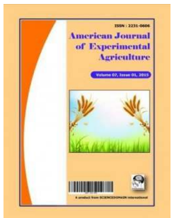

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Effects of Lime and Nitrogen on Properties of an Acidic Soil and Nutrient Content of Sugarcane under Sugarcane – Soybean Intercropping in Kenya

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Authors' contributions

This work was carried out in collaboration between all the authors. Author JOO designed the study, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Authors ES, JM and PO provided guidance and supervision during design and implementation of the study including write up of the study findings. All authors read and approved the final manuscript.

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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. Split – split plot randomized complete block arrangements was employed. The main plots

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were; LPM (lime broadcasted [L-BC], lime shallow banded, 0 – 15 cm [L-SB] and lime deep banded, 15 – 30 cm [L-DB]). Sub plots were lime rates (0, 1 and 2 t ha^{-1}) and sub – sub plots were N rates (0, 50 and 100 kg N ha-1). Lime rates significantly affected soil pH for both the 0 – 15 cm and 15 – 30 cm soil depth. Lime rate, 2 t ha-1 led to the highest soil pH. Lime placement methods 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. 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.

Keywords: Lime placement methods; lime rates; nitrogen rates; soil properties; nutrient content; sugarcane leaves.

1. INTRODUCTION

Soil acidity causes detrimental effects on plants and soil organisms [1]. Nitrogen (N) is the most important plant nutrient for crop production because it is 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. 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 (catch or cover crops, legumes) is often added 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. 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]. Legumes are used in sugarcane production through intercropping system. Intercropping of sugarcane refers to cultivating alternative crops along with sugarcane, [6]. Sugarcane intercropping is practiced on small - holder farms of less than 2 ha in western Kenya with an aim of food security and household income [7,8,9]. The benefits of sugarcane soybean intercropping are diverse crops yield, increased income, nutrition and also biological nitrogen fixation (BNF) which cut costs on the use of N fertilizers and therefore reduce soil N mining [10].

According to Alexander [11], 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, 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 soils, biological N_2 fixation can be improved [12,1].

In Kenya, most of the soils under sugarcane cultivation are low in soil nitrogen [13]. The low soil N coupled with long - term monocropping as a consequence of its pereniality, ability of the sugarcane to ratoon severally after harvesting, and land scarcity justifies continued use of N fertilizer for sugarcane production. Further, sugarcane is also capable of rapidly depleting the soil of nutrients, particularly N and potassium if sufficient N is not applied. On average, one tonne of sugarcane removes 1.16 kg N in a given crop cycle [14].

Liming is a management practice to reduce the soil acidity and therefore one of the soil fertility management practices [15]. Most plants grow well at a pH range of 5.5 – 6.5 and liming is aimed to increase the pH to this range. The benefits of liming include: enhanced physical, chemical and biological conditions of soil. The indirect benefits include mobilization of plant nutrients, immobilization of toxic heavy metals, and improvements in soil structure. Liming also creates optimal conditions that favour biological activities including N_2 fixation and mineralization of N, P and S in soils [16,17].

Enhancing the activities of beneficial microbes such as rhizobia, diazotropic bacteria, and mycorrhizae in the rhizosphere has improved plant growth by the fixation of atmospheric nitrogen, suppressing pathogens, and producing phytohormones, enhancing root surface area to facilitate uptake of less mobile nutrients such as P and micronutrients and mobilizing and solubilizing unavailable nutrients [18]. Previous studies provides ample evidence that low soil pH adversely affects activities of rhizobium, including a loss of its ability to fix N [19], and reduce the activity and their ability to multiply [20]. Low soil pH increased the number of ineffective rhizobia in soil [21]. Soil pH below 5.5 reduces rhizobial populations, and rhizobia that survive such a pH lack the capacity to fix atmospheric N [19]. Plants growing in acidic soils often exhibit low N_2 fixation, while high rates of N_2 fixation even under high concentrations of heavy metals are reported under near neutral pH [22]. A drop in pH of nutrient solutions from 5.5 to 5.0 decreases the number of nodules formed by common bean (*Phaseolus vulgaris*) [23].

