
Effects of Cropping Systems and Agricultural Lime on Soil Properties and Nutrient Content of Sugarcane on Acidified Soils of Kisumu County, Kenya

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Abstract: Acid soils cause soil fertility problems such as Al and Mn toxicity, Ca, Mg, N deficiency and P fixation. These are constraints to high crop yields. Historically, liming is the common management practice used to neutralize soil acidity and to overcome the problems associated with soil acidification. A field experiment was conducted to investigate the effects of cropping systems, lime placement methods and lime rates on some soil chemical properties and nutrient uptake by sugarcane during the plant crop and ratoon one cycle under acidified Cambisols of Kibos, Kisumu, Kenya. A Split - split plot in randomized complete block arrangement was employed. The factors and respective levels (in parenthesis were): main plot; two cropping systems (sugarcane monoculture [MC] and intercropped sugarcane and soybeans [IC]). The sub - plots were three lime placement methods (lime broadcasted [L-BC], lime shallow banded, 0 – 15 cm [L-SB] and lime deep banded, 15 – 30 cm [L-DB] and the sub - sub plots were three lime rates (0, 1 and 2 t ha⁻¹). Lime rate of 2 t ha⁻¹ significantly ($P \leq 0.05$) increased soil pH to 6.4 and 5.2 as determined in water and 1 N KCl, respectively compared to 1 t ha⁻¹ and control (0 t ha⁻¹). Increased lime rate led to decreased levels of manganese, iron, and copper hence confirms the inverse relationship between soil pH and these micronutrients. Lime deep banded (L-DB) increased soil pH and available phosphorus for soil depth 15 – 30 cm compared to lime shallow banded (L-SB) and lime broadcasted (L-BC). Intercropped sugarcane and soybeans (IC) led to increased soil acidity and soil organic carbon (SOC) than did sugarcane monoculture (MC). For nutrient content of sugarcane leaves, IC system led to increased Ca and Mn compared to MC. Lime broadcasted (L-BC) caused high nitrogen and phosphorus content of sugarcane leaves and lime shallow banded resulted in increased Ca and Zn content of sugarcane to optimum levels. In view of the findings, the lime rate of 2 t ha⁻¹ is recommended for use to ameliorate soil acidity for acidified Cambisols of Kibos, Kisumu County, Kenya. Lime broadcasted (L-BC) is preferred to ameliorate acidity at top depth (0 – 15 cm) while lime banded both (L-SB) and L-DB) is preferred to reduce sub - soil acidity.

Keywords: Soil pH, Lime Rates, Lime Placements, Cropping, Nutrient Content

1. Introduction

Acidified soils are a major constraint to crop production. In western Kenya, soil acidity is an economic and natural resource threat [1]. Soil acidity causes soil fertility problems such as Aluminium (Al) and Manganese (Mn) toxicity,

Calcium (Ca) and Magnesium (Mg) deficiency and low Molybdenum (Mo) and Phosphorus (P) availability [2, 3, 4]. [4] highlighted the detrimental effects of soil acidity to plants and soil organisms. Activities of soil organisms are reduced leading to the inhibition of biological nitrogen fixation (BNF) by legumes and decomposition of organic matter. Low pH may also result in the deficiency of Ca and Mg in

soils [5]. Soil acidification is a natural process but it does also occur under managed ecosystems. [4] stated that regular fertilizer use is one of the major causes of soil acidification under managed ecosystems. Fertilizer – caused soil acidification occurs due to long term use of acidifying fertilizer such as urea and diammonium phosphate coupled with continuous monoculture.

Soil acidity affects availability of the macronutrients and micronutrients. Soils that are adequately limed are high in Ca. Very acid soils (soil pH less than 5.0) and soils that have received very excessive amounts of potassium and/or magnesium are conducive to Ca deficiency [6]. For Mg, acid soils, especially sands, frequently contain low levels of Mg. Soils of neutral or high pH usually contain adequate Mg. Mg deficiency in soils arises when the lime materials used are low in Mg, e.g. calcitic limestone. Ca and Mg deficiency, if it persists, leads to low yields since these nutrients play critical role in plant growth. Ca is a component of every cell wall and is involved in cell elongation and cell division. Mg is an essential part of chlorophyll molecule. It also activates many enzymes and aids in the formation of sugars, oils, and fats.

Soil pH is the most important factor influencing the availability of most micronutrients. As soil pH increases, the availability of iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) decreases. This is attributed to the cropping systems e.g. long term/ continual cropping have removed large amounts of the micronutrients, limited or lack of use of animal manure for crop production and use of high analysis fertilizers that lack micronutrients. As soil pH increases, the concentration of Fe in the soil solution decreases, with a minimum at pH 7.4 to 8.5. Mn availability to plants decreases as soil pH increases and may become deficient in soils with a pH above 6.5. Conversely, Mn availability increases as soil pH decreases and may become toxic in soils with pH below 5.5. The amount of soluble Mn increases 100 fold for each unit decrease in soil pH, e.g. pH 5.0 down to 4.0 [7].

Zinc availability to plants also decreases as soil pH increases and may become deficient in soils with a pH above 6.5 [7]. Liming soil to pH above 6.0 or 6.5 leads to reduction or elimination of Zn toxicity. The available Cu is held on the cation exchange complex in soils [8]. Increasing the soil pH by liming increases the amount of Cu held by clay and organic matter, decreasing Cu availability. Soils with a pH above 7.5 are more likely to be Cu deficient [4].

Liming is considered as a management practice to reduce the soil acidity [9]. Most plants grow well at a pH range of 5.5 – 6.5 and liming is aimed to maintain the pH at this range. The benefits of liming include: enhanced soil physical, chemical and biological conditions. The indirect benefits include mobilization of plant nutrients, immobilization of toxic heavy metals, and improvements in soil structure. Liming also causes optimal conditions that enhance biological activities like N₂ fixation and mineralization of N, P and S in soils [10, 11].

In Kenya, the common sugarcane production practice is continuous sugarcane monoculture and use of acidifying

fertilizers such as urea and diammonium phosphate [12]. These fertilizers are favoured due to their high levels of nutrient element per weight compared to other nutrient fertilizer sources. The advantage of these fertilizers means their use will be continued. This therefore calls for integrated use of these fertilizers with other soil improvement strategies that will mitigate against soil acidification, improve soil fertility and sugarcane nutrient uptake.

However, the cost of lime is prohibitive due to large amounts required. Alternative application strategies such as placement of lime in a band may allow lower rates of lime to be used and thereby offset economic constraints posed by high application rates. Liming, integrated with appropriate cropping systems may also lead to improved soil pH but also structure for sustained crop yields. Benefits of intercropping are: yield advantages of diverse crops, income, nutrition and also nitrogen (N₂) fixation which can cut costs on the use of N fertilizers. Farmers benefit from biological nitrogen fixation and therefore reduce soil N mining, which is estimated at 22 kg Nha⁻¹ for Sub Saharan Africa [13].

This study investigated whether lime use and intercropped sugarcane and soybeans leads to amelioration of soil pH, soil nutrient status and nutrient content in sugarcane leaves. Also, the study determined the best lime rate, placement methods for improved soil pH, soil fertility and sugarcane nutrition for plant crop and ratoon one crop cycle.

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), KALRO – Sugar Research Institute, Kisumu County, Kenya. The site elevation is 1268 m above sea level. The area is in agro-ecological zone (AEZ) LM 2, which is a marginal sugarcane zone and is sub humid. The soil type in field 6 is Eutric Cambisol [14] with the following soil properties: dark reddish brown friable sandy clay loam underlain by gravely red loam to light clay. The soil is well drained and has good physical properties and is slightly acid [15].

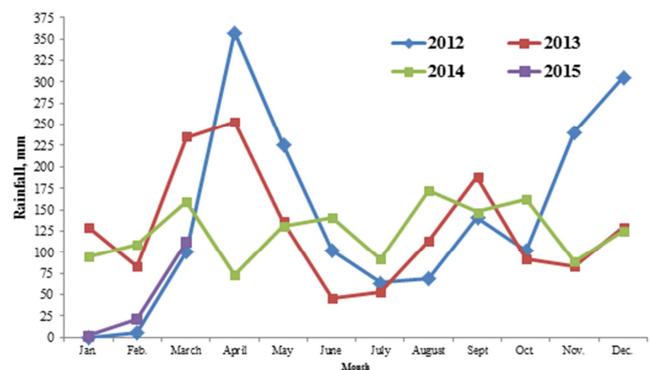


Figure 1. Precipitation data for the study site during the period of experiment (January 2012 to March 2015).

The weather data during the experiment period (2012 to

2014) is shown in Figure 1, 2 and 3. The total annual rainfall was 1714 mm, 1544 mm and 1497 mm in 2012, 2013 and 2014, respectively (Figure 1).

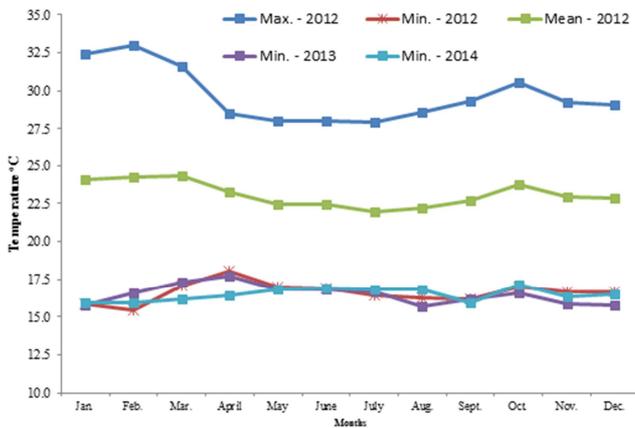


Figure 2. Temperature data for the study site during the period of experiment (2012 to 2014).

