	0	6.25	5.04	0.11	8.08ab	0.53	23.21	2.65
	50	6.22	5.03	0.10	7.09b	0.54	21.95	2.52
	100	6.24	5.04	0.11	9.02a	0.48	22.43	2.61
	LSD ($P \leq 0.05$)	ns	ns	ns	1.82	ns	ns	ns
	CV (%)	3	4.3	13	43	24.1	16.7	10.2

276 Any two means not followed by the same letter down a column are significantly different at $P = 0.05$

277 LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Avail. – Available; Ex. – extractable; N – nitrogen; P
 278 – phosphorus; K – potassium; Ca – calcium; Mg – magnesium; LBC – lime broadcasted; LDB – lime deep banded; LSB –
 279 lime shallow banded; ns – not significant

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Table 5. Means for the effects of lime placement methods, lime rates and nitrogen rates LPM, LR and NR on micronutrients, organic carbon, sodium and cation exchange capacity OC, Na and CEC at 0 – 15cm soil depth

Factors	Levels	Ex. Mn, mg kg ⁻¹	Ex. Fe, mg kg ⁻¹	Ex. Zn, mg kg ⁻¹	Ex. Cu, mg kg ⁻¹	OC, %	Ex. Na, cmol(+)/kg	CEC, cmol(+)/kg
LPM	LBC	200	85	1.66	2.05	1.41	0.11	16.53
	LDB	192	79	1.53	1.96	1.37	0.11	16.39
	LSB	198	81	1.56	2.07	1.35	0.10	16.00
	LSD (P ≤ 0.05)	ns	ns	ns	ns	ns	ns	ns
LR, tha ⁻¹	0	214a	82	1.57ab	2.06	1.38ab	0.11	15.77
	1	199a	83	1.75a	2.09	1.45a	0.11	16.53
	2	178b	80	1.44b	1.93	1.30b	0.10	16.63
	LSD (P ≤ 0.05)	15.8	ns	0.29	ns	0.11	ns	ns
NR, kg Nha ⁻¹	0	201	86	1.69	2.08	1.40	0.11	16.39
	50	195	79	1.50	1.95	1.34	0.11	16.15
	100	194	81	1.56	2.05	1.38	0.11	16.38
	LSD (P ≤ 0.05)	ns	ns	ns	ns	ns	ns	ns
	CV (%)	14.7	41.0	33.0	30.3	15.2	30.4	9.6

Any two means not followed by the same letter down a column are significantly different at P = 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; LBC – lime broadcasted; LDB – lime deep banded; LSB – lime shallow banded; ns – not significant

Table 6. F – test probabilities for effects of lime placement methods, lime rates and nitrogen rates 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 ≤ 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; bold figures indicate significant difference at level P ≤ 0.05.

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Table 7. F – test probabilities for effects of soil micronutrients, organic carbon, sodium and cation exchange capacity OC, Na and CEC at 15 – 30 cm depth

	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; **bold figures indicate significant difference at level $P \leq 0.05$.**

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Table 8. Means for the effects of **lime placement methods, lime rates and nitrogen rates** LPM, LR and NR on soil pH and macronutrients at 15 – 30 cm soil depth

Factors	Levels	Soil pH, In H ₂ O	Soil pH, in KCl	Total N, %	Avail. P, mg kg ⁻¹	Ex. K, cmol(+)/kg	Ex. Ca, cmol(+)/kg	Ex. Mg, cmol(+)/kg
LPM	LBC	6.08	4.77b	0.09b	6.01ab	0.32	19.53	2.70
	LDB	6.13	4.87a	0.10ab	6.75a	0.33	19.80	2.76
	LSB	6.14	4.84ab	0.11a	5.20b	0.33	19.55	2.89
	LSD (P ≤ 0.05)	ns	0.078	0.009	1.35	ns	ns	ns
LR, tha ⁻¹	0	6.01c	4.71b	0.10	5.75	0.33ab	19.13	2.77
	1	6.13b	4.88a	0.11	6.76	0.35a	20.85	2.75
	2	6.21a	4.89a	0.10	5.45	0.29b	18.89	2.85
	LSD (P ≤ 0.05)	0.067	0.078	ns	ns	0.047	ns	ns
NR, kg Nha ⁻¹	0	6.13	4.86	0.10	6.86a	0.35	20.82	2.85
	50	6.12	4.82	0.10	5.16b	0.32	19.31	2.83
	100	6.10	4.80	0.10	5.92ab	0.32	18.75	2.68
	LSD (P ≤ 0.05)	ns	ns	ns	1.35	ns	ns	ns
	CV (%)	2.0	2.9	15.2	41.3	26.2	19.0	13.0