Lime ameliorates the harmful effects of soil acidity [24]. Studies on bacteria suggest that the success of liming may be due not only to an effect on the soil pH but also to a direct effect of increased calcium for the bacteria themselves [25].

In Kenya, sugarcane is cultivated under continuous monoculture along with the use of acidifying fertilizers such as urea and diammonium phosphate [26]. These fertilizers are favoured due to their cost and levels of nutrients 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 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 N use hence improve N use efficiency, other nutrients availability, yields and quality of sugarcane.

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

2. MATERIALS 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 [13]. Soil test for the study site was carried out prior to establishment of the field experiment. 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 rainfall and temperature during the experiment period (2012 to 2014) are shown in Fig. 1. The study area experiences bimodal rainfall, characterized by two rainy seasons per year known as long and short rains. Annually, long rains occur between March and May while short rains are observed during September to October. This weather pattern is in agreement with [13], 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_20)	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; [1]AAS – Atomic absorption spectrophotometer. Ratings are according to Landon (1984), Estefan (2013)*

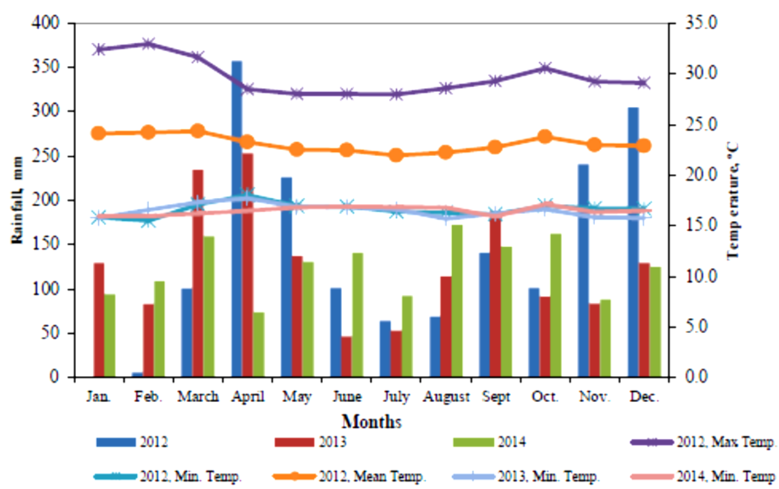

Fig. 1. Rainfall and temperature for the study site during the period of field experiment

2.2 Treatments and Experimental Design

The experiment was split – split plot in randomized complete block design. The main plots were 3 lime placement methods (LPM), 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, namely 0, 1 and 2 t ha^{-1}. The sub – sub plots were 3 nitrogen rates, namely 0, 50 and 100 kg N ha^{-1}. This gave a total of 27 treatments, which were replicated three times. The experiment unit was gross plot, which measured [5 m x 5 rows each 1.2 m apart]. Data were collected from the net plots, i.e. the three inner rows with the one row on each side referred as guard rows.

2.3 Experiment Management

The field experiment was established in 2012 and managed up to 2014. The field research period coincided with sugarcane plant crop (0 – 18 months after planting sugarcane setts) and ratoon one crop (0 – 16 months after ratoon emergence) cycle. 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 [27]. Sugarcane variety used was KEN 83 – 737 referred 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 seeded in between sugarcane rows. Soybean seeds were sowed in the 30th day after sugarcane setts were planted. In this period, sugarcane setts had germinated and the shoots emerged. The soybean was inoculated with rhizobial (Biofix ®) inoculant. The inoculant contained 6.5 x 10^9 cells per gram of inoculum. 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 hoes.

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 48 days (on 29th June 2016) prior to planting of sugarcane setts which was carried out on 15th August 2012. Germination was observed at 30 to 45 days after planting. 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.