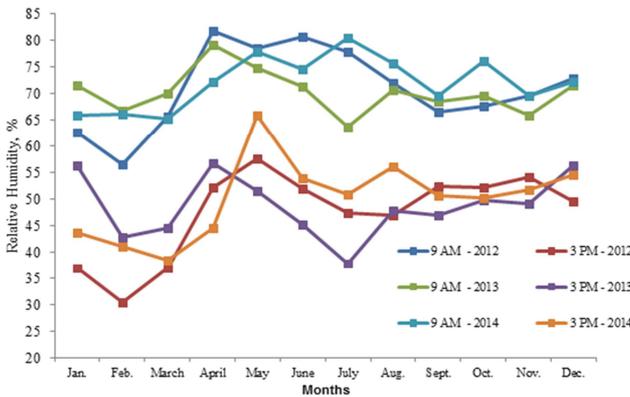


Figure 3. Relative humidity for the study site during the period of experiment (2012 to 2014).

The study area experiences bimodal rainfall characterized by two rainy seasons per year known as long and short rains. Long rains during 2012 to 2014 were from March to May while short rains were in September to October annually. This bimodal rainfall pattern reflects the pattern for the lake regions in Kenya [15]. Rainfall amounts are higher during

long rains than short rain periods. The mean maximum temperature was 30°C while the minimum temperature ranged from 16°C to 17°C (Figure 2). The mean temperature was 23°C. Relative humidity (% RH) was recorded at 9 AM (0900 hours) and 3 PM (1500 hours) in 2012, 2013 and 2014 (Figure 3). Relative humidity at 9 AM was higher than at 3 PM for all the years. Annual RH at 9 AM was 71%, 70% and 72% for 2012, 2013 and 2014, respectively, while it was 47%, 49% and 50% at 3 PM for 2012, 2013 and 2014, respectively.

2.2. Soil Chemical Properties Prior to Establishment of Field Experiment

Soil testing for the study site was carried out prior to establishment of the field experiment. An area of about 0.5 ha was sampled. Diagonal sampling pattern was used and sampling points randomly selected. Soil auger was used to collect soil at depth 0 – 15 cm and also 15 – 30 cm. The soil samples per depth across sampling points were composited and about a kg of soil was packaged in a well labelled brown paper bags. They were later dried, ground using pestle and mortar and sieved through a 2 mm sieve for chemical analysis. The soils were analysed for selected chemical properties using recommended methods as given in Table 1.

Generally, the magnitudes of the results for depth 0 – 15 cm were higher as compared to depth 15 – 30 cm except extractable copper which showed the reverse. The ratings soil results were rated according to [16, 17] and [18]. For depth 0 – 15 cm, the soil reaction was slightly acid (in water) and very strongly acid (in KCl). For 15 – 30 cm, soil reaction was medium acid (in water) and very strongly acid (in KCl). Organic carbon was medium and low for 0 – 15 cm and 15 – 30 cm respectively. Total nitrogen was low at both depths. Available P was high at 0 – 15 cm and medium for 15 – 30 cm. The high P levels depicted residual P attributed to high and continual use of phosphorus fertilizer at planting, e.g. diammonium phosphate in the field for sugarcane production prior to establishment of field experiment. The micro – elements copper, zinc, iron and manganese were sufficient, above the critical levels.

Table 1. Some chemical properties of the soils of the study site.

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	1.53	High	1.60	High
Ex. Zn mg kg ⁻¹	DTPA	1.79	High	1.52	High
Ex. Fe mg kg ⁻¹	DTPA	147.9	High	137.2	High
Ex. Mn mg kg ⁻¹	DTPA	206.2	High	193.7	High

DTPA – diethylenetriaminepenta acetic acid; AAS – Atomic absorption spectrophotometer. Ratings are according to [16, 17, 18]. Landon (1984), Estefan (2013), IUSS (2015)

2.3. Field Experiment

The field experiment was established in 2012 and managed up to 2014. The field research period coincided with the sugarcane crop cycle, namely the plant crop (0 – 18 months after planting sugarcane setts) and the ratoon one crop cycle (0 – 16 months after ratoon emergence). Soybean was intercropped and managed during the stage when sugarcane was young (the period for sugarcane germination stage is usually between 0 – 60 days after planting) and sugarcane tillering stage (this period is usually between 2nd month and 7th month after planting).

The experiment unit was a plot which measured [5 m x 5 rows each 1.2 m apart] referred to as gross plot. Data was collected in the net plots which are the three inner rows with the one row in each side referred to as guard rows. The sugarcane variety used was KEN 83 – 737, which is of medium maturity at 0 – 18 months and 0 – 16 months for plant crop and ratoon crop cycle, respectively. Soybean variety SB 19 was used as intercrop which was sowed in between sugarcane rows. The soybean was inoculated with a rhizobial (Biofix ®) inoculant.

The experimental design for the field experiment was the split – split plot arranged in randomized complete blocks. The main plot was cropping system (CS) with two levels, namely sugarcane monoculture (MC) and intercropped sugarcane (IC). The sub – plots were lime placement methods (LPM) with three levels namely; lime broadcasted (L-BC), lime shallow banded (L-SB) at soil depth 0 – 15 cm and lime deep banded (L-DB) at soil depth 15 – 30 cm. The sub – sub plots were lime rates with three levels namely 0, 1 and 2 tonnes ha⁻¹. This gave a total of 18 treatments which were then replicated three times to give a total of 54 plots. Agricultural lime (20% CaO) mined in Koru, Kisumu County, was used as the liming material. The raw limestone is carbonanite which is volcanic in origin. The lime treatments were applied prior to planting of sugarcane setts. Sugarcane setts were treated with imidacloprid (confidor ®) at 200g / L to control termite attack. Termite mounds within the vicinity of the field experiment sites were identified and drenched with confidor. Similarly, the sugarcane planting furrows were drenched using confidor. After 30 to 45 days after planting sugarcane, germination of sugarcane was started. This time, soybean was sowed as intercrop, in between the sugarcane rows. Soybean was inoculated with rhizobial (biofix ®) inoculant. 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. Ratoon crop establishment involved 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 soybean biomass residue was then incorporated into the soil during manual weed control using a hoe. Soil sampling per plot

was carried out after harvest of sugarcane plant crop and soon after trash alignment. Sugarcane leaf sampling for plant tissue tests was carried out at 18th month of the plant crop cycle, and also during the ratoon crop cycle at 9th and 12th month after sugarcane ratoon emergence.

2.4. Soil Analysis During the Field Experiment

2.4.1. Soil Sampling at Post-Harvest of Sugarcane

Soil was sampled in each of the treatment plots. In every plot, a 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). Soils sampled were then composited per depth for each treatment. About 0.5 kg of soil was then packed and the package well labelled.

2.4.2. Soil Analysis

Soil samples were air - dried, crushed using a mortar and pestle and sieved using a 2 mm sieve to remove debris. The parameters analysed were soil pH, total nitrogen (N), extractable phosphorus, organic carbon, exchangeable bases (sodium, calcium, magnesium and potassium), cation exchange capacity and also micro – nutrients, i.e. manganese, iron, zinc and copper. Soil pH was determined in water and also 1 N KCl at the ratio of 1 soil: 2.5 extractant. About 10 g of soil was transferred into 100 ml plastic bottle followed by 25 ml of the extractant. The mixture was shaken for 30 minutes, allowed to settle for 5 minutes and the supernatant solution read using an electrode pH meter [19, 20]. Total N was determined by the Kjeldahl method [21] whereby one gram of soil was put in a digestion tube, followed by addition of 10 ml 98% H₂SO₄ and a scoop of mixed catalyst which contained 100 g potassium sulphate, 10 g copper sulphate and 1.55 g selenium powder. This mixture was then digested in a digestion block for 1 hour at 360°C. The digest was then distilled after adding 40% NaOH, and the distillate collected over 4% boric acid, followed by titration with 0.05 N H₂SO₄. The titre value was used to compute total N. The Wakley - Black Method was used to determine soil organic carbon (OC) [20]. One gram of finely ground soil was put in a conical flask. Ten ml of K₂Cr₂O₇ solution, 10 ml phosphoric acid (85% H₃PO₄) solution and 20 ml of 98% H₂SO₄ were added. The mixture was swirled to mix, left for 30 minutes, cooled and then titrated. Diphenylamine indicator was added and mixture titrated using ferrous sulfate. Organic carbon was then computed using amount of dichromate used in the oxidation.

Extractable P was determined using the Bray 1 method [20]. Five grams of soil was put in 50 ml plastic bottle followed by 25 ml of extraction solution. The mixture was hand shaken for one minute and then filtered. Five ml of the filtrate was then transferred into a 50 ml volumetric flask. About 30 ml distilled water was added followed by 10 ml of the phospho - molybdate reagent. The mixture in the volumetric flask was then made to the mark using distilled

water and was allowed to settle for about 30 minutes for colour development. The absorbance was measured by spectrophotometer at 884 nm wavelength [20].

Soil cation exchange capacity (CEC) and exchangeable bases were determined by ammonium acetate saturation at pH 7.0 [20]. Five grams of soil was placed in 100 ml plastic bottle followed by 35 ml of 1 M ammonium acetate buffered at pH 7. This mixture was shaken for half an hour and left overnight. The suspension was filtered into 100 ml volumetric flask which was then used to determine exchangeable Ca, Mg, K and Na. The remaining soil was washed with 80% ethanol and leached with 1 M KCl and then filled into 100 ml volumetric flask. The leachate was transferred into a Kjeldtex distillation tube, 10 ml of 40% NaOH added, the distillate collected over 4% boric acid and thereafter titred using 0.1 N H₂SO₄ [20]. The titre value from titration was used to calculate CEC. The ammonium acetate leachate was used to determine exchangeable Ca and Mg using an atomic absorption spectrophotometer while for exchangeable K and Na the flame emission spectrophotometer was used.

