COMPARISON OF VARIATIONS IN SOIL-FOLIAR NUTRIENTS LEVELS AND PRODUCTIVITY OF THREE RATOON-SUGARCANE CULTIVARS DUE TO NITROGEN-POTASH RATES AND HARVESTING AGE IN WESTERN KENYA

BY

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DECLARATION

I declare that this thesis is the result of my own research except as cited in the references. The report has not been accepted or submitted in candidature of any other degree anywhere.

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DEDICATION

I dedicate this work to my late son Washington Otieno Oginga, late father Dishon Nyandere Okongo and loving daughters Alma, Christine, Cynthia and Lauryn.

ABSTRACT

Sugarcane productivity in Kenya has declined despite increased acreage and new cultivars possibly due to use of old-cultivar agronomic inputs. The N-K_2O optimal rates for new cultivars are unknown. Kenya Sugar Industry intends to pay farmers based on sucrose instead of tonnage however, factors that influence productivity e.g. N-K_2O rates and harvesting age have not been evaluated. Foliar analysis is a diagnostic tool, but has not been embraced. The objective was to compare variations in soil-foliar nutrients levels and productivity of three ratoon-sugarcane cultivars due to N-K_2O rates and harvesting age**.** Design was 3x4x2 split-split plot, four replications (CO421-control) and test cultivars (KEN82-472 and KEN83-737) in main plots; 0-50-100-150kg N/ha (sub-plots), 0-100kg K_2O/ha (sub-sub plots-6x10m; 8 rows-1.2m apart). The trial was a continuation of an experiment on sugarcane plant crop at Kibos. Soil-foliar analyses, yields and quality were done using standard methods. Cultivars significantly ($p \leq 0.05$) influenced soil K at 0-15cm depth (post-harvest) indicating that ratoon had higher K-extracting ability than plant crops. Only K_2O applications significantly ($p \leq 0.05$) varied both pH and soil nutrients implying that it was inadequate. Cultivars recorded higher increments in foliar nutrients of new cultivars than in the old from 3^{rd} - 6^{th} MAR with the peak at 5^{th} MAR, but nutrients levels declined afterwards. This showed that foliar contents are cultivar dependent and foliar sampling conducted later than the 5^{th} MAR would give lower levels. Nitrogen and potash significantly increased foliar contents with 100kg N-K_2O rates. Cultivars significantly ($p \leq 0.05$) influenced yields with new cultivars having higher yields than control. Increasing N-K_2O rates significantly increased yield with 100kg N-K_2O/ha recording the highest. Cultivars and N-K_2O rates significantly ($p \leq 0.05$) increased pol%, brix% and commercial cane sugar (CCS%) between 10-16^{th} MAR with the peaks at 14^{th} MAR. After the peaks, the quality depreciated more rapidly in new than old cultivars. The regression showed maximum CCS% of 11.88% and above 14.3% for CO421 and test cultivars at 13^{th} and 12^{th} MAR respectively; which illustrated that cultivars benefited from N-K_2O applications. The $R^2 > 0.85$ meant that CCS% may be used to predict harvesting time. Frequent soil analysis may not be necessary because treatment effects can manifest after a longer time while foliar sampling can be conducted before the 5^{th} MAR. Proper cultivar selection be done, 100kg N/ha be maintained, K_2O application be re-introduced while new and old cultivars be harvested at 12^{th} and 13^{th} MAR respectively; for realization of higher ratoon-cane productivity.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ANNEXES

ABREVIATIONS AND ACRONYMS

ADP	Adenosine diphosphate
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
BSES	Bureau of Sugar Experiment Station
CNL	Critical nutrient level
CCS%	Commercial cane sugar %
CO	Coimbatore
DRIS	Diagnosis and recommendation integrated system
FAO	Food and Agriculture Organization
ICUMSA	International Commission for Uniform Methods of Sugar Analysis
Kg/ha	Kilogram per hactare
KALRO	Kenya Agricultural and Livestock Research Organization Foundation
KEN	Kenya