Fertilizer used was urea 46% N, applied 4 months after planting sugarcane setts for plant crop cycle and 3 months after ratoon emergence for the ratoon crop cycle. The method of application was side dressing along the sugarcane rows [28].

Ratoon crop establishment involved alignment of the sugarcane trash in between sugarcane rows following green sugarcane harvest of plant crop cycle. The above ground biomass residue was then incorporated into the soil during manual weed control using hoes. Weed control and other management practices were undertaken according to KESREF recommendations [29].

2.4 Measurements

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 [30,31]. The soil chemical results were interpreted according to ratings by [32] and [33].

2.4.2 Sugarcane nutrient content

Sugarcane leaves were sampled at 18th month of sugarcane planting for plant crop cycle and also at 9th and 12th month after ratoon crop 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. The leaves sampled were then taken to the laboratory and processed. In the laboratory, the leaf samples were gently washed with distilled water to remove soil and debris. Using a sharp knife, the leaf midrib was removed from the leaf blade. These were then placed in brown bags and dried in a hot air oven (72℃) to constant weight. The dried leaf samples were ground to fine texture using a plant mill. The ground leaf samples were subjected to dry ashing and also wet digestion. For dry ashing, 0.5 grams of the leaf sample was weighed in crucibles. The crucibles were then placed in a muffle furnace and heated for 3 hours at 600℃. Ten ml of 6 N HCl and 10 ml of distilled water were added into the crucible to dissolve the ash, and the solution was filtered using Whatman number 42 filter paper. The amount of filtrate collected was then put into 25 ml volumetric flask and then topped up to mark using distilled water. The parameters analysed included total N, P, K, Ca, Mg, Mn and Zn using standard procedures [31]. The Mn, Fe, Zn and Cu content in leaves were measured using respective wavelengths in an atomic adsorption spectrophotometer (AAS). Results of the sugarcane leaf nutrient content were interpreted against the critical levels according to [34] and [35].

2.5 Statistical Analysis

The statistical significance was determined using ANOVA to test treatment effects on soil chemical properties, sugarcane leaf nutrient content, sugarcane yield and quality. GENSTAT statistical package was used for the statistical analysis [36]. Comparisons of means were carried out using least significance difference (LSD) at the 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Soil Chemical Properties for 0 – 15 Cm and 15 – 30 Cm Depth

Lime rates significantly affected soil pH, Ca, Mn and OC for the 0 – 15 cm depth (Table 2 and 3). The respective means as affected by the treatments for 0 – 15 cm depth is shown in Tables 4 and 5.

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

Increased lime rate led to increased soil pH and exchangeable Ca (Tables 4, 5, 8 and 9). Plots that received 2 t ha^{-1} lime rates showed the highest soil pH and Ca while the lowest soil pH and Ca were in no lime plots. This trend was noted for both depths, 0 – 15 cm and also 15 – 30 cm, and also when pH was determined in water and KCl solution (Table 4 and 8). The least amount of soil extractable Mn, Zn and OC was recorded in plots that received 2 t ha^{-1} of lime compared to the control and 1 t ha^{-1} (Tables 5 and 9).

The increase in pH was due to the increase in basic cation calcium and neutralization of H^+ at the exchange complex [37]. The CaO component of lime dissolves in the soil, and the Ca generated moves to the surface of exchange site replacing the acidity. Meanwhile, the carbonate forms CO_2 and water [37]. This finding is consistent with findings of [38] and [39].

