Evaluation of sugarcane cropping systems in relation to productivity at Kibos in Kenya

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Low sugarcane productivity is widespread and has persisted in all zones in western Kenya over the last decade despite the release of many improved sugarcane varieties during the same period. Three sugarcane varieties, two potassium and four nitrogen rates were randomly arranged in a split-split plot design with three replications under two sugarcane cropping systems. Data were collected on chlorophyll concentration, agronomic yields, agronomic efficiencies and quality parameter. The data were managed and subjected to statistical analysis systems (SAS) version 8.2 for analysis of variance (ANOVA); means were separated by least significant difference (LSD) at five percent significant levels. Results showed low chlorophyll concentration except at 13 MAP, inconsistent responses to N and K applied with non significant differences in productivity and agronomic efficiencies under both cropping systems. However, sugarcane quality data indicated that plant crops of all varieties tested should be harvested at 19 MAP. The study recommends use of both integrated nutrient management and improved legume fallows in the current sugarcane cropping systems; this is not only to improve sugarcane productivity but also to enhance nutrient supply through soil organic C improvement. Harvesting sugarcane plant crops at 19 MAP enhances sugar production through maximization of sucrose content.

Key words: Sugarcane productivity, fertilizer rates, sugarcane cropping systems

INTRODUCTION

Kenya sugar industry is a key contributor to poverty reduction and national development [Kenya Sugar Research Foundation (KESREF), 2010]. Low sugarcane productivity has been widespread and persistent in all the growing zones in western Kenya over the last decade [Kenya Sugar Board (KSB), 2012] despite the release of improved sugarcane varieties during the period (KESREF, 2007). This indicates that factors other than sugarcane varieties may be responsible for low productivity. About 13 improved sugarcane varieties have been developed and released for commercial production but their nutrient use efficiencies are unknown. Two of the improved varieties (D8484 and KEN 83-737) are included in the current study. Several research studies indicated low sugarcane productivity as a problem (Odada 1987; Wawire et al., 1987; Nyongesa 1992; KESREF 2002, 2003). But the

Authors have never evaluated the factors that are responsible for low sugarcane production. So, we hypothesized that unsustainable sugarcane cropping systems might be major contributing factors for low productivity. This study focussed on sugarcane cropping systems and their productivities.

The productivity is assessed by various methods such as chlorophyll concentration, agronomic yields and efficiencies. Stalk relative growth in sugarcane occurs when critical leaf N concentration is at least 1.6 % N (Thorburn et al., 2005). Wood et al., (1996) reported that sugarcane photosynthetic rates were positively correlated with the N per unit leaf area value, indicating that an elevation in the N concentration in green leaves allows for increases in stalk production. Allison et al., (1997) reported that photosynthetic rate is associated with a marked increase in

leaf N indicating that N is fundamental element in determining leaf area indices and tiller populations among other sugarcane growth and development parameters. Increase in total biomass is related to sugarcane and sugar yields (Shoko et al., 2007; Shoko et al., 2005). The SPAD readings of at least 40 % of a 10 months and 7 months plant- and ratoon crop respectively indicate that medium to high N content still remains in sugarcane plant, resulting in active vegetative growth, biomass accumulation and high productivity (Okalebo et al., 2002; Barrick et al., 2011). But low soil nutrient levels led to a decrease in sugarcane leaf area index (LAI), resulting in poor photosynthetic efficiency hence low productivity (Shoko et al., 2009). There was a strong and positive correlation (r=0.78; P≤ 0.01) between chlorophyll content and SPAD chlorophyll meter readings (Jangpromma et al., (2010). Further, the Authors also reported that drought significantly reduced chlorophyll content and SPAD chlorophyll meter readings. Chlorophyll concentration consistently reduces in the vegetative parts as the crop approaches final growth phase, implying that crop N requirements are met by N remobilization from older to developing parts of the plant (Almeida de Oliveira et al., 2013).

