EFFECTS OF CROPPING SYSTEMS, LIME PLACEMENT METHODS AND RATES ON SUGARCANE YIELDS AND QUALITY UNDER ACIDIFIED SOILS OF KIBOS, KENYA

ABSTRACT

This field study was conducted to investigate whether appropriate lime placement methods, lime rates and intercropped sugarcane with soybeans leads to amelioration of soil Ph, hence, increased yields and quality of sugarcane for plant and ratoon one crop cycles. Cambisols of the study site at Kibos, Kisumu County are acidified due to long term use of acidifying fertilizers and continuous sugarcane monoculture. Acidified soils are a constraint to crop production due to imbalance in availability of essential plant nutrients. Appropriate cropping systems and liming are therefore advocated. The field experiment design was split - split plot in randomized complete block arrangements. The factors and respective levels: the main plots were two cropping systems namely, sugarcane monocultureand also intercropped sugarcane and soybeans. 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 ; lime rates (0, 1 and 2 t ha^{-1}). Intercropped sugarcane led to high sugarcane yields than the sugarcane monoculture for plant crop cycle. No significant effect was observed for ratoon crop harvest. Lime use caused changes on sugarcane quality [pol % cane and commercial cane sugar] for plant crop and that lime placement method [lime shallow banded] gave the highest reading while the least was for sugarcane under lime broadcasted. It is therefore concluded that liming plays a limited role on the direct effect on sugarcane yield. Liming only plays a significant and direct role on amelioration of soil acidity and nutrient transformations. Liming should be integrated with other cropping and nutrient management strategies for increased yields.

Keywords: Soil acidity, lime rates, lime placements, sugarcane yields

1. INTRODUCTION

Acidification of the soils of western Kenya threatens the productivity of economic crops such as sugarcane and annual legume crops such as soybeans. The acid soils cause 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 which are constraints to crop production [1, 2]. Inherently, the soils of western Kenya are acid. The major soil types in western Kenya are Acrisols and Cambisols [3]. Acrisols are acid soils at pH in water less than 5.0, low base status, strongly leached but less weathered than Ferralsols and base saturation of the B horizon is less than 50 %. Cambisols are inherently less weathered than most of the other soils of the humid tropics. It has a Cambic B horizon and the layers are differentiated and changing characteristically due to their relatively young age [3]. Cropping systems such as mono – cropping and long term use of acidifying fertilizers accelerate soil acidity. However, Cambisols in the sugarcane growing areas of western Kenya are acidic, to a pH as low as 5.5, due to acidification caused by long term use of ammonium based fertilizers namely diammonium phosphate (DAP) and urea [4]. Soil pH of 5.5 and below causes some nutrient unavailability for sugarcane and also soybeans used as intercrop. At this pH, P, Mg, Ca, K and Mo availability declines [5]. Studies have reported the optimum soil pH for sugarcane is 6.5 [6, 7]. The optimal pH for soybeans is 7.0 since it reduces the negative effects of low pH on nodulation and increases the efficiency of fertilizer use [8]. The soil acidification is further exacerbated by continuous sugarcane monoculture through plant removal and leaching of basic cations [9]. Fertilizer application in managed ecosystems used for agricultural production is a major contributor for soil acidification according to findings by [2]. Acidity equivalent of urea and DAP was 79 and 74, respectively. In comparison, elemental sulphur showed the highest acidity equivalent, at 310, followed by ammonium sulphate, at 110 acidity equivalent. Acidity equivalent is the number of parts by weight of pure lime (calcium carbonate) required to neutralize the acidity caused by 100 parts of the fertilizer. Liming offers the opportunity to ameliorate soil acidity, improve nutrient availability and yields [10, 11, 12]. Despite the benefits of liming, the costs are prohibitive due to the broadcast method of lime application and the corresponding large quantities required. Increased soil pH to the range of 5.8 - 6.5 at lime rate of 2 t ha^{-1} was observed from field trials on lime use for maize - groundnut production [11].