Extractable Fe, Mn, Zn and Cu were determined after extraction using the DTPA – extractant. Fifteen grams of soil was placed in 100 ml plastic bottles followed by addition of 40 ml of DTPA. The mixture was then shaken for 2 hours and filtered into 50 ml plastic bottles. The filtrate was used to determine Fe, Mn, Zn and Cu at respective wavelengths using an atomic absorption spectrophotometer [20].

2.5. Plant Tissue Analysis

As already mentioned sugarcane leaf was sampled at 18th month of sugarcane age after planting for the plant crop cycle and also at 9th and 12th months of the ratoon one crop. The sampling unit was sugarcane stool. Four sugarcane shoot 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 brown bags and well labelled. The leaves sampled were then taken to the laboratory.

Preparation of the leaf samples

In the laboratory, the leaf samples were gently cleaned using distilled water and debris / dirt removed. Using a sharp knife, the leaf midrib was removed, leaving only the leaf sheath. This was then placed in brown bags which were then placed in the oven to dry at 72°C to constant weight. The dried leaf samples were ground to fine texture using a plant mill. The ground leaf samples were subjected to dry ashing and also wet digestion. For dry ashing, 0.5 grams of the leaf samples was weighed in crucibles. The crucibles were then placed in a muffle furnace and heated for 3 hours at 600°C. Ten ml of 6 N

HCl and 10 ml of distilled water were added into the crucible to dissolve the ash, and the solution was filtered using Whatman number 42 filter paper. The amount of filtrate collected was then put into 25 ml volumetric flask and then topped up to mark using distilled water. The extract following dry ashing was used for determining Mn, Fe, Zn and Cu using respective wavelengths in an atomic adsorption spectrophotometer (AAS). One ml of extract was diluted and used for determining Ca and Mg in AAS and for K using a flame photometer.

The amount of P in the extract was determined using the ascorbic acid molybdate blue method. Total N in the plant samples was determined by the Kjeldahl method. One gram of the plant samples was put in digestion tube, followed by addition of 10 ml 98% H₂SO₄ and a scoop of mixed catalyst. This mixture was then digested in a digestion block for 1 hour and at 360°C. The digest was then distilled after adding 25 ml of 40% NaOH followed by titration with 0.05 N H₂SO₄ and boric acid indicator. The titre value was used to compute total N.

2.6. Statistical Analysis

Data on soil chemical properties, nutrient content of sugarcane leaves as affected by the treatments were subjected analysis of variance using the GENSTAT software [22]. A 2 x 3 x 3 general treatment structure in randomized blocks was used to analyse the data. Main plot effects and respective interactions on treatments were also analysed [22]. Comparison of means test was carried out using the least significance difference (LSD) at the 5% probability level.

3. Results and Discussions

3.1. Effects of Cropping Systems, Lime Placement Methods and Lime Rates on Soil Chemical Properties

3.1.1. Effects of Lime Rates on Some Soil Chemical Properties

Findings from this study shows that some soil chemical properties were significantly affected by cropping systems (CS), lime placement methods (LPM), lime rates (LR) and respective interactions as shown in Table 2, 3, 4, 5 and 6. Lime rates significantly affected the soil pH (in water and KCl) for both 0 – 15 cm and 15 – 30 cm depth (Table 2 and 3). Plots limed at 2 t ha⁻¹ recorded highest soil pH compared to plots limed at 1 t ha⁻¹ and control plots (not limed, 0 t ha⁻¹) (Table 3). Lime rates significantly affected soil extractable Mn for 0 – 15 cm soil depth (Table 4 and 5). Highest amount of extractable Mn was recorded in control (not limed plots) while lowest amount was recorded in plots limed at 1 t ha⁻¹ and 2 t ha⁻¹ (Table 5).

Table 2. *F* – test probabilities of the effects of cropping systems (CS), lime placement methods (LPM) and lime rates on soil pH, organic carbon, total nitrogen and extractable phosphorus for 0 – 15 cm (top) and 15 – 30 cm (sub) soil depth.

F – Test probabilities	Soil pH (in H ₂ O)		Soil pH (in KCl)		OC		Total N		Extractable P	
	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub
CS	NS	< 0.001	< 0.001	0.003	0.026	0.008	NS	NS	NS	NS
LPM	NS	< 0.001	NS	0.003	NS	0.039	NS	NS	0.039	0.003
LR	0.013	< 0.001	0.004	0.002	NS	NS	NS	NS	NS	NS
CS x LPM	NS	NS	< 0.001	NS	NS	0.01	NS	0.013	NS	0.014
CS x LR	NS	NS	NS	NS	0.011	NS	NS	NS	NS	NS
LPM x LR	NS	NS	NS	0.021	NS	NS	NS	NS	NS	NS
CS x LP x LR	NS	NS	0.002	NS	NS	NS	NS	NS	NS	NS
CV (%)	3.2	2.7	4.5	5.2	21.3	21.1	13.4	12.9	35.7	26.8

Significant effect at $P \leq 0.05$; CS – cropping systems; LPM – lime placement methods; LR – lime rates; OC – organic carbon; N – nitrogen; P – phosphorus

Table 3. Effects of cropping systems (CS), lime placement methods (LPM) and lime rates (LR) on soil pH, organic carbon, total nitrogen and extractable phosphorus for 0 – 15 cm depth (top soil) and 15 – 30 cm depth (sub soil).

Factors	Levels	Soil pH (in Water)		Soil pH (in 1N KCl)		OC (%)		total N (%)		Extractable P (mg / kg)	
		Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub
CS	MC	6.33	6.20a	5.19a	4.99a	1.53a	1.218b	0.10	0.102	20.30	12.48
	IC	6.17	5.94b	4.95b	4.77b	1.75b	1.416a	0.11	0.105	18.76	13.23
	LSD ($P \leq 0.05$)	NS	0.09	0.131	0.141	0.192	0.193	NS	NS	NS	NS
LPM	L-BC	6.21	5.94c	5.02	4.74b	1.6	1.409a	0.10	0.104	18.26b	14.3a
	L-DB	6.29	6.20a	5.08	5.05a	1.7	1.353a	0.11	0.104	23.91a	14.04a
	L-SB	6.25	6.07b	5.12	4.86b	1.6	1.189b	0.10	0.103	16.41b	10.22b
	LSD ($P \leq 0.05$)	NS	0.159	NS	0.172	NS	0.154	NS	NS	5.38	3.08
LR (t ha ⁻¹)	0	6.20ab	5.93c	5.04b	4.73c	1.6	1.226	0.10	0.104	20.52	11.91
	1	6.11b	6.07b	4.96b	4.85b	1.7	1.318	0.11	0.105	17.53	12.25
	2	6.37a	6.21a	5.22a	4.99a	1.6	1.407	0.11	0.103	20.54	14.4
	LSD ($P \leq 0.05$)	0.137	0.091	0.156	0.118	NS	NS	NS	NS	NS	NS
	CV (%)	3.2	2.7	4.5	5.2	21.3	21.1	13.4	12.9	35.7	26.8

Means in the same column followed by the same letter (s) are not significantly different at 0.05 level of significance Key: NS – not significant at ($P = 0.05$); CV – coefficient of variation; MC – Sugarcane monoculture; IC – Intercropped sugarcane; L-BC – lime broadcasted; L-DB – lime deep banded; L-SB – lime shallow banded.

Table 4. *F* – test probabilities of the effects of cropping systems (CS), lime placement methods (LPM) and lime rates on soil extractable manganese, iron, zinc and copper for 0 – 15 cm and 15 – 30 cm soil depth.

F – Test probabilities	Extractable Mn		Extractable Fe		Extractable Zn		Extractable Cu	
	Top	Sub	Top	Sub	Top	Sub	Top	Sub
CS	0.018	< 0.001	0.025	0.004	NS	< 0.001	0.026	0.008
LPM	NS	NS	NS	0.003	NS	NS	NS	0.039
LR	0.012	NS	NS	NS	NS	NS	NS	NS
CS x LPM	NS	0.049	NS	0.007	NS	0.041	NS	0.010
CS x LR	NS	NS	NS	NS	NS	NS	0.011	NS
LPM x LR	NS	NS	NS	NS	NS	NS	NS	NS
CS x LPM x LR	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	16	9.9	20	18.5	13.4	11.7	10.4	11

Significant effect at $P \leq 0.05$; CS – cropping systems; LPM – lime placement methods; LR – lime rates; Mn – Manganese; Fe – Iron; Zn – Zinc; Cu – Copper

Table 5. Effects of cropping systems (CS), lime placement methods (LPM) and lime rates (LR) on soil extractable manganese (Mn), iron (Fe), zinc (Zn) and copper (Cu) for 0 – 15 cm depth (top soil) and 15 – 30 cm depth (sub soil).