Any two means not followed by the same letter down a column are significantly different at $P = 0.05$

LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Avail. – Available; Ex. – extractable; N – nitrogen; P – phosphorus; K – potassium; Ca – calcium; Mg – magnesium; LBC – lime broadcasted; LDB – lime deep banded; LSB – lime shallow banded; **ns – not significant**

Table 9. Means for the effects of **lime placement methods, lime rates and nitrogen rates** LPM, LR and NR on micronutrients, **organic carbon, sodium and cation exchange capacity-OC, Na and CEC** at 15 – 30 cm soil depth

Factors	Levels	Ex. Mn, mg kg ⁻¹	Ex. Fe, mg kg ⁻¹	Ex. Zn, mg kg ⁻¹	Ex. Cu, mg kg ⁻¹	OC, %	Ex. Na, cmol(+)/kg	CEC, cmol(+)/kg
LPM	LBC	199	77	1.19	1.92	1.78b	0.14	16.19
	LDB	193	84	1.24	1.88	2.03a	0.12	16.13
	LSB	211	82	1.15	2.06	1.94ab	0.13	16.76
	LSD (P ≤ 0.05)	ns	ns	ns	ns	0.176	ns	ns
LR, tha ⁻¹	0	203	69b	1.08b	1.82	1.82b	0.13	15.61
	1	205	101a	1.38a	1.96	2.12a	0.13	16.41
	2	194	73b	1.11b	2.09	1.81b	0.13	17.06
	LSD (P ≤ 0.05)	ns	20.4	0.199	ns	0.176	ns	ns
NR, kg Nha ⁻¹	0	199	83	1.28	1.93	2.02	0.13	16.10

	50	203	79	1.14	2.10	1.87	0.13	16.24
	100	200	81	1.16	1.83	1.86	0.13	16.73
	LSD (P ≤ 0.05)	ns	ns	ns	ns	ns	ns	ns
	CV (%)	17.9	46.3	30.6	24.9	16.8	21.8	17.0

Any two means not followed by the same letter down a column are significantly different at P = 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; LBC – lime broadcasted; LDB – lime deep banded; LSB – lime shallow banded; ns – not significant

Table 10. Effects of interaction between lime placement methods and lime rates on soil chemical properties for 0 – 15 cm soil depth

Treatment	Soil pH (In H ₂ O)	Soil pH (In KCl)	Total N, %	Av. P	Ex. Mg, cmol(+)/kg	Ex. Fe, mgkg ⁻¹	OC, %	CEC, cmol(+)/kg
LBC x 0	6.24c	5.02cd	0.10ab	6.69bcd	2.70ab	61c	1.29bcd	16.53ab
LBC x 1	6.26bc	5.01cd	0.11a	10.67a	2.48bc	84bc	1.49ab	16.80ab
LBC x 2	6.29abc	5.18bc	0.11a	9.76ab	2.48bc	110ab	1.45abc	16.27abc
LDB x 0	6.01de	4.72e	0.11a	7.08bcd	2.69abc	63c	1.35bcd	16.04abc
LDB x 1	6.14cd	4.95d	0.10ab	9.63abc	2.62abc	109ab	1.58a	17.04ab
LDB x 2	6.46a	5.44a	0.09b	4.43d	2.63abc	64c	1.16d	16.09abc
LSB x 0	5.94e	4.69e	0.11a	11.56a	2.40c	120a	1.49ab	14.73c
LSB x 1	6.44ab	5.24ab	0.10ab	6.54bcd	2.79a	56c	1.26cd	15.73bc
LSB x 2	6.28abc	5.06bcd	0.10ab	6.14cd	2.51bc	66c	1.28bcd	17.52a
LSD (P ≤ 0.05)	0.175	0.206	0.013	3.15	0.25	31	0.2	1.48
CV (%)	3.0	4.3	13	41.3	10.2	41	15.2	9.6