Increased maize yields from 2.6 to 3.6 t ha^{-1} were recorded in acid soils of western Kenya when lime use was integrated with inorganic fertilizer [13]. Therefore, studies on lime use in Kenya have centered on the lime rate on maize production, with limited work on lime use efficiency [14]. Another study by [15] suggested that alternative application strategies such as placement of lime in a band beneath the row at seeding may allow lower rates of lime to be used and thereby offset economic constraints posed by high lime application rates. Soil acidity in the surface 10 cm was effectively reduced when lime rate 220 kg ha^{-1} was banded at the subsurface according to a study at eastern Washington [16]. However, no grain yield response was observed in the same study [16]. According to [17], surface liming caused increases up to 66 % in the root growth (0 – 60 cm) and up to 140 % in the grain yield. Root density and grain yield were correlated positively with soil pH and exchangeable Ca^{2+}, and negatively with exchangeable Al^{3+} and Al^{3+} saturation in the surface and subsurface layers.

It was concluded in a study by [18] that lime management promoted chemical and physical changes in soil properties through the profile. The study found out that lime surface application at rate 2.7 t ha^{-1} and incorporation with intermediate disk harrow followed by leveling disk harrow, or lime surface application and incorporation with chisel plough, followed by intermediate disk harrow and leveling disk harrow led to better lime incorporation in the layer 10 - 20 cm and 20 - 30 cm. Also highest soybean yields of about 3,330 kg ha^{-1} were recorded in plots that received lime surface application and incorporation with chisel plough, followed by intermediate disk harrow and leveling disk harrow [18]. Lime is an input cost to soil fertility management and therefore its judicious use is paramount. Lime placement is considered a strategy that can increase lime use efficiency in crop production. Incorporation of lime to the depth of 30 cm resulted in higher grain yields than when lime was incorporated only in the top 15 cm [19]. Another study by [20] found out that surface application of lime at 4 t ha^{-1} under no till system significantly reduced acidity problems (increased pH and decreased Al, and increased basic cations) at different 0 – 5 cm soil depth and 5 – 10 cm soil depth within 1 year onward and also at 10 – 20 cm depth from 2.5 years onwards. To increase yields and sustainability of soil production, site specific nutrient management is required. Therefore, a field experiment was established and the objective of the study was to evaluate the lime placement methods and lime rates on yields and quality of sugarcane under sugarcane monocrop and intercropped sugarcane and soybeans in acid soil of Kibos, Kenya.

2. MATERIAL AND METHODS

2.1 STUDY SITE

The field experiment was conducted at field 6, experimental plots of Kibos (35°13 E, 0°06 S), under KALRO – Sugar Research Institute, Kisumu County, Kenya. The site elevation is 1268 m above sea level and the agro-ecological zone is LM 2 referred to sub humid, marginal sugarcane zone. The soil type in field 6 is Eutric Cambisols [21] characterized as dark reddish brown, friable sandy clay loam underlain by gravely red loam to light clay. Also, the soil is inherently well drained, has good physical properties and is slightly acid [3].

The weather data during the experiment period (2012 to 2014) is shown in Figure 1. The total annual rainfall was 1714 mm, 1544 mm and 1497 mm in 2012, 2013 and 2014, respectively. 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 in March to May while short rains were in September to October annually. This bimodal rainfall pattern reflects the pattern for lake regions in Kenya [3]. The range for maximum and minimum temperatures was 28 – 33°C and 21 – 24°C, respectively, while the average temperature was 23°C (Figure 1).

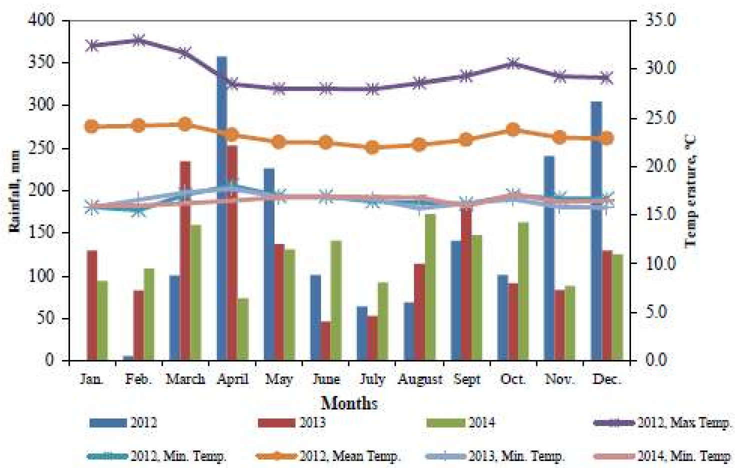


Fig. 1. Rainfall and temperature for the study site during the period of field experiment