KESREF	Kenya Sugar Research Foundation
SRI	Sugar Research Institute
KSI	Kenya Sugar Industry
LM	Lower midland
MAP	Months after planting
MAR	Months after ratooning
$p \leq 0.05$	Confidence level
pH	Potential hydrogen
Pol	Polarization
SAS	Statistical Analysis System
TCH	Ton cane per hectare
TVD	Third visible dewlap

CHAPTER 1

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is a perennial grass belonging to the family Graminae/ Poceae (Muhammad *et al.*, 2013). Modern canes are inter-specific hybrids of *Saccharum spp*. that have arisen through breeding of species of the *Saccharum* involving crosses between *S. officinarum* and *S. spontaneum* (Cox *et al.*, 2000). Sugarcane accumulates sucrose in the stem and can be harvested over three to six cycles (ratoons) before replanting (Salassi *et al.*, 2000). It is a valuable plant for sugar production among other genera (Lingle *et al.*, 2000). Sugarcane is cultivated in the warm tropical and sub-tropical regions of the world where the prevailing temperatures, humidity and sunlight intensity favour its germination, tillering, vegetative growth and maturity (Plaut *et al.*, 2000). Such regions include Brazil, China, India, Pakistan, U.S.A and Kenya. In Kenya, sugarcane is cultivated in western (Migori, Kisumu, Kakamega, Bungoma and Busia Counties) and some parts of coastal region including Mombasa and Kwale Counties (KESREF, 2007).

Sugarcane and its co-products contribute to the world economy as food, fodder, fibre, fuel and fertilizer and about 60% of world sucrose comes from sugarcane (Hunsigi, 1993). For India, about 70% of the harvested sugarcane is used to produce sugar and 30% for the production of alternate sweeteners and for seeds (Raju *et al.*, 2009). In Brazil, ethanol as a by-product of cane is used as a motor fuel while bagasse is used for the manufacture of paper and chip boards (Lingle *et al.*, 2000). Trash is a mulch and low- grade cattle feeds in Queensland, Australia (Dawson, 2002). In Kenya, cane provides sugar as the calorie component (Wawire *et al.*, 2006).

Furthermore, it supplies fodder, press mud (organic fertilizer) and is a source of employment to a larger sector of the rural population (CBS, 2004b). Sugarcane is ranked 3rd as a single commodity contributing to the economy after tea and coffee (KESREF, 2008).

Globally, sugarcane has been cultivated on over 2.4 x 10^6 ha, harvested in three to six cycles (ratoons) with a production of 1.7x10^9 ton cane per hectare (TCH), consequently supplies approximately 70% of the world's sugar (Salassi *et al*., 2000). However, this production is lower than the achievable potential of existing cultivars (KESREF, 2010) among the main world producers such as Brazil, China, India, Pakistan and U.S.A (Plaut *et al*., 2000). In Kenya, the total area under cane (Figure 1a) expanded from 145,000 to 215,000 ha while yields (Figure 2b) declined about 73 to 51 TCH during 2005-2014 periods. The expansion in acreage is attributed to opening up of several new small-scale farming areas under sugarcane cultivation (CBS, 2002).