Primary nutrient elements for sugarcane are nitrogen (N), phosphorous (P) and potassium (K). Of the three nutrients (N, P, and K) nitrate-N is volatile and is not adsorbed by soil particles thereby making it subject to leaching losses. Unlike N, P and K are not volatile and are adsorbed by clay particles. Therefore, P and K are not subject to leaching losses except through eroded soils (Krauss, 2004). If lost to aquatic environment P contributes to eutrophication; whereas there is no practical environmental or health hazard known for K (Krauss, 2004). Nitrogen is important because when applied in in-adequate doses it limits sugarcane productivity while when excessively applied may contaminate underground waters as it is liable to losses through leaching, volatilization and de-nitrification. Sigunga et al., (2002) reported that soil pH especially alkalinity (pH≥ 7.5) was the main inherent characteristic influencing ammonia volatilization in Vertisols. But the Authors used only one soil type and one mode of N loss; other soil types and modes of N losses such as leaching and denitrification were never considered. Nitrogen cycle terms are the major contributors to the acidification under cropping systems, and N fertilizer management is the most critical acidification factor (Moody and Aitken, 1997). Soil N is vulnerable to loss if not taken up by the plant early in the growing season (Robinson et al., 2007). Perhaps current fertilizer use in the sugar industry may not be sustainable. Current fertilizer recommendations such as 100 kg N ha^{-1}; 80 kg P$_2$0$_5$ ha^{-1} and 120 kg N ha^{-1} for plant crops and ratoons (KESREF 2010) respectively are not specific to sugarcane varieties and soil types. Further, the rates were developed for commercial old sugarcane varieties, and have not been reviewed for over a decade; and there has been widespread inappropriate use of

inorganic fertilizers without initial soil tests (Jamoza et al., 2013).

Unbalanced fertilization is a cause of low nutrient use efficiency by plants (Krauss, 2004). Potassium plays a key role in N metabolism, and that plants inadequately supplied with K fail to transport nitrate efficiently to the shoots (Krauss, 2004). Therefore, with inadequate K supply, plant yields remain low since soils depleted in K do not have capacity to supply the element to meet the crop needs. Such K depleted soils have in-efficient N fertilizer use even if recommended doses are applied (Krauss, 2004). Use of K fertilizers in the Kenyan Sugar Industry is minimal, leading to unbalanced nutrition in the current sugarcane cropping systems.

Fertilizer use efficiency (FUE) may also be used to assess productivity. The FUE is yield improvement due to unit weight of nutrient applied. The higher the value the more efficient the nutrient is utilized. Treatment effects that increase stalk population at harvest without also increasing stalk weights are unlikely to increase yields (Bell and Garside, 2005). Low levels of soil organic matter (SOM) contribute to poor crop responses to inputs and it is difficult to maintain yields with inorganic fertilizers alone (Greenland 1994). Best results (in terms of long-term sustained yield response) are those that combine inorganic and organic inputs (Bationo et al., 2012). Use of 5-10 t ha^{-1} of farm yard manure (FYM) in combination with chemical fertilizers at 60 kg N and 60 kg P$_2$0$_5$ ha^{-1} is the most promising integrated nutrient management strategy for long term improvement (Bationo et al., 2012). The current sugarcane growing soils in western Kenya were found to be acidic, inadequate in available nutrients and low in soil organic C, regardless of the cropping systems (Amolo et al., unpublished).

Cropping systems are cropping patterns used in a farm which interact with farm resources, other farm enterprises and the available technology. Cropping systems are sustainable when they involve successful management of resources to satisfy changing human needs while maintaining or enhancing environmental and natural resource conservation [Sugarcane Breeding Institute (SBI), 2011]. Sustainable crop mixtures promote efficient utilization of incident solar radiation, thus exploiting variation between component crops in rates of canopy development, photosynthetic efficiencies and rooting depth (Midmore et al., 1993; Keating and Carberry, 1993).

Fallow sugarcane cropping systems are either natural fallows (farms left under natural vegetation after sugarcane crop) or improved legume fallows where farms are rotated with alternative crops such as grain legumes for 8-12 months (Glaz and Ulloa, 1995). In addition, the fallow systems may also be farms newly introduced to sugarcane for the first time. Natural fallows are common in the sugarcane growing areas but the period varies from a few weeks to months. Long duration natural fallows may contribute to soil fertility improvement. But currently they

are not feasible due to limited and occasioned by population pressure.

Inclusion of improved fallows in the current sugarcane cropping systems may offer some solutions. Reports indicated that the improved fallows had moderate to neutral soil pH, high sugarcane yields; and few or absence of parasitic nematodes (Pankhurst et al., 2004; Glaz and Ulloa, 1995). A pasture break for 7 years increased biological suppression of soil organisms associated with yield decline compared to soil that had been under continuous sugarcane (Pankhurst et al., 2005). Yield improvements of 20-30 % were achieved when sugarcane monoculture was broken with soybean (*Glycine max*), pasture and bare fallow (Garside et al., 1999, 2000, 2002). Further, the yield improvements were associated with improvements on chemical and physical soil properties (Braunack et al., 2003) and biological (Stirling et al., 1996, 1999, 2001; Pankhusrt et al., 1999, 2000, 2003) soil properties, particularly the latter.   Use of legumes in rotation to sugarcane not only provided a source of fixed nitrogen but also soil health improvement (Garside et al 1996, 1997c, 1998; Noble and Garside, 2000). Simulation studies suggested that legume N was available to the sugarcane crop up to the fourth ratoon, resulting in potential reductions in fertilizer application rate that could be approximately 100% in the first ratoon, and 60%, 25% and 10% in the subsequent ratoons (Sarah et al., 2010).