2.2 EXPERIMENTAL DESCRIPTION

The experiment design was split – split plot in randomized complete block design. The main plot was cropping system (CS) with two levels namely sugarcane monoculture (MC) and intercropped sugarcane (IC). The sub plot was lime placement methods (LPM) with three levels namely; lime broadcasted (L-BC), lime shallow banded (L-SB) at depth 0 – 15 cm and lime deep banded (L-DB) at depth 15 – 30 cm. The sub – sub plot was lime rates with three levels namely 0, 1 and 2 t ha^{-1}. This gave a total of 18 treatments which were then replicated three times to give 54 plots. The field experiment was established in 2012 and managed upto 2014. The field research period coincided with sugarcane crop cycle namely plant crop (0 – 18 months after planting sugarcane setts) and ratoon one crop cycle (0 – 16 months after ratoon emergence). Soybean was intercropped and managed during the 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 described as the three inner rows with the one row in each side referred to guard rows. Sugarcane variety used was KEN 83 – 737, of medium maturity (0 – 18 months and 0 – 16 months for plant crop and ratoon crop cycle, respectively). Soybean variety SB 19 was used as intercrop which was sowed in between sugarcane rows. The soybean was inoculated with rhizobial (Biofix ®) inoculant. Agricultural lime (20 % CaO) mined in Koru, Kisumu County was used as the liming material. The raw material limestone is carbonanite which is volcanic in origin. The lime as per treatment, was applied prior to planting of sugarcane setts. Lime placement methods used were broadcasting, banding at 0 – 15 cm and also 15 – 30 cm. Sugarcane setts were treated with the chemical 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 sown as an intercrop, in between the sugarcane rows. Soybean was inoculated with rhizobial (Biofix ®) inoculant. The sugarcane was managed for 18 months and harvested as plant crop. It was also managed for ratoon one crop for the following 16 months and harvested. Ratoon crop establishment involved alignment of the sugarcane trash in between sugarcane rows following green sugarcane harvest of the 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 hoe. Weed control and other management practices were undertaken according to KESREF recommendations [22].

2.3 MEASURED PARAMETERS

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. Sugarcane yield components recorded were sugarcane stalk girth, height, population and weight. Sugarcane was harvested on the 18th month after planting for plant crop cycle and on the 16th month after ratoon one crop cycle. The mature sugarcane stalks were cut from the base and chopped at the end (breaking point) using a sharp disinfected knife. Girth is the diameter of the sugarcane stalk. The girth was measured using vernier calipers. The height of sugarcane stalk was measured using meter rule from the base of the stalk to the top of the stalk. The population of sugarcane stalks was determined by converting sugarcane stalks per net plot and converted to per ha basis to give total population. The weight of the sugarcane stalks per plot was measured using a weighing balance. The weight per net plot was then converted to per hectare basis to give tonnes cane per ha (TCH). Sugarcane quality components determined were pol % cane, brix % cane, fibre % cane and tons sugar hectare [23, 24]. Brix % cane is the total soluble solids content present in the juice and corrected to more accurately represent those of the total juice in cane. Brix % in cane = Brix in juice x [100 – (fibre % + 3)] / 100. Pol % in juice is the sucrose content present in the juice expressed in %. Pol is derived from the name of the machine that measures the sucrose content, a polarimeter. Pol % in cane is the sucrose content present in the juice expressed in % and corrected to more accurately represents those of the sucrose in cane. Pol % cane = Pol in juice x [100 – (fibre % + 5)] / 100. Fibre % cane is the amount of fibre in the cane expressed in %. Sampled sugarcane stalks were cut and shredded through a cutter grinder. The ground sample was placed in a fibre machine and washed to remove brix (soluble solids) and fine dirt. The sample was then dried in an oven. The final weight divided by initial weight provided fibre %. Fibre % = [final weight / original weight] x 100. Purity % refers to the measure of the level of sucrose present in cane relative to the total level of soluble solids. Purity along with sucrose aids in determining maturity of sugarcane. Purity = [pol in cane / brix in cane] x 100. Commercial cane sugar (CCS) is the total recoverable sugar % (sucrose) in the cane. CCS (tons ha-1) = [(yield (tons ha-1) x sugar recovery (%)] / 100. Sugar recovery (%) = [S – 0.4 (B – S)] x 0.73, where, S = sucrose % in juice and B = corrected brix (%)