Table 2. F – test probabilities for effects of lime placement methods, lime rates and nitrogen rates on soil pH and macronutrients at 0 – 15 cm soil depth

	F test probabilities						
	Soil pH (H_2O)	**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; bold figures indicate significant difference at level P ≤ 0.05

Table 3. F – test probabilities for effects of soil micronutrients, organic carbon, sodium and cation exchange capacity 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; Zinc – Zinc; Cu – Copper; OC – Organic carbon; Na – Sodium; CEC – Cation exchange capacity; bold figures indicate significant difference at level P ≤ 0.05

Table 4. Means for the effects of lime placement methods, lime rates and nitrogen rates on soil pH and macronutrients at 0 – 15 cm soil depth

Factors	Levels	Soil pH (In H_2O)	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 ≤ 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 ≤ 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 ≤ 0.05)	ns	ns	ns	**1.82**	ns	ns	ns
	CV (%)	3	4.3	13	43	24.1	16.7	10.2

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 5. Means for the effects of lime placement methods, lime rates and nitrogen rates on micronutrients, organic carbon, sodium and cation exchange capacity at 0 – 15 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	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

The concentration of soil extractable Mn and Zn decreased in the soil solution as lime rate increased (Tables 5 and 9). These findings are in agreement with the results of [40] and [1].

A decrease in Mn with increased liming was reported by [40]. According to [41], the gradual decrease in Zn activity with increasing pH is attributed to increasing CEC. Similar observation was also noted by [42] who reported that increasing surface charge due to liming increased Zn retention.

Table 6. F – test probabilities for effects of lime placement methods, lime rates and nitrogen rates on soil pH and macronutrients at 15 - 30 cm soil depth

	F test probabilities						
	Soil pH (H_2O)	**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

Table 7. F – test probabilities for effects of soil micronutrients, organic carbon, sodium and cation exchange capacity 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 ≤ 0.05. LPM – Lime placement methods; LR – Lime rates; NR – Nitrogen rates; Ex. – Extractable; Mn - – Manganese; Fe – Iron; Zinc – Zinc; Cu – Copper; OC – Organic carbon; Na – Sodium; CEC – Cation exchange capacity; bold figures indicate significant difference at level P ≤ 0.05

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

Factors	**Levels**	**Soil pH, In H_2O**	**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 on micronutrients, organic carbon, sodium and cation exchange capacity 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

Lime placement methods did not significantly affect the soil chemical properties for 0 – 15 cm depth (Tables 4 and 5), but it affected the soil pH (in KCl), total N and OC for 15 – 30 cm depth (Tables 6, 7, 8 and 9). Nitrogen rate affected only the soil available P for the 15 – 30 cm depth (Tables 6 and 8). The probable reason could be that sugarcane under plots that received 100 kg N ha^{-1} performed well to extent that sugarcane roots extracted P better compared to sugarcane under control plots (0 kg N ha^{-1}). There was no significant influence of nitrogen rates on all the soil chemical properties for the 0 – 15 cm depth.

Interaction effects of the LPM and LR treatments were recorded for both the 0 – 15 cm and 15 – 30 cm depth. Interaction between LPM and LR significantly affected ($P < 0.05$) the soil pH (both in water and KCl), soil total N, available P, exchangeable Mg, OC, CEC and extractable Fe for 0 – 15 cm depth (Tables 2, 3, 10 and Fig. 2). Similarly, LPM by LR interactions significantly affected soil pH, total N, extractable Mg and OC for 15 – 30 cm depth (Tables 6, 7 and 11).

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_2O)	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

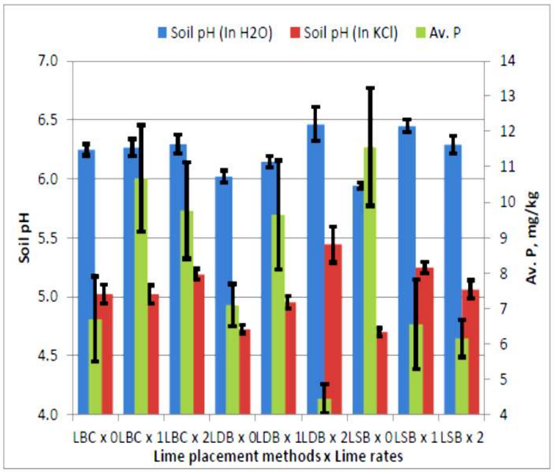

Fig. 2. Effects of interaction LPM x LR on soil pH and available phosphorus for 0 – 15 cm depth