Factors	Levels	Extractable Mn		Extractable Fe		Extractable Zn		Extractable Cu	
		Top	Sub	Top	Sub	Top	Sub	Top	Sub
CS	MC	172.6b	171.2b	121.7 b	121.7 b	1.72	1.43 b	1.53b	1.22b
	IC	196.5a	200.4a	142.5 a	137.7 a	1.82	1.62 a	1.75a	1.42a
	LSD ($P \leq 0.05$)	17.9	12.5	19.9	13.18	NS	0.114	0.192	0.142
LPM	L-BC	185.1	195.5a	137.30	145.3a	1.73	1.552	1.60	1.41a
	L-DB	175.2	177.8b	134.50	112.3b	1.873	1.497	1.67	1.36ab
	L-SB	193.4	184.0ab	124.5	125.0b	1.694	1.519	1.64	1.19b
	LSD ($P \leq 0.05$)	NS	15.4	NS	18.8	NS	NS	NS	0.107
LR ($t\ ha^{-1}$)	0	203.2a	193.7	147.9a	137.2	1.796	1.524	1.61	1.602
	1	175.4b	188.0	118.4b	126.8	1.729	1.509	1.67	1.634
	2	172.1b	185.2	129.9ab	125.0	1.773	1.535	1.63	1.57
	LSD ($P \leq 0.05$)	21.9	NS	18.22	NS	NS	NS	NS	NS
	CV (%)	17.6	12.2	24	21.9	16.3	15.1	21.3	18.9

Means in the same column followed by the same letter (s) are not significantly different at 0.05 level of significance. Key: NS – not significant at ($P = 0.05$); CV – coefficient of variation; MC – Sugarcane monoculture; IC – Intercropped sugarcane; L-BC – lime broadcasted; L-DB – lime deep banded; L-SB – lime shallow banded.

The amounts of exchangeable Ca at both 0 – 15 and 15 – 30 cm increased with increase in lime rates. Lime rate, 2 $t\ ha^{-1}$ gave the highest exchangeable Ca at both depths while the least was where there was no lime (Table 7).

Table 6. F – test probabilities for the effects of CS, LPM and LR on exchangeable bases for 0 – 15 and 15 – 30 cm depth.

F – test probabilities	Top, 0 – 15 cm				Sub, 15 – 30 cm			
Treatments	Mg	Ca	K	Na	Mg	Ca	K	Na
CS	0.146	0.633	0.415	0.102	0.750	0.599	0.674	0.137
LPM	0.324	0.866	0.633	0.184	0.195	0.106	0.850	0.448
LR	0.192	0.004	0.872	0.059	0.200	0.015	0.328	0.550
CS x LPM	0.032	0.846	0.794	0.161	0.885	0.915	0.100	0.142
CS x LR	0.846	0.324	0.132	0.985	0.374	0.687	0.467	0.749
LPM x LR	0.121	0.142	0.092	0.269	0.434	< 0.001	0.589	0.793
CS x LPM x LR	0.276	0.790	0.835	0.125	0.284	0.215	0.463	0.508

Significant effect at $P \leq 0.05$; CS – cropping systems; LPM – lime placement methods; Lime rate 2 $t\ ha^{-1}$ led to highest soil pH and exchangeable Ca but lowest extractable Mn (Table 6 and 7).

Table 7. Effects of lime rates on exchangeable calcium.

Lime rates, t / ha	0 – 15 cm soil depth	15 – 30 cm soil depth
	Exc. Ca., $cmol (+) / kg\ soil$	Exc. Ca., $cmol (+) / kg\ soil$
0	19.37b	20.38b
1	20.49b	22.63a
2	23.92a	23.65a
LSD ($P \leq 0.05$)	2.69	2.09
CV%	18.7	13.9

Means in the same column followed by the same letter (s) are not significantly different at 0.05 level of significance. Key: Exc. – exchangeable, Ca – calcium, CV – coefficient of variation

Several studies in Kenya reported that agricultural lime (21% CaO) led to increased soil pH and exchangeable Ca [23, 24 and 25]. [4] stated that liming enhances the chemical, physical and biological characteristics of soil. Hence the

chemical characteristics, soil pH and exchangeable Ca of the study site were enhanced. Lime reaction in acidic soil is that, lime dissolves in the soil then Ca moves to the surface of the soil particles (exchange sites) replacing the acidity. The

acidity reacts with the carbonate (CO₃) to form carbon dioxide (CO₂) and water (H₂O). The result is a soil with higher pH or less acidic and more exchangeable Ca [26].

The primary purpose of liming acid soils is to overcome the chemical problems associated with acidity for example high Mn level [4]. Liming acid soil is suggested as the best method to attain and maintain a suitable pH for the growth of a variety of crops. Benefits of liming include improved nitrogen fixation and availability of essential nutrients (Ca, P, Mo) and decreasing the solubility of toxic elements Al and Mn [10].

Other soil chemical properties that were not significantly affected by liming in this study were total N, soil extractable P, soil extractable Mg, soil extractable K, and soil extractable Na, soil extractable Fe, Zn and Cu. The results are contrary to study by [4] who found out that increased liming causes increased mineralization / nitrification. It is therefore expected that plots that received lime should have indicated increased soil total N. Liming has often been shown to enhance the mineralization of organic matter, thereby releasing inorganic plant nutrients such as N, S and P to soil solution. Unless these nutrients are actively taken up plants they are liable for leaching losses. The possible lack of significant difference may have been a result of the leaching of the soil nitrates [4]. Lime rates did not significantly affect soil extractable P (Table 2 and 3). The reason could be the adequate level of available P in the soil prior to establishment of the experiment (Table 1).

3.1.2. Effects of Lime Placement Methods on Soil Chemical Properties for 0 – 15 cm and 15 – 30 cm Depth

Lime placement methods significantly affected soil pH (in water), soil pH (1 N KCl), soil OC, exchangeable Ca, extractable Fe and Cu for 15 – 30 cm depth (Table 2, 4 and 6). Lime placement methods also affected soil extractable P for 0 – 15 cm and 15 – 30 cm (Table 2). Plots that were deep banded with lime (LDB) recorded highest soil pH, exchangeable Ca and extractable P for 15 – 30 cm depth (Table 3). Plots broadcasted banded with lime (LBC) recorded the highest soil OC, extractable Fe and Cu for 15 – 30 cm. Lime deep banded (L-DB) plots showed highest exchangeable Ca, while the least was in plots which were lime broadcasted (L-BC) as given in Table 8.

Table 8. Effects of lime placement methods on exchangeable calcium.

Lime placement methods	15 - 30 cm soil depth
	Exc. Ca., cmol (+) / kg soil
Lime broadcasted (L-BC)	20.87b
Lime shallow banded (L-SB)	21.88ab
Lime deep banded (L-DB)	23.91a
LSD (P ≤ 0.05)	2.09
CV%	13.9

Means in the same column followed by the same letter (s) are not significantly different at 0.05 level of significance. Key: Exc. – exchangeable, Ca – calcium, CV – coefficient of variation

Similar results of lime placement were reported on lime management in soybean no – tillage system in Brazil [27]. [27] worked with lime application using implements e.g. intermediate disk harrow and chisel plough. [27] noted that deeper incorporation raises the pH value to acceptable levels for improved yields. The results of this study are in agreement to those of [27] who concluded that lime incorporated with disc harrow and also lime incorporated with chisel plough resulted in improved chemical condition which then led to higher soybean yields. [27] noted that lime applied on the surface (broadcasted) increased exchangeable Ca and Mg until 0 – 15 cm depth. While lime incorporated in 0 – 20 cm depth led to increased Ca and Mg until 30 cm depth.

3.1.3. Effects of Cropping Systems on Soil Chemical Properties for 0 – 15 cm and 15 – 30 cm Depth

Cropping systems (CS) significantly affected the soil pH, soil OC, extractable Mn, Fe and Cu for 0 – 15 cm and 15 – 30 cm (Table 2 and 4). Cropping systems affected extractable Zn for 15 – 30 cm depth. Plots under sugarcane monocrop recorded highest soil pH and also soil OC for 0 – 15 cm compared to plots under intercropped sugarcane and soybeans (Table 3). Plots under intercropped sugarcane and soybean recorded highest soil extractable Mn, Fe, Cu for both 0 – 15 cm and 15 – 30 cm. For 15 – 30 cm, extractable Zn was recorded in plots intercropped with sugarcane and soybeans (Table 5).

The low pH under IC than MC is related to the decomposition of the soybean residues which were incorporated. According to [11] nodulated legumes acquire their N from the air as diatomic N rather than from the soil as nitrate which then leads to a net effect of lowered soil pH. Decomposition of organic matter and transformation of N are some of the soil induced processes amongst others that contribute to acid generation in soils [4]. Decomposing plant litter rich in organic compounds but low in basic cations lead to production of organic acids by soil microorganism [28]. Soybeans residues are rich in organic compounds hence explain the possible reason for low soil pH under IC than MC system.

The high soil extractable Mn, Fe, Zn and Cu under IC is linked to the low pH recorded under IC system. These micronutrients tend to available under acid conditions. Generally, the solubility and phyto - availability of metals are inversely related to soil pH. Several studies reported increased levels of soluble Mn with decrease in soil pH [5, 29]. [4] stated that Zinc (Zn) activity increases rapidly with decreasing pH. The pH-dependent solubility of Zn in soils is governed by a complex mixture of mechanisms including adsorption on sesquioxides, co - precipitation with Al, and complexation with organic matter [30].

3.2. Interaction Effects of Cropping Systems, Lime Placement Methods and Lime Rates on Some Soil Chemical Properties

3.2.1. Effects of CS x LPM on Soil pH (in 1 N KCl) for 0 – 15 cm Soil Depth

There was a significant (P < 0.001) interaction effect between cropping systems and lime placement method on

soil pH (Table 2 and Figure 4). This result indicates that the change in soil pH with regard to type cropping system and lime placement methods varies at different magnitude. The findings imply that, use of one lime placement method to a given cropping system will not show similar result to a different cropping system. Therefore each cropping system should have a respective lime placement method.