A common sugarcane cropping system is monoculture where the crop is continuously or successively grown for many years followed by a short duration of natural fallow period for land preparation in readiness for the next crop (Glaz and Ulloa, 1995). Successive systems were unsustainable since they harbored deleterious fungi and nematodes which retarded plant establishment and early growth leading to decline in sugarcane productivity (Pankhurst et al., 2005). Further, soils of the successive systems had high bulk densities, low pH values, low labile organic carbon (C), low cation exchange capacity (CEC) and manganese (Mn), low copper (Cu) and zinc (Zn) but high exchangeable aluminium (Al) (Antwerpen et al., 2007). But in Kenya sugarcane cropping systems have not been evaluated in relation to productivity.

MATERIALS AND METHODS

Site characteristics

Kibos site (0° 04'S; 34° 48'E; 1184 m altitude) is situated 16 km North East of Kisumu City in western Kenya and has a sub-humid climate with the following long term climatic parameters: 1476.5 mm annual average rainfall, 5.2 mm evaporation, 26.5 MJm^{-3} radiation, 7.2 hours sunshine, 60 % mean relative humidity and 22.5°C mean daily temperature. Experimental location one was on a Cambisol soil series (Jaetzold et al., 2007) on a farm which been under

natural fallow for over five years. Location two was a Vertisol soil series (Jaetzold et al., 2007) and the farm had continuously been under sugarcane cultivation for over 20 years. Soils of the two experimental locations at Kibos site were slightly acidic (soil pH_w 6.1) with a strong exchangeable acidity (soil pH_{KCl} 5.1), and had low soil organic carbon (C) of 1.1 %. Other soil parameters were not reported because the samples were erroneously discarded before analysis completion.

Three sugarcane varieties D 8484, KEN 83-737 and Co 421 as a early, medium and late maturity classes respectively were planted in the main plots having sizes of 67.2 and 57.6 m^2 in location one and two respectively; two K rates (0 and 50 kg K_2O ha^{-1}) in Potash form (60 % K_2O) were applied in sub-plots at time of planting. Four N rates (0, 50, 100 & 150 kg N ha^{-1}) in Urea form (46% N) were applied in sub-sub plots at five months. The treatments were randomly arranged in split-split plot design and replicated three times at the two locations. Three budded setts (12-14 months healthy seedcane) of the three sugarcane varieties were laid end to end furrows spaced at 1.2 m. Phosphorous [di-ammonium phosphate] (DAP) (46 % P_2O_5 and 18 % N) was applied in all plots at rate of 80 kg P_2O_5 ha^{-1} on planting time. Weed control was manually executed five times until the crop formed canopy when it was able to smother weeds, thereafter border maintenance was executed when necessary until harvest time to ensure cleanliness.

In both locations, data were collected on chlorophyll concentration (% SPAD reading) at 5, 6, 8, 9,10,11,13 14, 15 months after planting (MAP), and prior to harvest for each variety as proposed by (Kieffer, 2009). Each variety was harvested at its maturity (D 8484, KEN 83-737 and Co 421 at 16, 18 and 20 MAP respectively) by cutting mature stalks at the base within the net plots, millable stalks weighed by Salter balance and their numbers manually counted. Sugarcane yields in tones per hectare (t ha^{-1}) were computed as follows: cane weight (kg/net plot) divided by net plot size in m^2 multiplied by 10. Fertilizer use efficiency (FUE) was calculated by using the formula FUE = (Yf-Yo)/FN (Simmonis, 1988). Data was also collected on sugarcane quality (Pol % juice) according to Bureau of Sugar Experiment Stations (BSES) (1970). The Pol % juice was expressed as percent juice instead of percent cane. The data was managed and subjected to statistical analysis systems (SAS) version 8.2 for analysis of variance (ANOVA); means were separated by least significant difference (LSD) at five percent significant levels.