2.4 DATA PROCESSING AND STATISTICAL ANALYSIS

Comparison of means test was carried out using least significance difference (LSD) at the 5% probability level. Main plot effects and respective interactions on treatments were also analysed [25]. Comparison of means test was carried out using least significance difference (LSD) at the 5 % probability level.

3. RESULTS AND DISCUSSION

3.1 SOIL CHEMICAL PROPERTIES PRIOR TO ESTABLISHMENT OF FIELD EXPERIMENT

The soil chemical properties of the experiment site are shown 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. 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. Chemical properties of experimental soil

Soil properties	Method of analysis	0 – 15 cm depth	Rating	15 – 30 cm depth	Rating
pH (H_2O)	1: 2.5 soil / water. Potentiometrically	6.19	Slightly acid	5.93	Medium acid
pH (KCl)	1 : 2.5 soil / 1 N KCl. Potentiometrically	5.04	Very strongly acid	4.73	Very strongly acid
Org. C (%)	Dichromate Wet Oxidation	1.30	Medium	1.23	Low
O.M (%)	Convert using factor 1.72 x Org. C	2.24	Medium	2.11	Medium
Total N (%)	Kjeldhal Method	0.10	Low	0.1	Low
Avail. P (mg kg^{-1})	Bray 1	20.52	High	11.91	Medium
Ex. Cu mg kg^{-1}	Extracted using DTPA* and measured using AAS[1]	1.53	High	1.60	High
Ex. Zn mg kg^{-1}	DTPA	1.79	High	1.52	High
Ex. Fe mg kg^{-1}	DTPA	147.9	High	137.2	High
Ex. Mn mg kg^{-1}	DTPA	206.2	High	193.7	High

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

3.2 EFFECTS OF CROPPING SYSTEMS, LIME PLACEMENT METHODS AND RATES ON SUGARCANE YIELD FOR PLANT CROP CYCLE

Plant crop cycle is the period of growth of newly planted sugarcane [26]. Plant crop cycle starts when sugarcane is propagated vegetatively from setts referred to pieces of sugarcane stalk planted as three eyed bud stalks [27]. F – Test probabilities for the effects of cropping systems (CS), lime placement methods (LPM) and lime rate (LR) on yield components for plant crop harvest is shown in Table 2. Only cropping systems significantly ($P = 0.004$) affected the weight (in tonnes per hectare, TCH) of sugarcane harvested (Table 3 and Figure 2). Other sugarcane yield components such as stalk girth, height and population were not affected by cropping systems, lime placement methods, lime rates and respective interactions ($P > 0.05$) as shown in Table 2. Higher sugarcane weight referred to yield was recorded in plots that were intercropped with sugarcane and soybeans (Table 3). This is attributed to the benefits of intercropping system compared to sugarcane monoculture. These results are consistent to findings by [28] who reported more sugarcane yield and dry weight biomass under sugarcane/soybean intercropping than in sugarcane monoculture. Soybean intercrop increases productivity per unit of land and enables sugarcane more effectively utilize nutrients and improve soil fertility [29, 30]. Soybean fixes Nitrogen and therefore, N requirement of sugarcane is met due to transfer of the symbiotically fixed N from the soybean legume crop to sugarcane, a non legume crop [31]. Other benefits of intercrop that leads to increased yield of companion have been reported. For example, Organic matter content of sugarcane soil increased due to companion crop [32]. This then leads to increased microbial number, increased decomposition of organic residues which translates to increased cycling of nutrients [33]. Application of lime did not affect the yield of sugarcane (Table 2). This finding is contrary to the findings of [34]. This may be attributed to use of lime treatment alone unlike combining lime with nutrient such as Phosphorus as in the findings of [34].