3.2 Nutrient Content of Sugarcane Leaf for Plant Crop and Ratoon One Cycle

Effects of lime placement methods, lime rates and nitrogen rates on sugarcane leaf nutrients; N, P, K, Ca, Mg, Mn and Zn for the 3 sampling times are presented in Tables 12–17. 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 (Tables 12 and 13). 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,while other nutrients such as sugarcane leaf N, P, Ca, Mg, Mn and Zn were not significantly affected by the treatments (Tables 14 and 15). For sugarcane leaf sampled at 12 months after ratoon emergence, LPM significantly affected sugarcane leaf K, Ca, Mg, Mn and Zn content, LR significantly affected sugarcane leaf N and Mg content, Interaction LPM x LR significantly affected sugarcane leaf K content, and interaction LPM x NR significantly affected sugarcane leaf N content (Tables 16 and 17). Highest amount of K, Ca, Mg, Mn and Zn in sugarcane leaf was recorded for L-SB while the lowest was in L-DB plots (Table 17). With exception of sugarcane leaf K content, all other nutrients were in adequate amount above critical levels according to [34] and [35]. The more sugarcane leaf nutrients content noted in L-SB plots (Table 17) was perhaps due to enhanced uptake of the nutrients from the 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 [34]. 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 [39] 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 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_2O)	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 ($P \leq 0.05$)	**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

Table 12. F – test probabilities for effects of lime placement methods, lime rates and nitrogen rates 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; bold figure indicate significant difference at level $P \leq 0.05$

Table 13. Means of the effects of lime placement methods, lime rates and nitrogen rates on N, P, K, Ca, Mn and Zn content of sugarcane leaves for plant crop cycle at 18 months after planting sugarcane setts

Factors	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 14. 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 $P \leq 0.05$

Table 15. Means of the effects of lime placement methods, lime rates and nitrogen rates 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 ($P \leq 0.05$)	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 ($P \leq 0.05$)	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 ($P \leq 0.05$)	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 16. 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; bold figures indicate significant difference at level $P \leq 0.05$

Table 17. Means of the effects of lime placement methods, lime rates and nitrogen rates 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 ($P \leq 0.05$)	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 ($P \leq 0.05$)	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 ($P \leq 0.05$)	ns	ns	ns	ns	ns	ns	ns
	CV (%)	12.5	36.2	19.1	37.5	67.7	19.9	44.7

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

4. CONCLUSIONS

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

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 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. 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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Bolan NS, Adriano DC, Curtin D. Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. Advances in Agronomy. 2003;78:215–272.
2. Barker AV, Bryson GM. Nitrogen. In: Handbook of plant nutrition (edited by Barker, A.V. and Pilbeam, D.J.). Taylor and Francis. CRC press. Florida. USA. 2007;21–50.
3. Sumner ME, Fey MV, Noble AD. Nutrient status and toxicity problems in acid soils. In: Soil acidity. (Edited by Ulrich, B and Sumner, M.E.), Springer - Verlag, Berlin. 1991;149–182.
4. Voss R. Micronutrients. Department of Agronomy, Iowa State University, USA; 1998.
   (Accessed 20 November 2015)
   Available:http://www.agronext.iastate.edu/soilfertility/info/Micronutrients_VossArticle.pdf
5. Hofman G, Cleempot OV. Soil and plant nitrogen. International Fertilizer Association. Paris; 2004.
6. Irwine JE. Sugarcane agronomy. In: Sugarcane. (James, G, editor). Blackwell Publishing Company, Oxford, London. 2004;143–158.
7. Amolo RA. Sugarcane intercropping systems in Kenya. In: Proceedings of Kenya Society of Sugarcane Technologists, 11th Biennial Conference, 5 – 6 November 2003, Nzoia, Kenya. 2003; 12–14.
8. Wawire NW, Jamoza JE, Shiundu R, Kipruto KB. Chepkwony P. Identification and ranking of zonal sugarcane production constraints in the Kenya Sugar Industry. Kenya Sugar Research Foundation Technical Bulletin. 2006;1:78–102.
9. KESREF. Kenya Sugar Research Foundation Strategic Plan 2009 – 2014. Kenya Sugar Research Foundation, Kisumu, Kenya. 2009;88.
10. Chianu JN, Vanlauwe B, Mahasi JM, Katungi E, Akech C, Mairura FS, Sanginga N. Soybean situation and outlook analysis: The case of Kenya; 2008.
    (Accessed 10 September 2014)
    Available:www.icrisat.org/situation-outlook-sbean-kenya.pdf
11. Alexander M. Introduction to soil microbiology, (2nd Ed.). Wiley, New York; 1977.