RESULTS

Effects on chlorophyll concentration

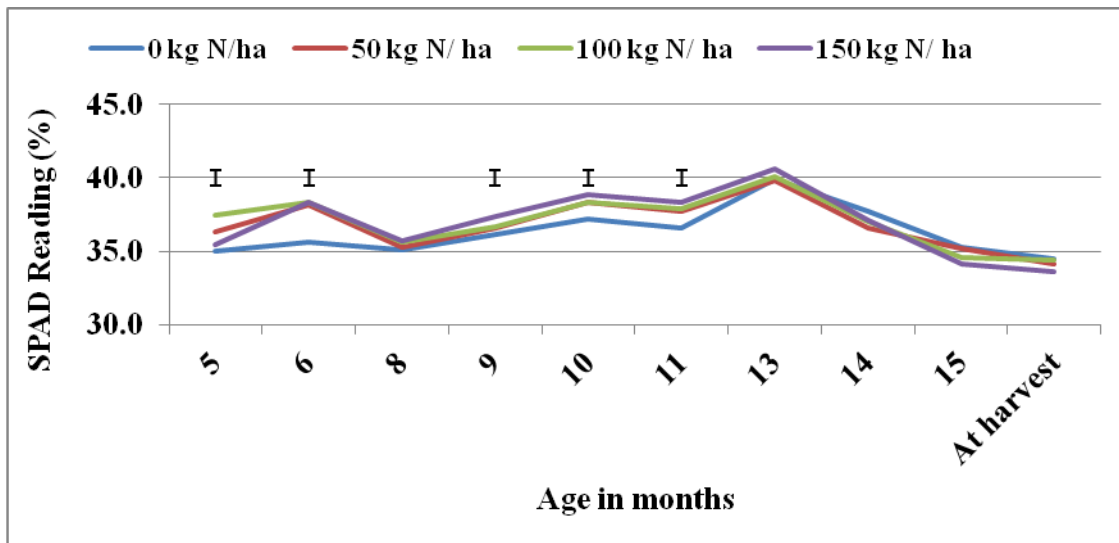Nitrogen application significantly (P≤0.05) increased chlorophyll concentration at 5, 6, 9 and 11 MAP compared

Figure 1: Effects of nitrogen rates on chlorophyll concentration averaged over two sites, three sugarcane varieties and two potassium rates; means of three replications
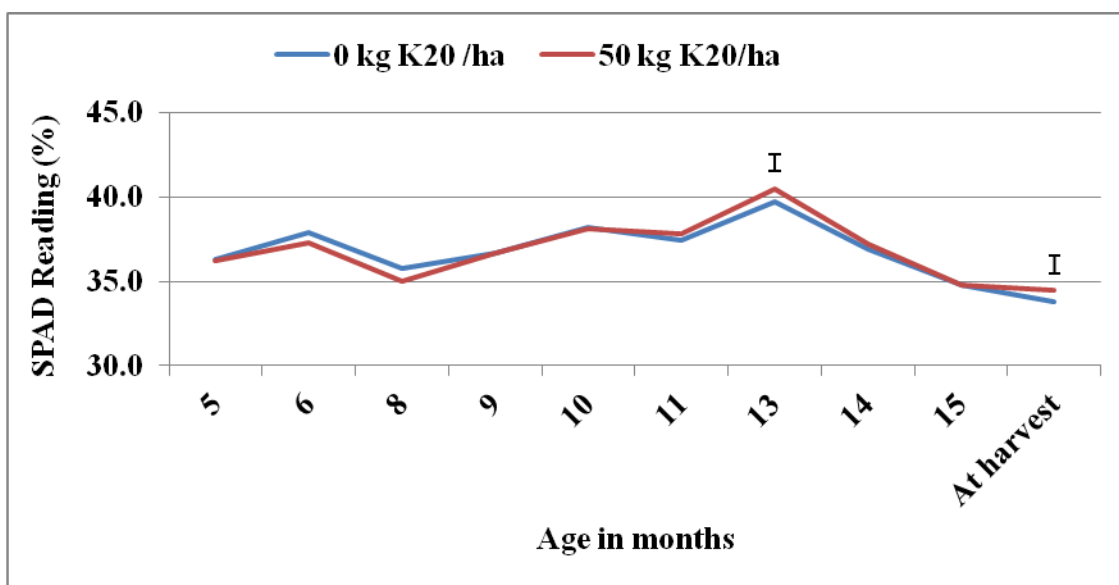

Figure 2: Effects of potassium rates on chlorophyll concentration averaged over two locations, three sugarcane varieties and four nitrogen rates; means of three replications

to the control (0 kg N ha^{-1}), reaching the peak at 13 MAP (Figure 1). However, there was depressed chlorophyll concentration at 8 MAP for all N rates including the control (Figure 1).