Table 2. F – test probabilities for the effects of cropping systems, lime placement methods and rates on sugarcane yield components for plant crop harvest

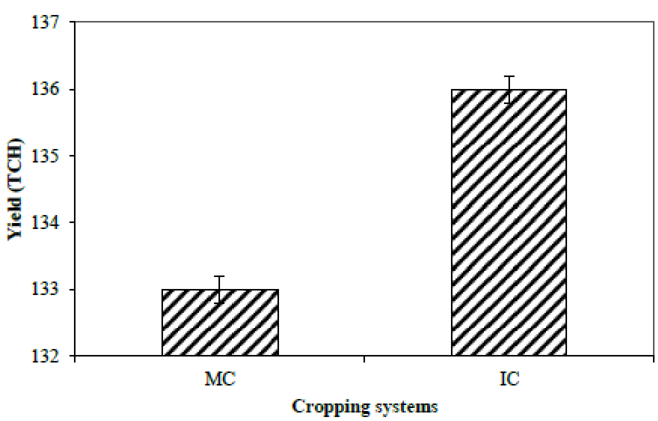
	F – test probabilities			
	Sugarcane stalk parameters			Stalk weight parameters
Source of Variation	Girth	Height	Population	Tonnes Cane per Hectare, TCH
CS	0.951	0.296	0.509	**0.004**
LPM	0.369	0.701	0.865	0.969
LR	0.739	0.445	0.589	0.782
CS x LPM	0.922	0.217	0.919	0.987
CS x LR	0.761	0.236	0.380	0.130
LPM x LR	0.190	0.440	0.359	0.426
CS x LPM x LR	0.279	0.102	0.235	0.136
CV (%)	6.7	4.9	21.6	20.8

CS – cropping systems; LPM – lime placement methods; LR – lime rates; CV - coefficient of variation

Table 3. Effects of cropping systems on sugarcane yield for plant crop cycle

Cropping systems	Stalk weight (TCH) Tonnes cane per hectare
Monoculture sugarcane (MC)	133b
Intercropped sugarcane (IC)	136a
LSD (P ≤ 0.05)	0.8
CV %	21

Means in the same column followed by the same letter(s) are not significantly different at 0.05 level. Key: CV – coefficient of variation; MC – Sugarcane monoculture; IC – Intercropped sugarcane



MC – Monocropped sugarcane   IC – Intercropped sugarcane and soybean

Fig. 2. Effects of cropping systems on sugarcane yield (tonnes cane per hectare) for plant crop cycle

3.3 EFFECTS OF CROPPING SYSTEMS, LIME PLACEMENT METHODS AND LIME RATES ON QUALITY OF SUGARCANE HARVESTED FOR PLANT CROP CYCLE

F – Test probabilities for the effects of cropping systems (CS), lime placement methods (LPM) and lime rates (LR) on quality of sugarcane for plant crop harvest is shown in Table 4. Cropping systems significantly (P = 0.005) affected the amount of sugarcane fibre (Table 4). Sugarcane harvested from plots under intercropped sugarcane and soybean recorded high fibre than sugarcane from plots under monocrop cropping system (Table 4 and 5). Similar pattern was noted in sugarcane weight as affected by cropping system (Table 5 and Figure 3). Fibre, being a dry matter in sugarcane increased in sugarcane under intercropped system attributed to the benefits of intercropping [29, 30, 28]. Sugarcane from plots lime shallow banded recorded high sucrose measured in pol % juice, pol % cane and CCS (Table 6 and Figure 4). The findings in this study are consistent to the findings of [35] and [34]. Application of lime at 3 t ha^{-1} incorporated at shallow depth led to improved quality of juice from sugarcane harvested [34]. Sugarcane quality parameters, brix and purity were not affected by cropping systems, lime placement methods and lime rates. Lime rates (P ≥ 0.05) did not affect all the sugarcane parameters tested (Table 4).