3.2.2. Effects of CS x LPM on Soil OC and Total N for 15 – 30 cm Soil Depth

There was a significant interaction effect between cropping systems and lime placement method on soil OC and total N at (P = 0.01) and (P = 0.013) respectively (Table 2 and Figure 5). This result shows that variation in soil OC and total N as influenced by cropping system type and lime placement method differs based on the combination. Under IC plots, soil N increased in the following pattern, LSB > LDB > LBC. While under MC plots, soil N and soil OC decreased in the following pattern, LBC < LDB < LSB (Figure 5). The findings signify that a given lime placement method to a given cropping system will not show similar result to a different cropping system. Therefore each cropping system should have varied suitable lime placement method so as to benefit on soil OC and total N

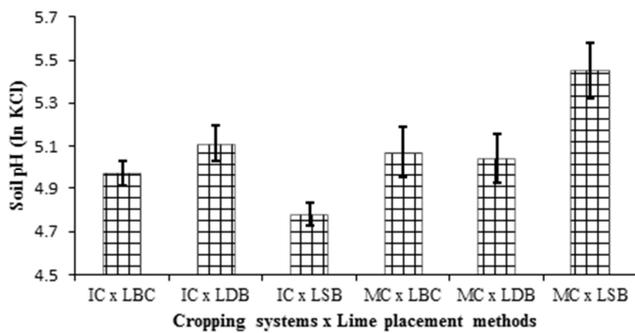


Figure 4. Interaction CS x LPM on soil pH for 0 – 15 cm depth.

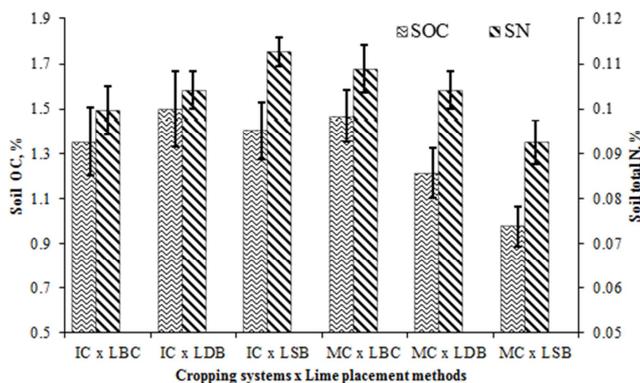


Figure 5. Interaction CS x LPM on soil OC and total N for 15 – 30 cm depth.

3.2.3. Effects of CS x LPM on Soil Exchangeable Mg for 0 – 15 cm Soil Depth

There was a significant (P = 0.032) interaction effect between cropping systems and lime placement method on soil extractable Mg (Table 6 and Figure 6). The CS x LPM

indicated that, the change in soil exchangeable Mg based on the cropping system and the lime placement methods do not vary at the same magnitude. The results imply that it is important to consider lime placement methods for either sugarcane monocrop or intercropped sugarcane and soybeans.

3.2.4. Effects of CS x LPM on Soil Extractable Manganese for 15 – 30 cm Depth

There was a significant (P = 0.007) interaction effect between cropping systems and lime placement methods on soil extractable Mn (Table 4 and Figure 7). Under MC system, amount of Mn decreased in the following pattern of lime placement method, LSB < LDB < LBC.

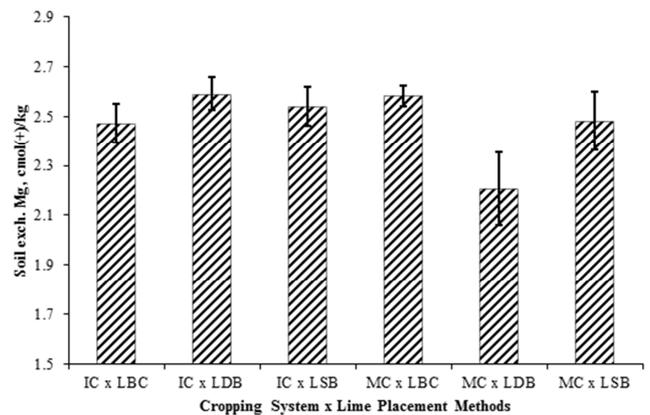


Figure 6. Interaction CS x LPM on soil exchangeable Mg for 0 – 15 cm depth.

This unlike under IC where soil Mn amount declined in plots broadcasted with lime (LBC) to plots LDB and then rose in plots LSB (Figure 7). Cropping systems (CS) influenced much on the soil Mn in the interaction. Therefore difference LPM should be used for each of the CS.

3.2.5. Effects of CS x LR on Soil OC for 0 – 15 cm Depth

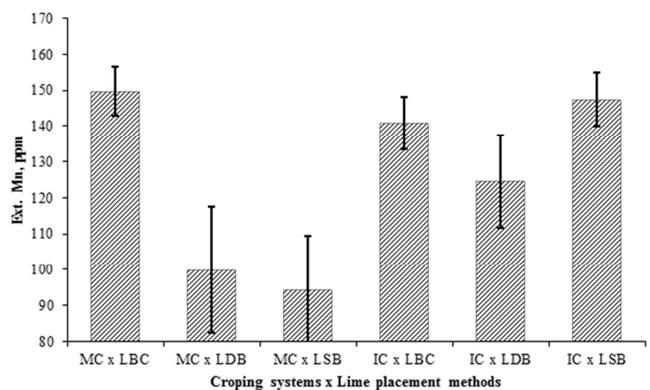


Figure 7. Interaction CS x LPM effect on soil extractable Mn for 15 – 30 cm depth.

There was a significant (P = 0.01) interaction effect between cropping systems and lime rates on soil OC for 0 – 15 cm depth (Table 2 and Figure 8). This result indicates that difference in soil OC as affected by CS and LR differs based

on the interaction. Under MC, soil OC decreased with increase in lime rates. While under IC, soil OC increased with increase in lime rates (Figure 8). This shows that in each cropping system, different lime rates should be used because the reaction of the lime rates varies.

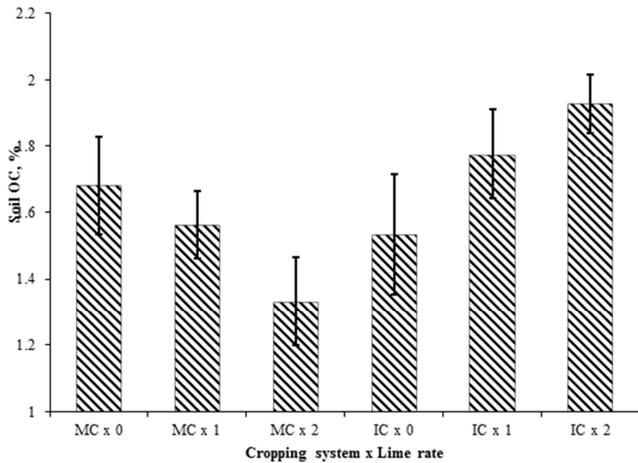


Figure 8. Effects of CS x LR on soil OC for 0 – 15 cm depth.

3.2.6. Effects of LPM x LR on Soil pH (In 1 N KCl) for 15 – 30 cm

There was a significant ($P = 0.021$) interaction effect between lime placement methods and lime rates on soil pH (in KCl) for 15 – 30 cm depth (Table 2 and Figure 9). There was increase in soil pH with increased lime where lime was banded deep and also shallow (Figure 9).

3.2.7. Effects of LPM x LR on Soil Exchangeable Ca for 15 – 30 cm Depth

There was a significant ($P < 0.001$) interaction effect between LMP and LR on exchangeable Ca (Table 6). Plots that had the combination LDB x 2 t ha⁻¹ showed the highest Ca (Figure 10). This indicates that variation in soil exchangeable Ca is affected by varied LMP and also varied LR. Therefore, different lime rates should be determined for different LPM.

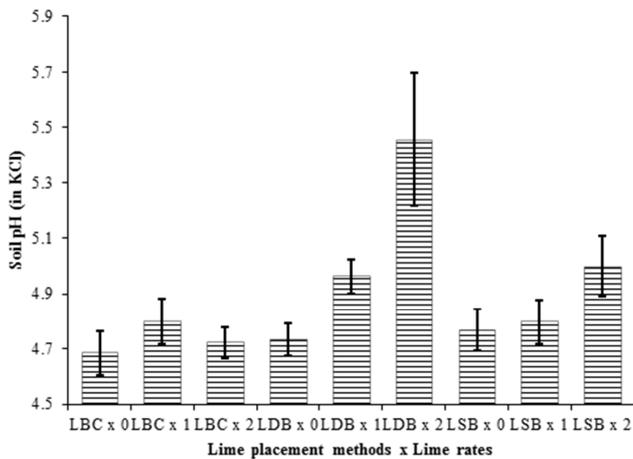


Figure 9. Effects of LPM x LR on soil pH for 15 – 30 cm.

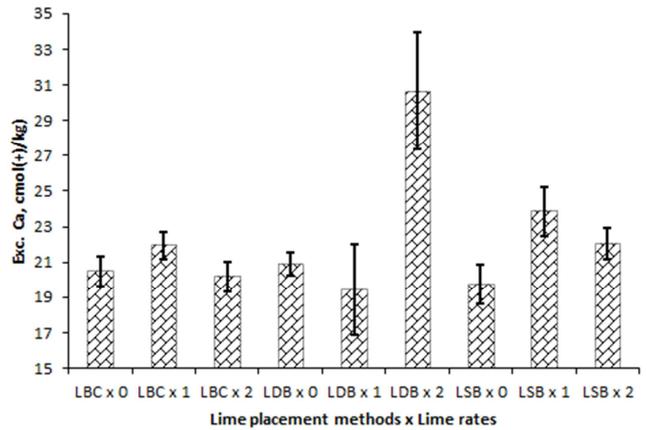


Figure 10. Effects of LPM x LR on exchangeable Ca for 15 – 30 cm depth.

3.3. Effects of Cropping Systems (CS), Lime Placement Methods (LPM) and Lime Rates (LR) on Sugarcane Nutrients Content at Plant Crop and Ratoon One Cycles

The macronutrient content tested for sugarcane leaves were total nitrogen (N), total phosphorus (P), total potassium (K), total calcium (Ca) and total magnesium (Mg) as shown in Table 9. The micronutrients were total manganese (Mn) and total zinc (Zn) as shown in Table 10.