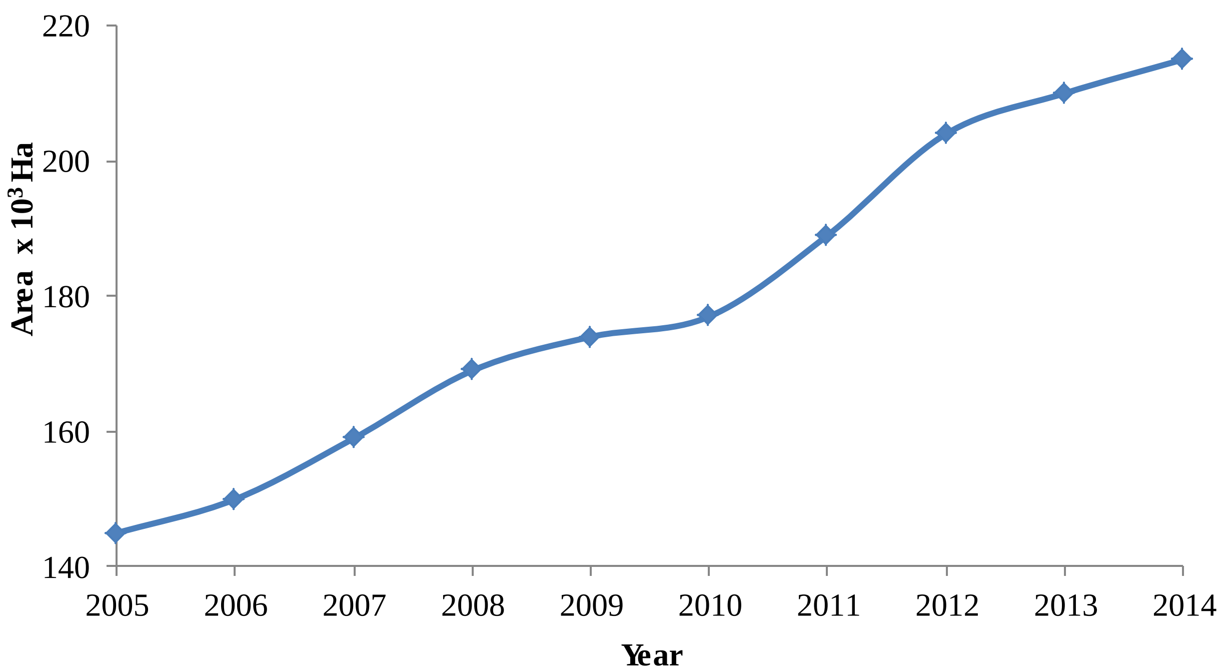

Figure 1a: Trends in area under sugarcane (2005 to 2014); *Source:* KSB, 2015

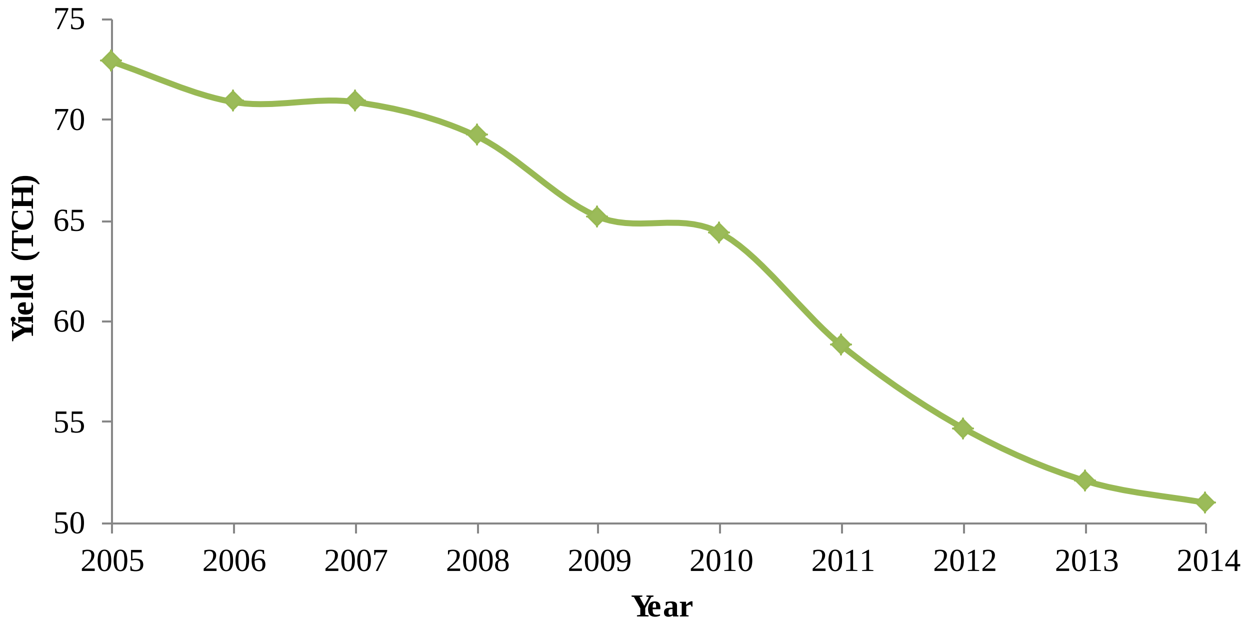

Figure 1b**:** Yield trends of sugarcane (2005 to 2014); *Source:* KSB, 2015

During the same period, quality dropped from 15.5 to 13.5% pol (KSB, 2015). In mitigation, new cultivars such as KEN82-472 and KEN83-737 were released (Jamoza, 2005). They are faster-maturing and higher yielding cultivars scheduled for harvesting before the 18th month after ratooning (MAR) (KESREF, 2007). Despite this intervention, low yields have persisted (Amolo *et al*., 2006) and attributed to management practices that are not optimized with regard to cane plant crops in the Kenya Sugar Industry (KSI) (Ochola *et al*., 2014). However, factors responsible for the low productivity have not been ascertained.

The decline in soil fertility due to depletion of macro (N, K and P) and micro-nutrients (Ca, Fe, Mn and Zn) cause low cane production in Australia (Bell *et al*., 2001; Garside *et al*., 2003). Macro-nutrients are vital for vegetative growth and development while micro-nutrients help in the absorption of various cane plant assimilates (Ehsanulla and Iqbal, 2001; Rice *et al*., 2002).

The availability of the soil nutrients is reported to be influenced by many factors including cultivars (Bischoff and Gravis, 2004), N and K_2O fertilizations (Yadav and Prasad, 1992). Sugarcane cultivars have different nutrients extracting abilities (Chattha *et al.*, 2006) and may have direct influences on nutrients availability. It has not been determined how new early maturing cultivars may extract nutrients levels. Nitrogen is vital for cane production (Singh *et al.