Table 4. F – test probabilities for the effects of cropping systems, lime placement methods and lime rates on sugarcane quality traits for plant crop cycle

	F – Test Probabilities						
	Sugarcane quality traits						
Source of Variation	Pol % Juice	Pol % cane	Brix % Juice	Brix % cane	Purity	Fibre	CCS
CS	0.373	0.493	0.592	0.339	0.776	**0.005**	0.788
LPM	**0.011**	**0.012**	0.069	0.078	0.133	0.639	**0.009**
LR	0.495	0.226	0.698	0.331	0.827	0.123	0.388
CS x LPM	0.077	0.070	0.069	0.086	0.725	0.794	0.170
CS x LR	0.415	0.302	0.136	0.089	0.357	0.661	0.687
LPM x LR	0.805	0.570	0.671	0.289	0.872	0.387	0.761
CS x LPM x LR	0.203	0.377	0.194	0.627	0.409	0.700	0.458
CV (%)	2.9	3.2	2.8	3.1	1.5	5.5	3.7

CS – cropping systems; LPM – lime placement methods; LR – lime rates; CV - coefficient of variation; CCS – commercial cane sugar

Table 5. Effects of cropping systems on fibre % cane for plant crop cycle

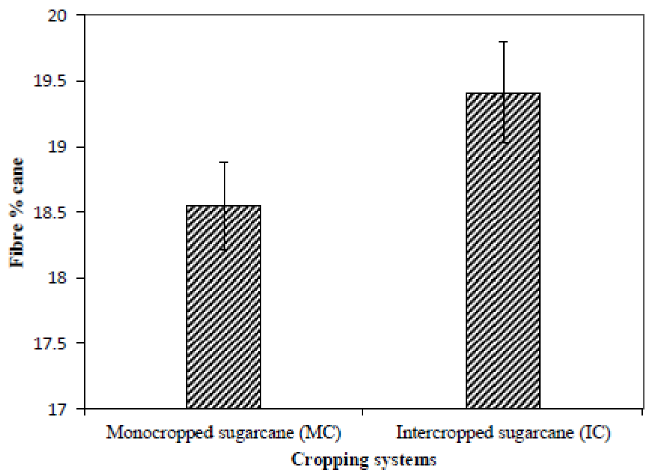
Cropping systems	Fibre % cane
Monoculture sugarcane (MC)	18.55b
Intercropped sugarcane (IC)	19.41a
LSD (P ≤ 0.05)	0.57
CV %	5.5

Means in the same column followed by the same letter(s) are not significantly different at 0.05 level.
Key: CV – coefficient of variation; MC – Sugarcane monoculture; IC – Intercropped sugarcane

Table 6. Effects of lime placement methods on pol % cane and CCS for sugarcane harvested for plant crop cycle

	Sugarcane quality parameters		
Lime Placement Methods	Pol % Juice	Pol % Cane	CCS
LBC	19.23b	14.59b	13.29b
LDB	19.56ab	14.85ab	13.48b
LSB	19.84a	15.09a	13.83a
LSD (P ≤ 0.05)	0.386	0.325	0.336
CV %	2.9	3.2	3.7

Means in the same column followed by the same letter(s) are not significantly different at 0.05 level
Key: CV – coefficient of variation; CCS – Commercial cane sugar