Potassium application only significantly (P≤0.05) increased chlorophyll concentration at 13 MAP and at harvest (Figure 2). Sugarcane variety KEN 83-737 was superior in chlorophyll concentration throughout the growing period (Figure 3). But all varieties reached their peak chlorophyll concentration at 13 MAP thereafter there was a drastic drop till harvest (Figure 3). At 8 MAP all

sugarcane varieties showed depressed chlorophyll concentration (Figure 3). Location two (successive sugarcane cropping systems) was superior to location one (natural fallows) in chlorophyll concentration from 6 to 9 MAP, reaching the peak at 13 MAP, then followed by a drastic drop till harvest (Figure 4). Whereas there was depressed chlorophyll concentration values at location one at 8 MAP, similar depressed values were observed at location two at 11 MAP (Figure 4). There were no significant interactions among the factors tested in relation to chlorophyll concentration.
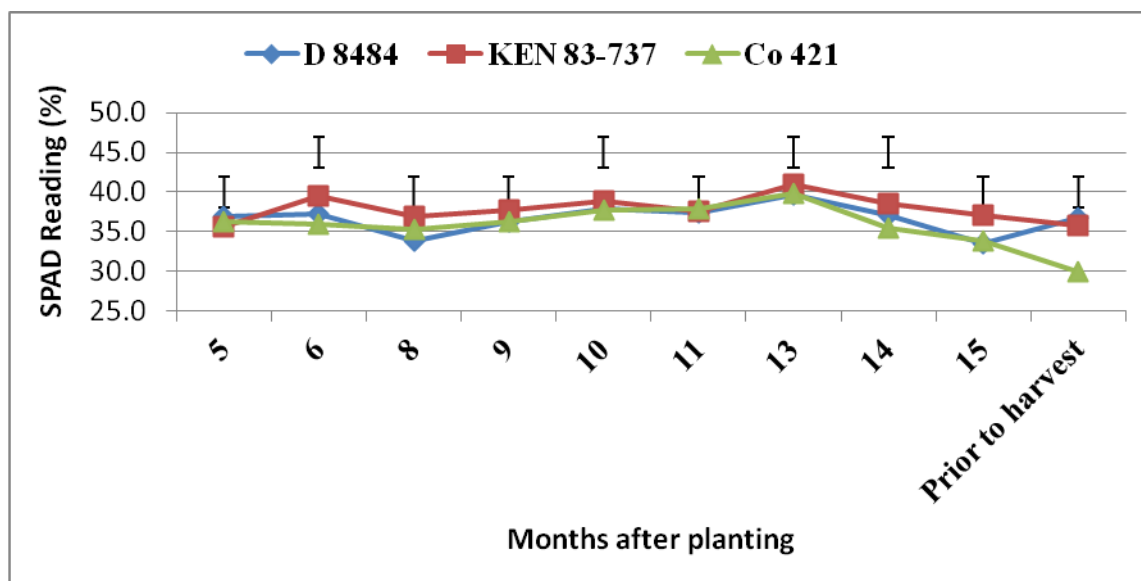
Figure 3: Effects of three sugarcane varieties on chlorophyll concentration averaged over two locations, two potassium and four nitrogen rates; means of three replications
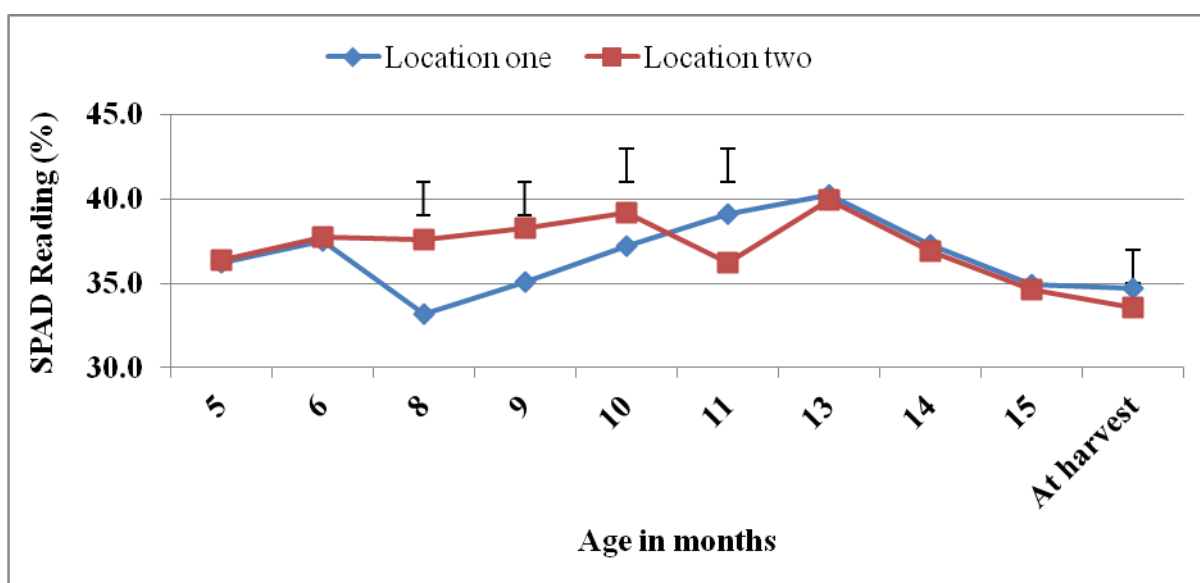