12. Unkovich MJ, Sanford P, Pate JS. Nodulation and N fixation by subterranean clover in acid soils as influenced by lime application, toxic Al, soil mineral N, and competition from annual rye grass. Soil Biology and Biochemistry. 1996;28:639–648.
13. Jaetzold R, Schmidt H, Hornetz B, Shisanya C. Farm management handbook of Kenya Vol. II – Natural Conditions and Farm Management Information – 2nd Ed. Part A, West Kenya Subpart A1 Western Province. Ministry of Agriculture, Kenya and German Agency for Technical Cooperation (GTZ); 2007.
14. Meyer J. Sugarcane Nutrition and Fertilization. In: Meyer J, editor. Good management practices manual for the cane sugar industry. Eds. J. Meyer. The International Finance Corporation (IFC). Johannesburg. South Africa; 2011.
15. AGRA. AGRA: Early accomplishments, foundations for growth. Alliance for Green Revolution in Africa, Nairobi; 2009. (Accessed 20 November 2015) Available:http://www.agraalli ance.org/early accomplishments
16. Haynes RJ, Naidu R. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review. Nutrient Cycling in Agroecosystems. 1998;51:123–137.
17. Bolan NS, Hedley MJ, White RE. Processes of soil acidification during nitrogen cycling with emphasis on legume based pastures. Plant and Soil. 1991;134: 53-63.
18. Baligar VC, Fageria NK. Plant nutrient efficiency: Towards the second paradigm. In: Soil fertility, soil biology and plant nutrition interrelationships. In: Siqueira JQ, Moreira FMS, Lopes AS, Guilherme LRG, Faquin V, Furtini Neto AE, Carvallo JG, editors. Brazilian Society of Soil Science and University of Lavras; 1999.
19. Angle JS. Impact of biosolids and co-utilization wastes on rhizobia, nitrogen fixation and growth of legumes. In: Beneficial co-utilization of agricultural, municipal and industrial by-products (Brown S, Angle JS, Jacobs L, editors, Kluwer Academic Publishers, Dordrecht; 1998.
20. Mulder EG, Lie TA, Houwers A. The importance of legumes under temperate conditions. In: Treatise on dinitrogen fixation, IV agronomy and ecology. (Hardy RWF, Gibson HA. Editors) John Wiley and Sons, New York; 1977.
21. Holdings AJ, Lowe JF. Some effects of acidity and heavy metals on the rhizobium - leguminous plant association. Plant and Soil. 1971;153–166.
22. Ibekwe MA, Angle JS, Chaney RL, Van Berkum P. Sewage sludge and heavy metal effects on nodulation and nitrogen fixation of legumes. Environmental Science and Technology. 1995;24:11199–11204.
23. Franco AA, Munns DN. Acidity and aluminium restraints on nodulation, nitrogen fixation, and growth of *Phaseolus vulgaris* in nutrient solution. Soil Science Society of America Journal. 1982;46:296–301.
24. Cregan DD, Hirth JR, Conyers MK. Amelioration of soil acidity by liming and other amendments. In: Soil Acidity and Plant Growth (Robson AD, editor), Academic Press, Sydney. 1989;205–264.
25. Reeve WG, Tiwari RP, Dilworth MJ, Glenn AR. Calcium affects the growth and survival of *Rhizobium meliloti*. Soil Biology and Biochemistry. 1993;25:581–586.
26. Amolo RA, Sigunga DO, Owuor PO. Spatial variability of some soil properties with sugarcane productivity in western Kenya. In: Proceedings of the 14th Biennial Kenya Society of Sugarcane Technologist, 15 – 16 September, Masinde Muliro University, Kakamega, Kenya. 2011;12–32.
27. Meyer J, Clowes M. Sugarcane and Its Environment. In: Good management practices manual for the cane sugar industry (Meyer J, editor). The International Finance Corporation (IFC). Johannesburg. South Africa. 2011;14–51.
28. KESREF. Kenya sugar research foundation strategic plan 2009 – 2014. Kenya Sugar Research Foundation, Kisumu, Kenya; 2009.
29. KESREF. Sugarcane Growers Guide (2nd Ed.). Kenya Sugar Research Foundation, Kisumu; 2010.
30. Moberg JR. Soil and plant analysis manual. The Royal Veterinary and Agriculture University, Chemistry Department, Copenhagen, Denmark; 2000.
31. Okalebo JR, Gathua KW, Woomer PL. Laboratory methods of soil and plant analysis: A working manual, 2nd edition, TSBF-CIAT and SACRED Africa, Kenya; 2002.