*, 2007) and World N rates for cane range is 45-300 kg N/ha (Srivastava and Suarez, 1992). In North America (Snyder and Bruulsema, 2007), early maturing cultivars require different N rates. The current 100 kg N/ha used in Kenya was developed in 1980s and is applied in a single dose for both plant and ratoon crops of the newer cultivars (Amolo *et al.*, 2006). However, it has not been evaluated if N fertilizer rates would vary soil pH and nutrients levels and still be beneficial to the new cultivars. The ratoon sugarcane demands for potassium are greater than other essential elements as potassium is required for sugarcane maturity (Abayomi, 1987). However, in the Kenya Sugar Industry, current fertilization regime is devoid of the recommended 100 kg K_2O/ha since it was discontinued in mid 1980s due to lack of yield responses to K_2O on the old cultivars (Amolo *et al*, 2006).

In the subsequent years, K deficiency had manifested in several sugarcane growing fields in Kenya (Jaetzold *et al.*, 2005) possibly due to long-term mono-culture with sugarcane crop. The continuous use of ammonium N is usually accompanied by high leaching of K (Lee and Jose, 2005). In a recent study, Ochola (2013) and Ochola *et al.* (2014) reported yield responses to potash (K_2O) application to plant crops of the new cultivars, but, the K demand of the ratoon crops of the new KEN series has not been established. It has not been evaluated if potash application can be re-introduced to the ratoon crops of the new cultivars.