Any means not followed by the same letter down a column are significantly different at P = 0.05. LBC – lime broadcasted; LDB – lime deep banded; LSB – lime shallow banded

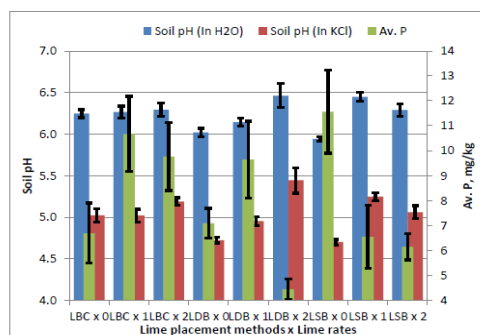


Figure 2. Effects of interaction LPM x LR on soil pH and available phosphorus for 0 – 15 cm depth

[What does the error bars Indicate?? Why mean separations are not presented???

Table 11. Effects of interaction between lime placement methods and lime rates on soil chemical properties for 15 - 30 cm soil depth

Treatment	Soil pH (In H ₂ O)	Soil pH (In KCl)	Total N, %	Ex. Mg, cmol(+)/kg	OC, %
LBC x 0	6.13cd	4.80cd	0.08c	2.77abc	1.35e
LBC x 1	6.02de	4.77cde	0.11ab	2.60bc	2.20ab
LBC x 2	6.09cd	4.72de	0.10abc	2.73abc	1.78cd
LDB x 0	5.95e	4.67de	0.11ab	2.94ab	2.07abc
LDB x 1	6.08cd	4.88bc	0.10abc	2.55c	2.29a
LDB x 2	6.34a	5.05a	0.09bc	2.79abc	1.72d
LSB x 0	5.95e	4.63e	0.12a	2.57bc	2.02abcd
LSB x 1	6.28ab	4.98ab	0.11ab	3.08a	1.85cd
LSB x 2	6.18bc	4.88bc	0.10abc	3.02a	1.92bcd
LSD (P ≤ 0.05)	0.116	0.134	0.015	0.343	0.305
CV (%)	2.0	2.9	15.2	13.0	16.8

Any means not followed by the same letter down a column are significantly different at P = 0.05. LBC – lime broadcasted; LDB – lime deep banded; LSB – lime shallow banded

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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 ≤ 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

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 ($P \leq 0.05$)	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

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 2. F test probabilities for main effects and interaction effects of the treatments; 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									

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).

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P, K, Ca, Mg, Mn and Zn for the 3 sampling times are plant crop cycle is given presented in Tables 12-17, 11, 12, 13, 14, 15, 16 and 176-8. 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 cycle, except total Mn in sugarcane leaves under interaction, LPM x LR x NR treatment (Table 8, 112 and 132). 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 cycle (Table 9) while other nutrients such as sugarcane leaf N, P, Ca, Mg, Mn and Zn were not significantly affected by the treatments (Table 143 and 1549). 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 content. Interaction LPM x LR significantly affected sugarcane leaf K content, and while interaction LPM x NR significantly affected sugarcane leaf N content (Tables 165 and 176-10). 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, 176). With exception of sugarcane leaf K content, all other nutrients were in adequate amount above critical levels according to Calcino et al. [29] and McCray and Mylavarapu [30]. The more sugarcane leaf nutrients content noted in L-SB sugarcane plots shallow banded with lime plots (Table 17) was perhaps due to enhanced uptake of the nutrients from the at 0 – 15 cm depth. The nutrients K, Ca, Mg, Mn and Zn observed plays a role in chlorophyll production and photosynthesis which is critical during sugar production and accumulation in sugarcane [29]. 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 Mutonyi [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 12.4. F – test probabilities for effects of lime placement methods, lime rates and nitrogen rates LPM, LR and NR on nutrient content of sugarcane leaves for plant crop cycle