MC – Monocropped sugarcane IC – Intercropped sugarcane and soybean

Fig. 3. Effects of cropping systems on fibre % cane for plant crop cycle

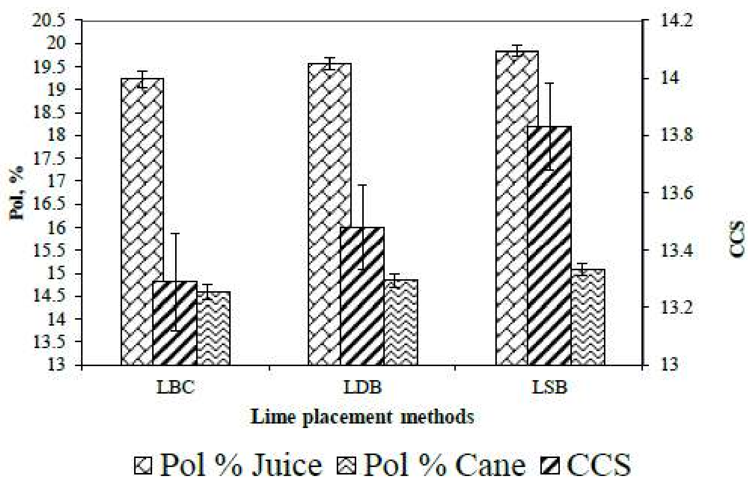


Fig. 4. Effects of lime placement methods on pol % cane, pol % juice and CCS for sugarcane harvested for plant crop cycle

3.4 EFFECTS OF CROPPING SYSTEMS, LIME PLACEMENT METHODS AND LIME RATES ON SUGARCANE YIELD FOR RATOON ONE CROP CYCLE

Ratoon sugarcane crop or stubble emerges after a newly planted sugarcane field has been harvested. The bud and root primordia of the stool develop when ecological conditions are favourable [26]. As the new shoots grow and develop roots, the old roots die and decompose. F – Test probabilities for the effects of cropping systems (CS), lime placement methods (LPM) and lime rate

(LR) on yield components for ratoon one crop harvest is shown in Table 7. The sugarcane yield and yield components for ratoon one crop cycle were not affected by the main treatments (Table 7). Yield of ratoon sugarcane mainly depends on the number of tillers from the previous crop [36]. These tillers translate to the population of stalks at time of harvest. Therefore, the probable reason for non-significance in this study is that population of sugarcane stalks at plant crop harvest were not affected by the treatments applied, so the same was reflected on the yield parameters for ratoon one crop. The interaction effect between the cropping systems and lime rates significantly affected the number of sugarcane stalks, population (Table 7 and Figure 5). Highest population of sugarcane stalks was recorded in plots that were under monoculture x lime rate, 1 t ha^{-1} (Figure 5). The least population of sugarcane stalks was in plots under monoculture x lime rate 2 t ha^{-1}.

Table 7. F – test probabilities for the effects of cropping systems, lime placement methods and rates yield components for ratoon one crop harvest

	Sugarcane stalk			Weight of sugarcane stalks
Source of variation	Girth	Height	Population	Tonnnes Cane per Hectare
CS	0.471	0.232	0.979	0.884
LPM	0.358	0.05	0.340	0.543
LR	0.186	0.238	0.099	0.524
CS x LPM	0.748	0.838	0.555	0.353
CS x LR	0.829	0.995	**0.031**	0.111
LPM x LR	0.252	0.256	0.421	0.556
CS x LPM x LR	0.473	0.168	0.567	0.783
CV (%)	6.3	5.8	12.1	17.9

CS – cropping systems; LPM – lime placement methods; LR – lime rates; CV - coefficient of variation

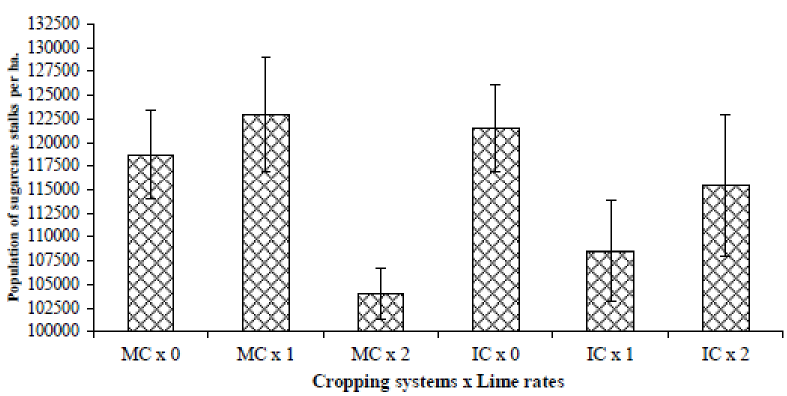


Fig. 5. Interaction effect between cropping systems and lime rates on population of sugarcane stalks per hectare