Foliar nutrients analysis has been widely used to optimize and formulate fertilizer programs (Miles *et al.*, 2010). If carried out timely, the analysis would allow for early interventions before nutrients deficiencies and imbalances can affect the production. The critical nutrient concentration (CNC) and Diagnosis and Recommendation Integrated System (DRIS) are currently used in foliar data interpretations (Ambachew *et al.*, 2012). However, numerous misinterpretations of foliar data have been reported (Miles *et al.*, 2010). Nutrients levels may be influenced by other factors including crop age and agronomic inputs such as N and K_2O fertilizer applications (Mengel and Kirkby, 2001). Consequently, sampling is done at a ratoon crop age of six weeks after fertilization, (Schroeder *et al.*, 1999). In Queensland/New South Wales, effective sugarcane ratoon foliar sampling ages of 3 - 5 and 4 - 7 months after ratooning (MAR) respectively had been recommended (Schroeder *et al.*, 1999). However, the recommendations were based on agronomic husbandry under sub-tropical conditions. In the tropical areas, such as in Kenya, optimal sampling time ranged between 4 - 7th MAP in sugarcane plant crops (Ochola, 2013). However, data to develop foliar analysis nutrient guide is lacking for Kenya Sugar Industry. Nitrogen fertilizer rates affect foliar nutrient contents during the growth regime with some fluctuations across sampling time (Muchovej and Newman, 2004a). For instance, foliar K levels increased with time during the 1st ratoon crop while N, P and the micro-nutrients were not affected by N rates (Muchovej and Newman, 2004b).

Foliar N and K levels markedly increased in third visible dewlap tissues with increasing the N rates (Ahmed *et al.*, 2009). In Kenya, N rates significantly increased foliar nutrients levels in cane crops with 100 kg N/ha giving the highest level (Ochola, 2013). It has not been assessed how N rates would vary with sampling period of the ratoon cane cultivars.

Potassium fertilizer application increased foliar nutrient levels in various studies (Malavolta, 1994; Singh and Jha, 1994). The 100 - 120 kg K_2O/ha, significantly increased foliar contents of both macro- and micro-nutrients levels in plant cane crops (Gascho *et al.*, 1983; Ezenwa *et al.*, 2008). In Kenya, Ochola (2013) indicated that potash fertilizer application did not affect nutrients levels in foliar tissues of early and late maturing sugarcanes plant crops. However, it is not known how K_2O rates may vary foliar nutrients contents in new and early maturing ratoon sugarcane crops. However, it has not been evaluated if K_2O rates would vary with sampling period of the ratoon cane cultivars.

The ratoon cultivars mature at different ages in different locations (Salassi, 2000). Early maturing cultivars mature between 8 - 10 months in India (Blackburn, 1984), 10 - 11 months in Indonesia (Gonzales and Galvez, 1998) and 12 - 14 months in Mauritius (Domaingue *et al.*, 1998). The late and early maturing ratoon cultivars are harvested after and before the 18th MAR in Kenya (KESREF, 2002) respectively. In Western Kenya, plant crops of early maturing and high quality cultivars such as KEN82-472 and KEN83-737 are harvested between 15 - 16th MAP for optimum sucrose yield (Ochola, 2013) while ratoon-sugarcane at the 16th MAR (KESREF, 2005). However, with respect to ratoon productivity, the consequences of harvesting the new ratoon cultivars earlier or beyond 16th MAR are not known.

Currently, KSI pays farmers based on weight of cane (KESREF, 2008). This payment system does not guarantee quality and consequently leading to low sugar recovery. In mitigation, KSI has proposed (Sugar Act, 2001) sucrose-based payment. Cultivars and agronomic practices such as N-K_2O rates were reported (Mengistu, 2013; Muhammad *et al.*, 2013) to influence quality.

Harvesting of plant cane of the new KEN series between 15 - 16th MAR significantly yielded higher sucrose (Ochola, 2013). However, it has not been evaluated if the payment system shall be affected by ratoon cultivars, N-K_2O rates and harvesting age.

1.1 Statement of the problem

Cultivars have varying abilities to extract soil nutrients, but it is not known how new cultivars would extract nutrients. Nitrogen is vital for production, but its appropriate rate for new cultivars is unknown. Application of N fertilizers changes soil chemistry, but the changes due to new cultivars have not been documented. Potassium is required for cane maturity, but K_2O application was discontinued. Lack of K has manifested in many soils but, it is not known if K_2O should be re-introduced. Foliar analyses are used to guide fertilizer regimes and foliar nutrients levels are influenced by crop age and N-K_2O rates. However, it has not been assessed if N-K_2O rates vary with sampling period. Despite increased acreage under cane and release of new cultivars with superior attributes (early maturity and high yield), decline in sugarcane productivity has persisted. New cultivars are subjected to agronomic inputs such as N-K_2O rates which are meant for old cultivars but without suitability tests. The Kenya Sugar Industry proposes sugar-based payment policy instead of the current tonnage-based system. Agronomic factors like cultivars, N-K_2O rates and harvesting period may influence quality. It is not known if these factors may affect the proposed payment system.