Nutrient content of sugarcane leaves for plant crop years							
	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

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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; **bold figure indicate significant difference at level $P \leq 0.05$.**

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Table 123. Means of the effects of **lime placement methods, lime rates and nitrogen rates** LPM, LR and NR on N, P, K, Ca, Mn and Zn content of sugarcane leaves for plant crop cycle at 18 months after planting sugarcane setts

Factor s	Levels	Total N, %	Total P, %	Total K, %	Total Ca, %	Total Mg, %	Total Mn, mg kg ⁻¹	Total Zn, mg kg ⁻¹
LPM	LBC	0.44	0.06	0.74	0.53b	0.12	102	11
	LDB	0.46	0.06	0.72	0.83a	0.14	99	11
	LSB	0.49	0.06	0.67	0.74ab	0.13	101	10
	LSD ($P \leq 0.05$)	ns	ns	ns	0.261	ns	ns	ns
LR, tha ⁻¹	0	0.47	0.06	0.69	0.66	0.13	103	11
	1	0.47	0.06	0.70	0.81	0.15	96	10
	2	0.45	0.06	0.75	0.64	0.12	103	10
	LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns	ns	ns
NR, kg Nha ⁻¹	0	0.47	0.06	0.76	0.73	0.13	102	10
	50	0.43	0.06	0.69	0.71	0.13	102	11
	100	0.49	0.06	0.68	0.68	0.13	98	10
	LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns	ns	ns
	CV (%)	23.9	24.3	39.2	67.9	59.1	18.8	46.2

Any two means not followed by the same letter down a column are significantly different at $P = 0.05$

LPM – lime placement methods; LR – lime rates; NR – nitrogen rates; Avail. – Available; Ex. – extractable; N – nitrogen; P – phosphorus; K – potassium; Ca – calcium; Mg – magnesium; LBC – lime broadcasted; LDB – lime deep banded; LSB – lime shallow banded; ns – not significant

Table 143. 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; **bold figures indicate significant difference at level $P \leq 0.05$**

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Table 154. Means of the effects of lime placement methods, lime rates and nitrogen rates LPM, LR and NR on N, P, K, Ca, Mn and Zn content of sugarcane leaves for ratoon one crop cycle at 9 months after ratoon emergence

Factors	Levels	Total N, %	Total P, %	Total K, %	Total Ca, %	Total Mg, %	Total Mn, mg kg ⁻¹	Total Zn, mg kg ⁻¹
LPM	LBC	1.10	0.13	0.58a	0.67	0.20	57	22
	LDB	1.11	0.14	0.52b	0.68	0.21	52	20
	LSB	1.06	0.14	0.52b	0.66	0.19	55	21
	LSD (P ≤ 0.05)	ns	ns	0.05	ns	ns	ns	ns
LR, tha ⁻¹	0	1.10	0.13	0.54ab	0.64ab	0.20	54ab	19
	1	1.07	0.14	0.51b	0.76a	0.23	58a	23
	2	1.11	0.13	0.57a	0.60b	0.17	52b	20
	LSD (P ≤ 0.05)	ns	ns	0.05	0.144	ns	6.19	ns
NR, kg Nha ⁻¹	0	1.10	0.13	0.51b	0.66	0.21	55	19
	50	1.09	0.14	0.54ab	0.70	0.20	55	22
	100	1.09	0.14	0.57a	0.66	0.20	54	21
	LSD (P ≤ 0.05)	ns	ns	0.05	ns	ns	ns	ns
	CV (%)	11.4	33.1	16.8	39.4	57.3	6.19	44