Cropping systems significantly ($P = 0.05$) affected sugarcane total N for ratoon one cycle at the 12th month after ratoon one emergence (MaR) (Table 9). Sugarcane under MC recorded higher total N (1.13%) compared to sugarcane under IC (1.09%) (Table 11). However, the levels of N recorded for both CS were below the critical value for sugarcane, which is $< 1.80\%$ [31, 32].

Cropping systems significantly influenced sugarcane total Ca ($P = 0.04$) and total Mn ($P = 0.05$) for plant crop cycle at the 18th month after planting (Table 9 and 10). Sugarcane under IC recorded higher total Ca (0.44%) and total Mn (76.96 ppm) compared to sugarcane under MC which was 0.38% and 64.93 ppm for total Ca and total Mn, respectively. The total Ca recorded was in the optimum range (0.2 – 0.45%) (Table 11 and 12). Likewise for total Mn was in the optimum range (20 – 100 ppm). The critical ranges are according to [31] and [32].

Lime placement methods significantly affected the sugarcane total N for plant crop cycle at 18th month after planting (MAP). Sugarcane under plots that lime was broadcasted (L-BC) showed highest total N (0.47%) compared to those under plots that lime was shallow - banded (L-SB) or deep - banded (L-DB), which was 0.41% and 0.40%, respectively (Table 11). However, the levels of total N were below the critical value ($< 1.80\%$). Lime placement methods significantly affected the sugarcane total P for plant crop cycle at 18th MAP (Table 11). Sugarcane under plots that were L-BC recorded the highest P (0.08%) compared sugarcane under L-SB and L-DB, which was 0.06% and 0.06%, respectively (Table 11).

Table 9. F – test probabilities for the effects of cropping systems (CS), lime placement methods (LPM) and lime rates (LR) on total Nitrogen (N), total Phosphorus (P), total potassium (K) and total calcium (Ca) content in sugarcane leaves at plant crop cycle and ratoon one cycle.

F test probabilities	SOV	d.f.	Total N			Total P			Total K			Total Ca		
			PC	R1, 9 MAR	R1, 12 MAR	PC	R1, 9 MAR	R1, 12 MAR	PC	R1, 9 MAR	R1, 12 MAR	PC	R1, 9 MAR	R1, 12 MAR
	CS	1	0.110	0.669	0.114	0.942	0.944	0.721	0.458	0.138	0.774	0.003	0.187	0.750
	LPM	2	0.015	0.828	0.177	< 0.001	0.134	0.969	0.518	0.538	0.460	0.021	0.159	0.366
	LR	2	0.109	0.521	0.293	0.127	0.238	0.140	0.773	0.824	0.153	0.641	0.163	0.334
	CS x LPM	2	0.340	0.828	0.716	0.904	0.951	0.986	0.165	0.366	0.659	0.278	0.242	0.811
	CS x LR	2	0.344	0.815	0.038	0.979	0.671	0.727	0.616	0.242	0.730	0.941	0.637	0.312
	LPM x LR	4	0.144	0.669	0.461	0.058	0.169	0.508	0.795	0.279	0.196	0.525	0.601	0.276
	CS x LPM x LR	4	0.153	0.049	0.732	0.787	0.224	0.743	0.669	0.039	0.389	0.868	0.619	0.513

Significant effect at $P \leq 0.05$; CS – cropping systems; LPM – lime placement methods; LR – lime rates; PC – plant crop cycle; R 1 – ratoon one crop cycle; MaP – months after planting sugarcane setts; MaR – months after ratoon one emergence; d.f. – degrees freedom;

Table 10. F – test probabilities for the effects of cropping systems (CS), lime placement methods (LPM) and lime rates (LR) on total Magnesium (Mg), total Manganese (Mn) and total Zinc (Zn) content in sugarcane leaves at plant crop cycle and ratoon one cycle.

F test probabilities	SOV	d.f.	Total magnesium			Total manganese			Total zinc		
			PC	R1, 9 MAR	R1, 12 MAR	PC	R1, 9 MAR	R1, 12 MAR	PC	R1, 9 MAR	R1, 12 MAR
	CS	1	0.077	0.419	0.336	0.004	0.419	0.479	0.600	0.896	0.941
	LPM	2	0.714	0.739	0.967	0.465	0.626	0.106	0.719	0.063	0.395
	LR	2	0.561	0.225	0.728	0.183	0.317	0.666	0.378	0.097	0.332
	CS x LPM	2	0.442	0.309	0.543	0.413	0.904	0.546	0.335	0.344	0.263
	CS x LR	2	0.624	0.876	0.559	0.918	0.696	0.003	0.927	0.917	0.965
	LPM x LR	4	0.626	0.449	0.455	0.845	0.647	0.964	0.792	0.692	0.078
	CS x LPM x LR	4	0.413	0.154	0.085	0.127	0.817	0.204	0.129	0.807	0.349

Significant effect at $P \leq 0.05$; CS – cropping systems; LPM – lime placement methods; LR – lime rates; PC – plant crop cycle; R 1 – ratoon one crop cycle; MaP – months after planting sugarcane setts; MaR – months after ratoon one emergence; d.f. – degrees freedom;

Table 11. Effects of cropping systems, lime placement methods and rates on sugarcane uptake of nitrogen, phosphorus and potassium at plant crop and ratoon one cycles.

Factors	Levels / Stage	Total nitrogen (% N)			Total phosphorus (% P)			Total potassium (% K)		
		PC – 18th MaP	R 1 – 9th MaR	R 1 – 12th MaR	PC – 18th MaP	R 1 – 9th MaR	R 1 – 12th MaR	PC – 18th MaP	R 1 – 9th MaR	R 1 – 12th MaR
Cropping systems (CS)	MC	0.42	1.17	1.13a	0.07	0.13	0.13	0.58	0.62	0.61
	IC	0.45	1.16	1.09b	0.07	0.13	0.13	0.63	0.56	0.60
	LSD ($P \leq 0.05$)	NS	NS	0.04	NS	NS	NS	NS	NS	NS
Lime placement Methods (LPM)	L-BC	0.47a	1.17	1.08	0.08a	0.13	0.13	0.55	0.57	0.62
	L-DB	0.40b	1.18	1.12	0.06b	0.13	0.13	0.61	0.62	0.63
	L-SB	0.41b	1.16	1.13	0.06b	0.14	0.13	0.66	0.58	0.58
	LSD ($P \leq 0.05$)	0.04	NS	NS	0.02	NS	NS	NS	NS	NS
Lime rates (LR) – t ha ⁻¹	0	0.43	1.17	1.12	0.06	0.14	0.12	0.58	0.59	0.61
	1	0.46	1.15	1.13	0.07	0.13	0.14	0.64	0.57	0.56
	2	0.41	1.19	1.08	0.06	0.13	0.13	0.59	0.60	0.65
	LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CS x LR	NS	NS	NS	NS	NS	NS	NS	NS	NS
	LPM x LR	NS	NS	NS	0.04	NS	NS	NS	NS	NS
	CS x LPM x LR	NS	NS	NS	NS	NS	NS	NS	0.04	NS
	CV (%)	16.1	8.3	8.3	25.9	11.8	19.3	41.3	22.8	20.2

Means in the same column followed by the same letter (s) are not significantly different at 0.05 level. Key: NS – not significant at ($P = 0.05$); CV – coefficient of variation; MC – Sugarcane monoculture; IC – Intercropped sugarcane; L-BC – lime broadcasted; L-DB – lime deep banded; L-SB – lime shallow banded. PC – plant crop cycle; R 1 – ratoon one crop cycle; MaP – months after planting sugarcane setts; MaR – months after ratoon one emergence

Table 12. Effects of cropping systems (CS), lime placement methods (LPM) and rates (LR) on sugarcane uptake of calcium, magnesium, manganese and zinc at plant crop and ratoon one cycles.

Factors	Levels	Total Calcium (% Ca)			Total magnesium (% Mg)			Total manganese (ppm, Mn)			Total zinc (ppm Zn)		
		PC - 18	R 1 - 9	R 1 - 12	PC - 18	R 1 - 9	R 1 - 12	PC - 18	R 1 - 9	R 1 - 12	PC - 18	R 1 - 9	R 1 - 12
CS	MC	0.38	0.39	0.41	0.07	0.13	0.17	64.93b	44.30	50.56	3.22	16.08	13.17
	IC	0.44	0.43	0.42	0.08	0.15	0.15	76.96a	47.02	48.55	3.67	15.86	12.94
	LSD ($P \leq 0.05$)	0.05	NS	NS	NS	NS	NS	11.43	NS	NS	NS	NS	NS
LPM	L-BC	0.37	0.44	0.43	0.07	0.13	0.17	67.44	45.13	52.09	3.50	13.03b	10.22
	L-DB	0.42	0.37	0.45	0.07	0.15	0.16	72.72	47.86	51.34	3.00	16.95a	13.61
	L-SB	0.44	0.42	0.37	0.07	0.14	0.16	72.67	43.99	45.23	3.83	17.93a	15.34
	LSD ($P \leq 0.05$)	0.03	NS	NS	NS	NS	NS	NS	NS	NS	NS	1.53	NS
	CV (%)	19.3	28.8	39.6	20.8	43.3	63.9	20.6	29.4	20.7	90.7	43.8	82.1
LR	0 t ha ⁻¹	0.40	0.40	0.46	0.07	0.12	0.16	76.22	49.16	51.29	3.11	18.14	11.71
	1 t ha ⁻¹	0.42	0.38	0.39	0.07	0.16	0.18	68.17	43.04	49.12	2.94	16.32	11.13
	2 t ha ⁻¹	0.40	0.45	0.39	0.07	0.14	0.16	68.44	44.78	48.25	4.28	13.45	16.32
	LSD ($P \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV (%)	19.3	28.8	39.6	20.8	43.3	63.9	20.6	29.4	20.7	90.7	43.8	82.1

Means in the same column followed by the same letter (s) are not significantly different at 0.05 level of significance. Key: NS – not significant at ($P = 0.05$); CV – coefficient of variation; MC – Sugarcane monoculture; IC – Intercropped sugarcane; L-BC – lime broadcasted; L-DB – lime deep banded; L-SB – lime shallow banded.