32. Landon JR. Booker tropical soil manual. A Handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman, New York; 1991.
33. Estefan G, Sommer R. Ryan J. Methods of soil, plant and water analysis: A manual for the West Asia and North Africa Region. 3rd Edition. International Centre for Agricultural Research in the Dry Areas. ICARDA, Beirut, Lebanon; 2013.
34. Calcino D, Kingston G, Haysom M. Nutrition of the plant. Sugar Research Australia; 2000. (Accessed 20 November 2015) Available:www.sugarresearch.com.au/icms../166943_Chapter_9_Nutrition_of_the_Plant.pdf
35. McCray JM, Mylavarapu R. Sugarcane nutrient management using leaf analysis. University of Florida Institute of Food and Agricultural Sciences. EDIS document SS-AGR-335; 2013. (Accessed 20 November 2015) Available: http://edis.ifas.ufl.edu/ag345.pdf
36. GENSTAT. Introduction to GENSTAT 13 for windows. Lowes Agricultural Trust, Rothamsted Experimental Station, Reading University, United Kingdom; 2011.
37. Brady NC, Weil RR. The Nature and Properties of Soils. 14th Ed. Prentice Hall. Upper Saddle River, New Jersey. USA; 2008.
38. Choudhry BA. The effect of quick lime application on soil properties and their correlation with sugarcane yields. Philippine Journal of Crop Science. 1984; 9(1):44–47.
39. Mutonyi J. Management strategies for potassium deficiency and low pH on sugarcane growth, yield and quality in the Mumias Sugar Zone of Western Kenya. Thesis for award of Ph.D. Degree at University of Nairobi, Nairobi, Kenya; 2014.
40. Edmeades DC. Effects of lime on effective cation exchange capacity and exchangeable cations on a range of New Zealand soils. New Zealand Journal of Agricultural Research. 1982;25:27–33.
41. Shuman LM. Effect of ionic strength and anions on zinc adsorption by two soils. Soil Science Society of America Journal. 1986;50:1438–1442.
42. Stahl RS, James BR. Zinc sorption by B horizon soils as a function of pH. Soil Science Society of America Journal. 1991; 55:1592–1597.

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