3.5 EFFECTS OF CROPPING SYSTEMS, LIME PLACEMENT METHODS AND LIME RATES ON QUALITY OF SUGARCANE HARVESTED FOR RATOON ONE CYCLE

F – Test probabilities for the effects of cropping systems (CS), lime placement methods (LPM) and lime rates (LR) on quality of sugarcane for ratoon one harvest is shown in Table 8. Liming significantly affected the purity of sugarcane harvested for ratoon one crop. Sugarcane from lime applied plots showed less purity unlike sugarcane from control plots (Table 9). Sugarcane purity is the % of sucrose in total solids in the juice. A higher purity is a result of higher sucrose content in the total solids present in juice [37]. The findings in this study are contrary to findings of [35] and [34] who observed high purity and high pol % juice (sucrose) in sugarcane from lime treated plots. There was significant interaction effect between LPM and LR on purity of harvested sugarcane (Table 8). Also interactions amongst the CS, LPM and LR significantly affected the brix % juice as shown in bold values in Table 8. For lime rates, sugarcane harvested from plots that received 2 t ha^{-1} showed the least purity while sugarcane from control plots recorded the highest purity as shown in Table 9.

Table 8. F – test probabilities for the effects of CS, LPM and LR on quality of sugarcane for ratoon one crop harvest

Source of variation	F – test probabilities: Sugarcane quality traits — Pol % Juice	Brix % Juice	Purity
CS	0.508	0.634	0.545
LPM	0.289	0.748	0.301
LR	0.367	0.096	**0.014**
CS x LPM	0.472	0.548	0.144
CS x LR	0.852	0.774	0.065
LPM x LR	0.452	0.247	**0.049**
CS x LPM x LR	0.186	**0.028**	0.859
CV (%)	4.2	4.1	1.3

CS – cropping systems; LPM – lime placement methods; LR – lime rates; CV - coefficient of variation

Table 9. Effects of lime rates on purity of sugarcane harvested for ratoon one cycle

Lime rates, t ha^{-1}	Purity
0	97.34a
1	97.42a
2	96.23b
LSD ($P \leq 0.05$)	0.857
CV %	1.3

Means in the same column followed by the same letter(s) are not significantly different at 0.05 levels
Key: CV – coefficient of variation

4. CONCLUSION

In view of the results, the following are concluded: Cropping systems affects sugarcane yields for the plant crop cycle but not for ratoon crop cycle. The high sugarcane yield witnessed under the intercrop system is a result of the benefits of the intercrop cropping system. Lime did not affect the sugarcane yields for the plant crop and ratoon crop cycles. This indicates that lime plays an indirect role in crop growth and yields. Lime plays a direct role on ameliorating soil acidity and nutrient transformations. These effects coupled with other factors then affect crop yields. Lime was found to affect the quality of sugarcane both for the plant crop and also ratoon crop cycles. For example, sugarcane under shallow - banded lime gave the highest pol % cane and commercial cane sugar. There was decreased yield with subsequent crop cycle. It is therefore recommended that, liming is a strategy that ameliorates soil acidity and transforms nutrient availability and has no direct effect on sugarcane yields. Liming as a soil improvement strategy should be integrated with other nutrient improvement strategies such as appropriate cropping and fertilizer use for high yields to be realised. Liming may be a strategy to improve the quality of sugarcane especially with the introduction of payment of sugarcane based on sucrose in addition to weight. However, further studies on the effect of lime on sugarcane quality are recommended.

CONSENT (WHERE EVER APPLICABLE)

ETHICAL APPROVAL (WHERE EVER APPLICABLE)

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