Figure 4: Chlorophyll concentration averaged over three sugarcane varieties, two potassium and four nitrogen rates under two locations; means of three replications
*Location one- natural fallow systems; Location two- successive sugarcane cropping systems

Effects on sugarcane yields

Sugarcane variety KEN 83-737 was superior in yields under the two cropping systems, followed by variety D 8484 and variety Co 421 (Table 1). Overall response to N application was not significant averaged over two K rates, three sugarcane varieties and two cropping systems (Table 1). Only sugarcane variety D 8484 significantly (P≤0.05) responded to K application; response of variety KEN 83-

737 was not significant while yields of variety Co 421 were depressed by K application under the cropping systems (Table 1).

Sugarcane variety KEN 83-737 significantly (P≤ 0.05) responded to K application under 0 and 50 kg N ha^{-1} input, and also responded to 100 and 150 kg N ha^{-1} input at 0 kg K_2O_5 ha^{-1} application (Table 1). Variety D 8484 responded to K application only at 100 kg N ha^{-1} (Table 1). Yields of variety Co 421 were consistently suppressed by K

Table 1: Yields of three sugarcane varieties tested with two potassium (K) and four nitrogen (N) rates in two locations at Kibos site; means of three replications

	Sugarcane varieties	K-rates (Kg K$_2$0 ha^{-1})	0	50	100	150	K-rate means	Sugarcane variety means	Location means
Location One	D 8484	0	82.6	145.2	99.8	104.2	108.0		
		50	114.0	113.6	128.6	124.3	120.1		
	N-means		98.3	129.4	114.2	114.3		114.0	
	KEN 83-737	0	125.7	119.7	144.6	157.1	136.8		
		50	153.6	150.1	143.1	125.1	143.0		
	N-means		139.7	134.9	143.9	141.1		139.9	
	Co 421	0	100.3	102.1	104.8	97.7	101.2		
		50	89.7	92.2	94.3	76.5	88.2		
	N-means		95.0	97.2	99.6	87.1		94.7	116.2
Location Two	D 8484	0	124.2	107.7	109.0	78.9	105.0		
		50	120.3	101.6	141.9	99.4	115.8		
	N-means		122.3	104.7	125.5	89.2		110.4	
	KEN 83-737	0	118.2	108.9	134.7	152.0	128.5		
		50	151.2	136.6	123.8	134.1	136.4		
	N-means		134.7	122.8	129.3	143.1		132.4	
	Co 421	0	93.4	124.4	82.5	128.4	107.2		
		50	92.2	107.9	115.9	107.3	105.8		
	N-means		92.8	116.2	99.2	117.9		106.5	116.4
	Overall N-means		113.8	117.5	118.6	115.5			
	LSD $_{(0.05)}$:						14.8	10.5	12.8	10.5

R^2 - 0.52; CV %   - 27.1

Location one- natural fallow systems; Location two- successive sugarcane cropping systems

application except at 100 kg N ha^{-1} (Table 1).

Effects on agronomic efficiency

All sugarcane varieties achieved poor (very low to negative) agronomic efficiencies regardless of N or K application rates, and the cropping systems (Table 2). All treatment effects and their interactions were not significant (Table 2). Similarly cropping systems were not significantly different in their agronomic efficiency (Table 2)

Effects on sugarcane quality (Pol % juice)

All sugarcane varieties reached their peak Pol % juice (sucrose content) at 19 MAP thereafter there was a steady reduction in sucrose content as the varieties approached 24 MAP regardless of the cropping systems (Figure 5).