Lime placement methods significantly affected the sugarcane total Ca for plant crop cycle at 18th MAP (Table 9 and 11). Sugarcane under plots that were L-SB recorded the highest Ca (0.44%) compared to sugarcane under L-BC and L-DB, which was 0.37% and 0.42%, respectively. The levels of total Ca was at optimum range (0.20 – 0.45% Ca). Lime placement methods significantly affected the sugarcane total Zn for ratoon one crop cycle at 9th month after ratoon emergence (Table 10 and 12). Sugarcane under plots that were L-SB recorded the highest Zn (17.93 ppm) compared to sugarcane under L-DB and also under L-BC which was 16.95 ppm and 13.03 ppm, respectively. In terms of levels, sugarcane total Zn at 17.93% was within optimum range (17 – 32 ppm), those at 16.95% was between critical value (> 15 ppm) and optimum range, those at 13.03 ppm were below the critical Zn value (< 15) according to [31] and [32].

There was no significant effect of lime rates on the nutrients content in sugarcane leaves during the plant crop cycle and also ratoon one cycle.

The leaf nutrient status was assessed based on the treatments, crop cycle and age at time of leaf sampling. Time of leaf sampling especially for fertilizer recommendations should be carried out during the actively growing stage of sugarcane, hereby referred to the grand growth stage [31] and [32].

The four sugarcane growth stages are germination and establishment phase; tillering phase; grand growth phase and ripening and maturation phase [33; 34]. Germination denotes activation and subsequent sprouting of the vegetative bud from the planted sugarcane setts (sugarcane vegetative planting material). Tillering involves physiological process of repeated under ground branching from compact nodal joints of the primary shoot. Grand growth involves actual sugarcane formation and elongation and thus yield build up.

Finally, Ripening and maturation phase entails sugar synthesis and rapid accumulation of sugar takes place while the vegetative growth is reduced.

Nitrogen is one of the main building blocks of proteins. Nitrogen is responsible for growth and expansion of green leaves and is essential for photosynthesis and sugar production [31]. The sugarcane leaf total N across the treatments, crop cycle and age was very low regarded as below the critical N level ($< 1.80\%$). At plant crop cycle and 18th month, the sugarcane leaf N content ranged from mean of 0.41 to 0.47% (Table 11). However, at ratoon crop cycle at 9th and 12th, sugarcane leaf N range was (1.15 to 1.17%) and (1.08 to 1.13%) respectively (Table 2.11). It appears the low total N is attributed to the time the leaves were sampled. [35] stated that sugarcane crop age as one of the factors influencing leaf analysis and nutrient content. [35] reported that leaf N decreased markedly from a mean of 2.70% at 1st month to 1.85% in the 4th month and further decreased to 1.67% in the 9th month.

Phosphorus is essential for the formation of a strong and vigorous root system and plays a role in photosynthesis and many other biochemical processes such as cell division and cell growth [31, 36]. The sugarcane leaf P content was very low regarded as below the critical leaf P level ($< 0.18\%$). At plant crop cycle and 18th month, the sugarcane leaf P content ranged from mean of 0.02 to 0.08% (Table 11). The ratoon crop cycle at 9th and 12th, sugarcane leaf P range was (0.13 to 0.14%) and (0.12 to 0.13%) respectively (Table 11).

Potassium is involved in chlorophyll development, helps the plant use other nutrients and water more efficiently and controls the movement of sugars in the plant. The sugarcane leaf K content was very low regarded as below the critical leaf K level ($< 1.11\%$). At plant crop cycle and 18th month, the sugarcane leaf P content ranged from mean of 0.55 to

0.64% (Table 11). The ratoon crop cycle at 9th and 12th, sugarcane leaf K range was (0.56 to 0.62%) and (0.56 to 0.65%) respectively (Table 11).

Calcium is essential for the growth and development of the spindle, leaves and roots. Calcium comprises part of the cell walls, thus strengthening the plant. The sugarcane leaf Ca content was adequate regarded as above the critical leaf Ca level (> 0.2%). At plant crop cycle and 18th month, the sugarcane leaf Ca content ranged from mean of 0.37 to 0.44% (Table 12). The ratoon crop cycle at 9th and 12th, sugarcane leaf Ca range was (0.37 to 0.45%) and (0.37 to 0.46%) respectively (Table 12).

Magnesium is an essential constituent of chlorophyll where photosynthesis takes place to underpin sugar production and other growth processes [36]. At plant crop cycle aged 18th month, the sugarcane leaf Mg content was very low regarded as below the critical leaf Mg (< 1.13%). However, at ratoon one crop cycle aged 9th and 12th month, Mg content was adequate regarded as above 1.13% Mg critical level. The range of leaf Mg content for ratoon was 0.12 to 0.16% while for plant crop cycle was 0.07 to 0.08%.

Manganese is involved in photosynthesis, chlorophyll production, and the formation of organic compounds, especially enzyme systems [31, 36]. The sugarcane leaf Mn content was adequate regarded as above the critical leaf Mn level (> 15 ppm). At plant crop cycle and 18th month, the sugarcane leaf Mn content ranged from mean of 64 to 72 ppm (Table 12). The ratoon crop cycle at 9th and 12th, sugarcane leaf Mn range was (43 to 49 ppm) and (48 to 52 ppm) respectively (Table 12).

Zinc is involved in chlorophyll formation, the regulation of plant growth and development, and the efficient use of water [31, 36]. At plant crop cycle aged 18th month, the sugarcane leaf Zn content was very low regarded as below the critical leaf Mg (< 10 ppm). However, at ratoon one crop cycle aged 9th and 12th month, Mg content was adequate regarded as above 10 ppm Zn critical level. The range of leaf Zn content for ratoon was 3.00 to 4.28 ppm while for plant crop cycle was 11.30 to 17.93 ppm.

3.4. Effects of Interactions of the Main Factors on Nutrient Content of Sugarcane Leaves

Influence of the interactions of the main factors on nutrient content of sugarcane during plant crop and ratoon one cycle is given in Table 9 and 10. There was significant interaction ($P = 0.01$) between CS and LR on total Mn in sugarcane leaves during ratoon one cycle at 12th month after ratoon one emergence (Table 10 and Figure 11). Under MC, total Mn in leaves increased with increase in lime rate. While under IC, total Mn decreased with increase in LR (Figure 11). There was significant interaction ($P = 0.038$) between CS and LR on total N in sugarcane leaves during ratoon one cycle at 12th month after ratoon one emergence (Table 9, 10 and Figure 12). Under MC, total N in leaves was high when LR used was 1 t ha⁻¹. While under IC, total N in sugarcane leaves decreased with increase in LR (Figure 12).

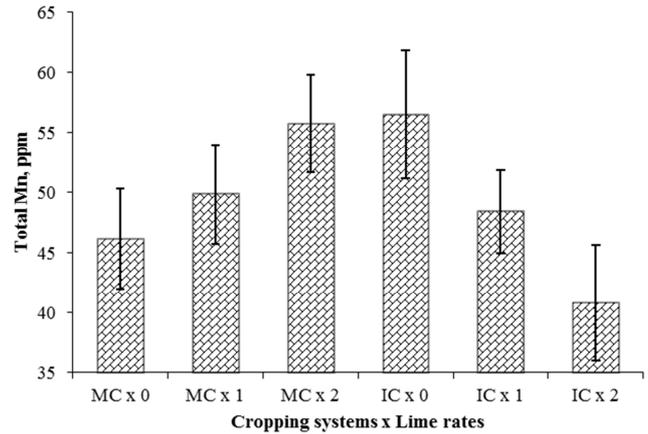


Figure 11. Effects of CS x LR on Mn content in sugarcane leaves.

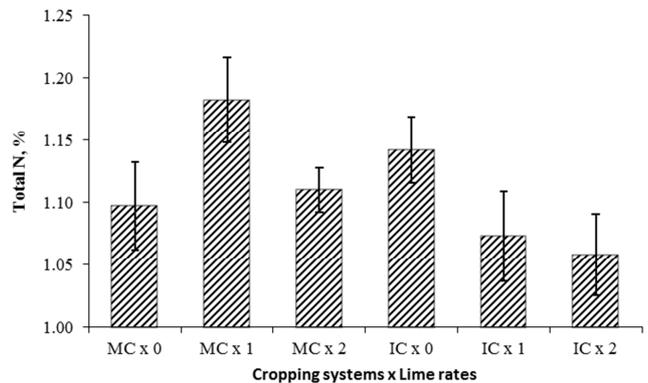


Figure 12. Effects of CS x LR on total N in sugarcane leaves.