1.2 Objectives

1.2.1 Broad objective

To compare variations in soil-foliar nutrients levels, yield, quality and appropriate foliar sampling and harvesting time of the three ratoon-sugarcane cultivars due to N-K_2O rates.

1.2.2 Specific Objectives

i. To compare variations in soil pH and nutrients (N, P, K, Ca, Fe, Mn and Zn) levels before ratooning and after harvest.

ii. To compare variations in foliar nutrients (N, P, K, Ca, Fe, Mn and Zn) levels and determine appropriate foliar sampling period due to N-K_2O rates.

iii. To compare variations in yields due to N-K_2O rates.

iv. To compare variations in quality (CCS %) and predict appropriate harvesting age due to N-K_2O rates.

1.3 Hypotheses - H_0

i. Soil pH and nutrients (N, P, K, Ca, Fe, Mn and Zn) levels will not vary with N-K_2O fertilizer rates before ratooning and after harvest.

ii. Foliar nutrients (N, P, K, Ca, Fe, Mn and Zn) levels will not vary with N-K_2O fertilizer rates and appropriate foliar sampling age will not be determined in the three cultivars.

iii. Yields will not vary with N-K_2O fertilizer rates in the three cultivars.

iv. Commercial cane sugar will not vary with N-K_2O fertilizer rates and appropriate harvesting age will not be predicted in the three cultivars.

1.4 Justification

Determination of soil pH and nutrients levels optimizes fertilizer rates. Foliar analysis will help predict nutrients imbalances and allow for timely interventions to guarantee better productivity. Optimizing N-K_2O fertilizer application rates will improve productivity. Appropriate harvesting age synchronizes with maximum sugar recovery, provide stable basis for proposed payment system, adequate supply and improved livelihood for the farmers.

1.5 Significance

This study will help to create guidelines for proper N-K_2O fertilizer regime and harvesting age, while increasing yield and quality of ratoon sugarcane crop thus improving the living standards of the farmers. Furthermore, it will help Kenya to attain self-sufficiency in sugar production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of sugarcane

Sugarcane is a mono-cotyledonous plant cultivated in the in the warm tropical and sub-tropical regions for the production of sucrose (Plaut *et al.*, 2000). The available temperature, humidity and sunlight intensity favour its germination, tillering, vegetative growth and maturity (Muhammad *et al.*, 2013). Sugarcane can be harvested over 3-6 times (ratoons) before new canes can be planted (Salassi *et al.*, 2000). It is grown in Brazil, China, India, Pakistan and U.S.A. In tropical regions e.g. Kenya, cane is cultivated in western and coastal regions (KESREF, 2007).

2.2 Economic importance of sugarcane

Sugarcane and its co-products are used as food additive, fodder, fibre, fuel and fertilizer (Hunsigi, 1993). In Brazil, ethanol, a by-product of sugarcane is used as a motor fuel while bagasse is used for the manufacture of paper and chip boards (Lingle *et al.*, 2000). For India, cane stalks is used for feeds (Raju *et al.,* 2009); in Australia, trash is used as mulch and livestock feeds (Dawson, 2002) while in Kenya, as a source of employment and food (Wawire *et al.*, 2006; CBS, 2004b).

2.3 Sugarcane cultivars and productivity

In India (Chattha *et al.*, 2006), Pakistan (Mian, 2006), cultivars registered significantly different cane and sugar yields per unit area of ratoon crops. Higher yield and sugar were achieved by planting genetically improved early-maturing and high-yielding cultivars while inferior cultivars recorded lower yields and quality. However, the cultivars with low genetic potentials recorded higher cane yield and sugar levels only with appropriate agronomic inputs such as N-K_2O rates.