DISCUSSIONS

For all varieties tested under the two cropping systems, peak chlorophyll concentration for plant crop was at 13 MAP (Figure 1, 2, 3, 4), and was not consistent with the findings at 10 MAP
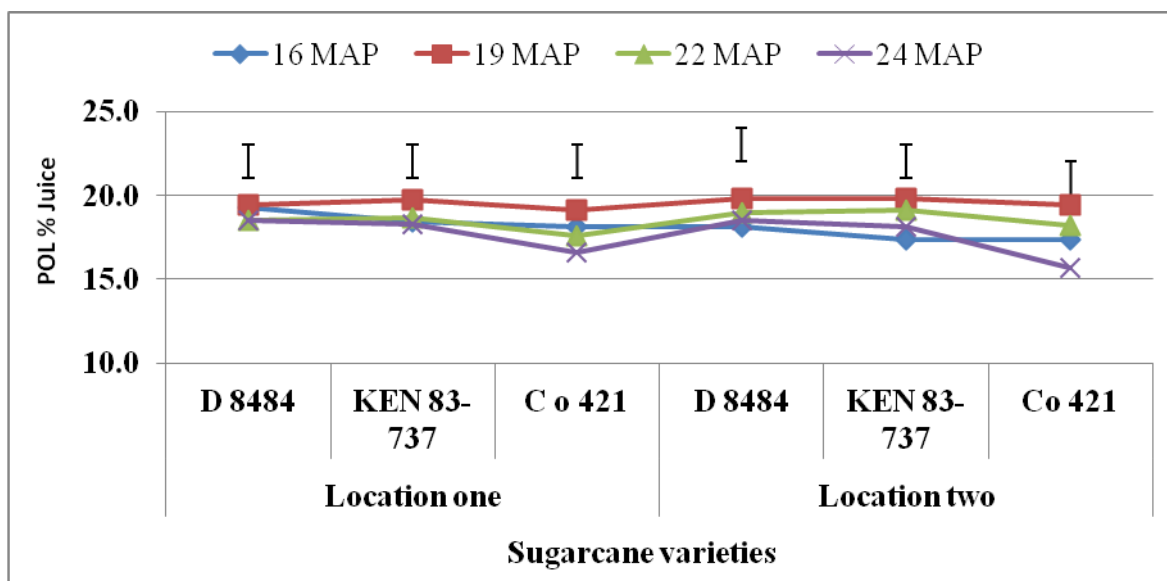
Figure 5: Effects of sugarcane varieties on Pol % juice; averaged over all K and N rates in two locations at Kibos site
*Location one- natural fallows; Location two- successive sugarcane cropping systems

as was reported by Okalebo et al., (2002). Both 10 and 13 MAP represents mid season growth phase for sugarcane development under Kenyan conditions. A steady decline in chlorophyll concentration after 13 MAP in both cropping systems, K and N applied indicated less leaf N associated with N re-mobilization from older to developing parts of the varieties. This was in agreement with Almeida de Oliveira et al., (2013) who reported that chlorophyll concentration consistently reduces in the vegetative parts as the crop approaches final growth phase, implying that crop N requirements are met by N remobilization from older to developing parts of the plant. Depressed chlorophyll concentration at 8 and 11 MAP at locations one and two respectively may be due to variation in soil moisture. This was in agreement with Jangpromma et al., (2010) who reported that drought significantly reduced chlorophyll content and SPAD chlorophyll meter readings.

Sugarcane variety KEN 83-737 was superior in chlorophyll concentration (Figure 3), resulting in superior yields under the two cropping systems (Table 1). Low chlorophyll concentration identified in the study is in agreement with Shoko et al., (2009) who reported that low soil nutrient levels led to a decrease in sugarcane leaf area index (LAI), resulting in poor photosynthetic efficiency (chlorophyll content) hence low productivity.

Lack of overall response to N application (Table 1), averaged over all varieties and K application under the two cropping systems was an indication of inadequate soil N for the crop, and this may be attributed to N losses either through leaching or ammonia volatilization. But we may dismiss N losses due to volatilization because slightly acidic soil pH might not favor it. However, soils of low to moderate organic matter predispose nitrate-N to losses