Any two means not followed by the same letter down a column are significantly different at P = 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; LBC – lime broadcasted; LDB – lime deep banded; LSB – lime shallow banded; ns – not significant

Table 156. 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 ≤ 0.05. N – nitrogen, P – phosphorus, K – potassium, Ca – calcium, Mg – magnesium, Mn – manganese, Zn – zinc; bold figures indicate significant difference at level P ≤ 0.05

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Table 176. Means of the effects of lime placement methods, lime rates and nitrogen rates LPM, LR and NR on N, P, K, Ca, Mn and Zn content of sugarcane leaves for ratoon one crop cycle at 12 months after ratoon emergence

Factors	Levels	Total N, %	Total P, %	Total K, %	Total Ca, %	Total Mg, %	Total Mn, mg kg ⁻¹	Total Zn, mg kg ⁻¹
LPM	LBC	1.00	0.12	0.47b	0.70a	0.23ab	57ab	17a
	LDB	1.06	0.14	0.47b	0.53b	0.15b	52b	13b
	LSB	1.03	0.14	0.57a	0.68a	0.25a	60a	18a
	LSD (P ≤ 0.05)	ns	ns	0.02	0.13	0.08	6.19	4.04
LR	0	1.01b	0.14	0.49	0.71a	0.28a	59	18
	1	1.08a	0.13	0.53	0.64ab	0.19b	57	17
	2	0.99b	0.12	0.50	0.56b	0.16b	55	14
	LSD (P ≤ 0.05)	0.07	ns	ns	0.132	0.079	ns	ns
NR	0	1.05	0.13	0.49	0.65	0.23	56	17
	50	1.03	0.13	0.49	0.68	0.22	60	17
	100	1.01	0.14	0.54	0.60	0.19	55	16
	LSD (P ≤ 0.05)	ns	ns	ns	ns	ns	ns	ns
	CV (%)	12.5	36.2	19.1	37.5	67.7	19.9	44.7

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Any two means not followed by the same letter down a column are significantly different at P = 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; LBC – lime broadcasted; LDB – lime deep banded; LSB – lime shallow banded; ns – not significant

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 ≤ 0.05. N – nitrogen, P – phosphorus, K – potassium, Ca – calcium, Mg – magnesium, Mn – manganese, Zn – zinc

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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	0.372
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 ≤ 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 at different rates affected the soil pH for both 0 – 15 cm and 15 – 30 cm.

The interaction between LPM and LR significantly affected soil pH, N, P, Fe, OC and CEC for 0 – 15

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cm depth. Similar effect was also observed for 15 – 30 cm depth whereby soil pH, N, Mg and OC were significantly affected. Lime placement alone influenced soil pH and N for 15 – 30 cm but none of the lack of effect on soil chemical properties for 0 – 15 cm depth.

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 lime placement methods, lime rates and also nitrogen rates. No mention of sugarcane yield in materials and Methods or Results and Discussion sections. So, either include the yield results in those sections or you cannot include this in conclusions. 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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ACKNOWLEDGEMENTS

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This research was funded by Alliance for Green Revolution in Africa (AGRA) through AGRA – Soil Health Training Programme at Sokoine University of Agriculture, Morogoro, Tanzania as part of a doctoral study. We thank Dr. Abel Kaaya the Co-ordinator of the training programme at SUA who facilitated the funding. We appreciate Kenya Agricultural and Livestock Research Organization – Sugar Research Institute (KALRO – SRI) for providing additional funds through the Director KALRO – SRI, Dr. Japheth Jomoza, The field and laboratory staff of KALRO – SRI assisted during experiment management are appreciated. Finally, we thank the laboratory staff led by Dr. C. Mhaiki (Head of Laboratory) and Prof. E. Marwa (Head of Department) of Soil Science Laboratories, Department of Soil and Geological Sciences, SUA, Morogoro, Tanzania who facilitated laboratory analysis.

512 **CONSENT (WHERE EVER APPLICABLE)**

513 Not applicable

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

515 Not applicable

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