In Kenya, major cultivars include CO421, CO945 and N14 which occupy over 65% of total cane area (KESREF, 2002). The late maturing and low sugar-content CO421 is the dominant cultivar in western Kenya. To improve productivity, new early maturing and high-yielding cultivars were released (KESREF, 2003). They include KEN82-247 and KEN83-737 which mature within 15 - 19^{th} MAR with high sugarcane and sugar yields**.** However, the variations in their cane and sugar yields have not been determined in ratoon crops in Kenya.

2.4 Sugarcane nutritional requirements

The essential that nutrients include macro-nutrients (N, K and Ca) and micro-nutrients (Mn, Fe, Zn, etc.) must be supplied adequately as they support growth and metabolism (Fauconnier, 1993). A deficiency or over-abundance of any of them compromises cane yield and quality (Rice *et.al.* 2002). The macro-nutrients N and K requirements for ratoon sugarcane are higher than those of other commercial crops because of its high dry matter and energy production per unit area (Khan, *et al.*, 2003). In India, ratoon crop with a yield of 100 TCH removes 207 kg N, 30 kg P and 233 kg K_2O from the soil (Jagtap *et al.,* 2006). Indeed, deficiencies of these nutrients lead to declines in both sugarcane yield and juice quality (Khan *et al.*, 2003). Therefore these elements need to be adequate for the crop to obtain improved yield and quality. New cultivars were introduced, but the N rate is applied across all the cultivars (KESREF, 2002). Phosphorus is a source of energy in the form of Adenosine Triphosphate (ATP) and Adenosine diphosphate (ADP) and regulates the manufacture of sugar and its storage (Kumar and Verma, 1997). Its deficiency reduces ratoon cane tonnage while oversupply increases stalk yield but with reduced sucrose content (Glaz *et al.*, 2000). The potassium demand for ratoon sugarcane is high (Garcia *et al.*, 2001) since it supports water uptake, nutrients and activation of enzymic metabolism. Potassium is involved in sucrose synthesis and phloem loading (Kumar and Verma, 1997).

However, excess K depresses sucrose recovery by raising its solubility as K^+ attaches to sucrose molecule leading to increased solubility but less sugar during cane milling (Cavalot, *et al.*, 1990). Deficient K causes depressed growth, slender stalks, 90% foliar sucrose lodging and 10% trans-located to the stalks leading to low sugar recovery during milling.

For micro-nutrients, Fe is a constituent of many enzymes, chlorophyll and essential for redox catalysis of carbohydrates (Marschner, 1986). Excess Fe is associated with soluble Fe^{2+} under reducing conditions that develop with water logging resulting in Fe leaching into the soil (Marinho and Albuquerque, 1981). Manganese which occurs in low pH soils, bridges ATP and enzymes during photosynthesis, hence its critical level (15ppm) declines sucrose contents (Marschner, 1986). Zinc directly affects tillering and synthesis of tryptophan which is a precursor of indole acetic acid responsible for cell elongation and growth (Filho *et al.*, 2001). Due to critical functions of Zn, ratoon crops are exposed to Zn deficiency (Hadi *et al.*, 1997), which interrupts development of chloroplasts thus leading to chlorosis (Anderson and Bowen, 1990). The micro-nutrients; Fe, Mn and Zn are not regularly supplied with fertilizers in Kenya Sugar Industry. However, it is not known if levels of soil physicochemical parameters and foliar nutrients are within the recommended sufficiency ranges. Moreover, it is not known if the agronomic inputs such as N-K_2O fertilizers applied influence the levels of the nutrients in the new early maturing and high-yielding cultivars.

2.4.1 Nitrogen rates and yield

Nitrogen is vital for plant protoplasm, proteins, nucleic acids, amino sugars, polypeptides and chlorophyll hence responsible for increasing cane yield (Taiz and Zeiger, 2002). According to Srivastava and Suarez (1992), the application of nitrogen fertilizers ranges from 45 to 300 kg/ha.