through leaching. Organic matter has a greater cation exchange capacity than a similar mass of clay, giving it a strong capacity to attract nutrients and to act as a potential source of N, P and S through mineralization. Soils of the two experimental locations had low soil organic carbon (1.1 % C), indicating that there may be losses of nitrate–N despite application. This was in agreement with Greenland (1994) who reported that at low soil organic matter, crop response to inputs is relatively poor and it is difficult to maintain yields with inorganic fertilizer alone. But other soil parameters were not reported because the samples were erroneously discarded before complete analysis. The result of low soil organic C was in agreement with previous work on soil nutrient survey in western Kenya which indicated that sugarcane growing soils in western Kenya were inadequate in nutrients due to increased soil acidity and low to moderate soil organic carbon contents (Amolo et al., unpublished). Adoption of integrated nutrient management (use of organic materials and inorganic fertilizers in combination) may improve productivity of current sugarcane cropping systems. Bationo et al., (2012) reported that integrated nutrient management was the best option to sustain crop yields in the long-term. It is hypothesized that there could be heavy nutrient losses especially nitrate-N under the current sugarcane cropping systems following fertilizer N application, requiring further investigation. Sigunga et al., (2002) reported that soil pH, especially alkalinity (pH≥ 7.5), was the main inherent characteristic influencing ammonia volatilization in Vertisols. But the Authors did not include studies on other soil types and modes of N losses such as leaching and denitrification.

Poor agronomic efficiencies achieved under the two cropping systems (Table 2) further confirmed that the

Table 2: Agronomic Efficiency of sugarcane varieties tested with two potassium (K) and four nitrogen (N) rates across two locations at Kibos site; means of three replications

	Agronomic Efficiency (tones cane per kg nutrient applied)						K-rate means	Sugarcane variety means	Location means
			N-rates (kg N ha-1)						
Location One	Sugarcane varieties	K-rates (kg K2O ha-1)	0	50	100	150			
	D 8484	0	0.00	1.25	0.17	0.15	0.39		
		50	0.82	0.57	0.47	0.28	0.54		
	N-means		0.41	0.91	0.32	0.22		0.46	
	KEN 83-737	0	0.00	-0.12	0.15	0.19	0.06		
		50	0.56	0.49	0.09	-0.12	0.26		
	N-means		0.28	0.19	0.12	0.04		0.16	
	Co 421	0	0.00	0.04	0.05	-0.02	-0.20		
		50	-0.21	-0.16	-0.06	-0.15	-0.15		
	N-means		-0.11	-0.06	-0.01	-0.09		-0.06	0.19
Location Two	D 8484	0	0.00	-0.33	-0.15	-0.30	-0.20		
		50	-0.08	-0.45	0.18	-0.17	-0.13		
	N-means		-0.04	-0.39	0.02	-0.24		-0.16	
	KEN 83-737	0	0.00	-0.19	0.17	0.23	0.05		
		50	0.66	0.37	0.06	0.11	0.30		
	N-means		0.33	0.09	0.12	0.17		0.18	
	Co 421	0	0.00	0.62	-0.11	0.23	0.19		
		50	-0.02	0.29	0.23	0.09	0.15		
	N-means		-0.01	0.46	0.06	0.16		0.17	0.06
	Overall N-means		0.15	0.20	0.11	0.05			
	LSD (0.05):						NS	NS	NS	NS
	R² - 0.96								

Location one- natural fallow systems at Kibos site; Location two- successive sugarcane cropping systems at Kibos site

cropping systems were not different and soil nutrients required by the crop might not be adequate. Low to moderate organic C (1.1 % C) was an indication that the soils could be poor in nutrient retention.

Plant crops of all varieties tested attained maximum quality (Pol % juice) at 19 MAP (Figure 5), indicating that harvesting operations beyond 19 MAP may not be economical because there may be cane and sugar losses due to stalk death especially for varieties D 8484 and KEN 83-737. Plant crop maturity of variety Co 421 at 19 MAP was contrary to a general perception that it was of late maturity (20 - 24 MAP) (KESREF 2007), and that it maintains its quality over long period of time.

Conclusions

Our study demonstrated that the current sugarcane cropping systems were not different in productivity. There was also lack of overall consistent responses to applied K and N, lack of significant differences in sugarcane productivities and poor agronomic efficiencies. Sugarcane variety KEN 83-737 was superior in chlorophyll concentration and yields under the two cropping systems. All sugarcane varieties reached their peak Pol % juice (sucrose content) at 19 MAP followed by a drastic reduction in sucrose content in all varieties tested under the

two cropping systems.

RECOMMENDATIONS

The study recommends use of both integrated nutrient management and improved legume fallows in the current sugarcane cropping systems; this is not only to improve sugarcane productivity but also to enhance nutrient supply through soil organic C improvement.

Harvesting plant crops of all maturity classes of sugarcane varieties should not exceed 19 months after planting for improved sugar production regardless of the cropping systems.

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