4. Conclusions

Increased lime rate has been found to ameliorate soil acidity, as evidenced by increased soil pH from 6.1 to 6.4 (soil pH in water) or from 4.9 to 5.2 (soil pH in KCl). Lime rate 2 tons ha⁻¹ was the best to ameliorate soil acidity. Also, increased lime rate led to decreased levels of extractable manganese, iron, and copper, hence confirms the inverse relationship between soil pH and these micronutrients. Therefore, liming has the potential to reduce toxicity caused by high levels of the micronutrients. Lime placement methods seemed to affect soil properties although variedly. Lime deep banded (L-DB) increased soil pH and available phosphorus for sub depth 15 – 30 cm. This shows that, sub soil acidity is best limed when lime is deep banded as a lime placement method is employed. Intercropped sugarcane and soybeans (IC) led to increased acidity and also soil organic carbon (SOC). The increased acidity is a result of the reaction during decomposition of soil organic carbon / soil organic matter generated from sugarcane and soybean residues. Intercropped sugarcane and soybeans increased Calcium and Manganese content in sugarcane leaves. This increase is attributed to decomposition of soybean residues which then produced calcium. Lime broadcasted (L-BC) caused high N and P content in sugarcane leaves; however the levels were below the critical values. Lime shallow banded resulted in increased Ca and Zn in sugarcane leaves to optimum levels. In view of the findings, lime rate 2

tons ha⁻¹ is recommended for use to ameliorate soil acidity for acidified Cambisols soils of Kibos, Kisumu County, Kenya. Also, lime placement methods should take into consideration the soil pH stratification with depth. Lime banded should only be employed when sub soil acidity is identified. Lime broadcasted, still remains the preferred lime placement method to ameliorate soil pH within plough depth 0 – 15 cm when acidity is identified.

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References

- [1] Okalebo, J. R., Othieno, C. O., Nekesa, A. O., Ndungu-Magiroi, K. W. and Kifuko-Koech, M. N. (2009). Potential for agricultural lime on improved soil health and agricultural production in Kenya. *African Crop Science Conference Proceedings* 9: 339-341.
- [2] Kamprath, E. J. (1984). Crop response to lime on soils in the tropics. In: Soil acidity and liming, 2nd ed. (Edited by Adams, F.). *Agronomy* 12, *American Society of Agronomy* 349-368 pp.
- [3] Kanyanjua, S. M., Ireri, L., Wambua, S. and Nandwa, S. M. (2002). *Acidic Soils in Kenya: Constraints and Remedial Options*. KARI Technical Note No. 11. KARI, Nairobi. 24 pp.
- [4] Bolan, N. S., Adriano, D. C. and Curtin, D. (2003). Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. *Advances in Agronomy* 78: 215-272.
- [5] Sumner, M. E., Fey, M. V. and Noble, A. D. (1991). *Nutrient status and toxicity problems in acid soils*. In: *Soil acidity*. (Edited by Ulrich, B and Sumner, M. E.), Springer-Verlag, Berlin. 149-182 pp.
- [6] Brady, N. C. and Weil, R. R. (2008). *The Nature and Properties of Soils, 12th edition*. Prentice-Hall, Inc., Upper Saddle River, NJ, USA. 881 pp.
- [7] Voss, R. (1998). *Micronutrients*. Department of Agronomy, Iowa State University, USA. [http://www.agronext.iastate.edu/soilfertility/Info/Micronutrients_VossArticle.pdf] site visited on 20/10/2015.
- [8] McCauley, A. (2009). *Soil pH and organic matter. Nutrient Management Module No. 8*, Montana State University Extension. USA. [<http://landresources.montana.edu/nm/documents/NM8.pdf>] sited visited on 20/10/2015.
- [9] AGRA (2009). *AGRA: Early Accomplishments, Foundations for Growth*. Alliance for Green Revolution in Africa, Nairobi. [<http://www.agraalliance.org/early-accomplishments>] site visited on 3/01/2011.
- [10] Haynes, R. J. and Ludeke, T. E. (1981). Effect of lime and phosphorus application on concentration of available nutrients and on P, Al and Mn uptake by two pasture legumes in an acid soil. *Plant and Soil* 62: 117 - 128.
- [11] Bolan, N. S., Hedley, M. J. and White, R. E. (1991). Processes of soil acidification during nitrogen cycling with emphasis on legume based pastures. *Plant and Soil* 134: 53 - 63.
- [12] Amolo, R. A., Sigunga, D. O. and Owuor, P. O. (2011). *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*. 12-32 pp.
- [13] Chianu, J. N., Vanlauwe, B., Mahasi, J. M., Katungi, E., Akech, C., Mairura, F. S., Chianu, J. N. and Sanginga (2008). *Soybean situation and outlook analysis: The case of Kenya*. [www.icrisat.org/situation-outlook-sbean-kenya.pdf] site visited on 10/09/2014.
- [14] FAO (2006). *World Reference Base for Soil Resources 2006: A frame work for international classification, correlation and communication*. World Soil Resources Report No: 103. Food and Agriculture Organization of the United nations, Rome. 145 pp.
- [15] Jaetzold, R., Schmidt, H., Hornetz, B. and Shisanya, C. (2007). *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). 317 pp.
- [16] Landon, J. R. (1991). *Booker Tropical Soil Manual. A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*. Longman, New York.
- [17] Estefan, G., Sommer, R. and Ryan, J. (2013). *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.
- [18] IUSS Working Group WRB (2015). *World Reference Base for Soil Resources 2014, update 2015*. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome
- [19] MacLean, E. O. (1982). *Aluminium In: Method of soil Analysis Part 2. Agronomy Monograph No. 9* (Edited by page, A. L., Miller, R. H. and Keeney, P. R.). American Society of Agronomy Inc. Madison, Wisconsin. 221-223 pp.
- [20] Moberg, J. R. (2001). *Soil and Plant Analysis Manual*. The Royal Veterinary and Agriculture University, Chemistry Department, Copenhagen, Denmark. 133 pp.
- [21] Bremner, J. M. and Mulvaney, C. S. (1982). *Total nitrogen*. In: *Methods of soil Analysis Part 2. Agronomy Monograph No. 9* (Edited by Page, A. L., Miller, R. H. and Keeney, P. R.). American Society of Agronomy Inc., Madison, Wisconsin. 149-157 pp.
- [22] GENSTAT (2011). *Introduction to GENSTAT 13 for windows*. Lowes Agricultural Trust, Rothamsted Experimental Station, Reading University, United Kingdom. 354 pp.

- [23] Nekesa, A. O. (2007). *Effect of Minjingu Phosphate Rock and Agricultural Lime in Relation to Maize, Groundnut and Soybean Yields on Acid Soils of Western Kenya*. Thesis for award of M. Phil. Degree at Moi University, Eldoret, Kenya. 110 pp.
- [24] Osundwa, M. A., Okalebo, J. R., Ngetich, W. K., Ochuodho, J. O., Othieno, C. O., Langat, B. and Omenyo, V. S. (2013). Influence of agricultural lime on soil properties and wheat (*Triticum aestivum* L.) yield on acidic soils of Uasin Gishu County, Kenya. *American Journal of Experimental Agriculture* 3 (4): 806-823.
- [25] Kisinyo, P. O. (2016). Long term effects of lime and phosphorus application on maize productivity in an acid soil of Uasin Gishu County, Kenya. *Journal of Agricultural Research* 5 (3): 48-55.
- [26] Brown, T. T., Koenig, R. T., Huggins, D. R., Harsh, J. B. and Rossi, R. E. (2008). Lime effects on soil acidity, crop yield and aluminium chemistry in direct-seeded cropping systems. *Soil Science Society of America Journal* 72: 3: 634-640.
- [27] Rosa, C. B. C. J., Marchetti, M. E., Serra, A. P., Rosa, S. M., Ensinas, S. C., Conrad, V. A., Altomar, P. H., Potrich, D. C. and Martinez, M. A. (2015). Short term effects of lime management in soybean no-tillage system implementation in Brazilian Savannah. *Australian Journal of Crop Science* 9 (3): 232-241.
- [28] Uren, N. C. (2001). *Types, amounts, and possible functions of compounds released into the rhizosphere by soil - grown plants*. In: *The Rhizosphere: Biochemistry, and Organic Substances at the Soil-Plant Interface* (Edited by Pinton, R., Varanini, Z. and Nannipieri, P.), Marcel Dekker, New York. 22-32 pp.
- [29] Patra, B. N., and Mohanty, S. K. (1994). Effect of nutrients and liming on changes in pH, redox potential, and uptake of iron and manganese by wetland rice in iron-toxic soil. *Biology and Fertility of Soils* 17: 285-288.
- [30] Stahl, R. S., and James, B. R. (1991). Zinc sorption by B horizon soils as a function of pH. *Soil Science Society of America Journal* 55: 1592-1597.
- [31] Calcino, D., Kingston, G. and Haysom, M. (2000). *Nutrition of the plant*. Sugar Research Australia. [www.sugarresearch.com.au/icms.../166943_Chapter_9_Nutrition_of_the_Plant.pdf] site visited on 16/06/2015.
- [32] McCray, J. M. and Mylavarapu, R. (2013). *Sugarcane nutrient management using leaf analysis*. University of Florida Institute of Food and Agricultural Sciences. EDIS document SS-AGR-335. [http://edis.ifas.ufl.edu/ag345.pdf] site visited on 16/06/2015.
- [33] Meyer, J. and Clowes, M. (2011). *Sugarcane and Its Environment*. In: *Good Management Practices Manual for the Cane Sugar Industry*. (Edited by Meyer, J). The International Finance Corporation (IFC). Johannesburg. South Africa. 14-51 pp.
- [34] Rossler, R. L., Singles, A., Oliver, F. C. and Steyn, J. M. (2013). *Growth and yield of a sugarcane plant crop under water stress imposed through deficit drip irrigation*. Proceedings of South Africa Sugar Technologist Association 86: 170-183
- [35] Schroeder, B. L. (2000). *Assessment of leaf analysis of sugarcane under moisture stress considerations*. Ph. D. thesis. University of Pretoria., South Africa. 149 pp.
- [36] Meyer J. (2011). *Sugarcane Nutrition and Fertilization*. In: *Good Management Practices Manual for the Cane Sugar Industry*. (Edited by Meyer, J). The International Finance Corporation (IFC). Johannesburg. South Africa. 173-226 pp.