In Australia (Thornburn *et al*., 2001), Brazil (Gascho, 1983), Pakistan (Saleem *et al*., 2012) and Egypt (Ahmed *et al*., 2009), Nigeria (Gana, 2008) and Kenya (Amolo *et al.*, 2006; Ochola, 2013) N rates are between 80 - 120 kg N/ha and progressively increased cane yield. The converse was reported in Iran (Koochekzadeh *et al*., 2009), Florida (Muchovej and Newman, 2004a) and Australia (Hurney and Berding, 2000) where non-significant yield responses occurred. In Kenya, a study (Ongin'jo and Olweny, 2011) was conducted at the hotter coastal region where than higher temperatures enhance plant metabolic processes, growth and maturity. The current 100 kg N/ha rate recommended for old, late maturing cultivars and low-yielding cultivars was applied on new sugarcane cultivars in a recent experiment (Ong'injo and Olweny, 2011) where ratoon cane yield was significantly increased. Optimal N rates for high yields for ratoon crops of early maturing cultivars have not been established in western Kenya.

2.4.2 Nitrogen rates and quality

Several studies have reported effect of N rates on sugarcane quality. In India (Naga *et al*., 2011), Iran (Koozechzadeh *et al*., 2009), Pakistan (Muhammad *et al*., 2013), Egypt (Ahmed *et al*., 2009), Ethiopia (Ambachew *et al*., 2012) and coastal region of Kenya (Ong'injo and Olweny, 2011) reported significant increases in pol%, brix% and CCS% with increasing N fertilizer rates. Non-responses to N fertilizer applications on quality attributes were reported in Australia (Thornburn *et al*., 2001) and Louisiana (Richard, 2007). However, in another study (Muchow *et al*., 1995) in South Africa, increasing N rates reduced ratoon cane quality levels. Influence of N rates on the quality of ratoon crops of new cultivars has not been determined in western Kenya.

2.4.3 Potassium rates and yield

Yield variations due to K_2O rates have been reviewed (Malavolta, 1994). In Sao Paulo (Korndorfer, 1990), Fiji (Yang and Chen, 1991), India (Prasad *et al.*, 1996) and in Pakistan (Muhammad *et al*., 2013) the potash (K_2O) rates progressively increased the ratoon cane yields.

In the converse, Perez and Melga (1998), reported non-significant yield responses under andisol soils. In other finding (Aguado-Lara *et al.*, 2002), 80 kg K_2O/ha was recommended for sugarcane either on its own or in combination with other fertilizers. In Kenya, a 100 kg K_2O/ha was recommended (KESREF, 2002), but was discontinued in 1980s due to lack of yield responses to old cultivars (KESREF, 2007). Many farms have continuously produced cane with no K_2O replenishment despite K being either harvested with crops or lost through other sources such as leaching. However, it is not known if lack of K in the soil is contributing to the low ratoon sugarcane yields being realized in western Kenya.

2.4.4 Potassium rates and quality

Potassium is required for sugarcane maturity (Ahmed *et al.,* 2009). In Pakistan (Muhammad *et al.,* 2013), cane juice quality displayed significant increase with K_2O rates. The 50 - 100 kg K_2O/ha exhibited significant ($p \leq 0.05$) effect on net pol%, brix% and CCS % (Ahmed *et al.*, 2009) in Egypt. This increase could have been due to the role of K in translocation of sugars to the cane stalks, which cause an increase in pol%, brix% and CCS%. Similar trends were demonstrated in Brazil (Korndorfer, 1990) and South Africa (Wood, 1990). However, above 160 kg K_2O/ha rate, the quality parameters were significantly ($p \leq 0.05$) depressed by about 13%. The decline could have been due to excessive uptake of K, which increased its solubility (Filho, 1985), thus resulting in lower sugar recoveries. In Mauritius (Kwong, 2002) and India (Gulati *et al.,* 1998), K_2O rates had no effect on juice quality parameters. For the Kenya Sugar Industry, K_2O application was discontinued and is speculated that its non-use could be contributing to the current low quality (pol%, brix% and CCS %) in ratoon cane juice. The role of K has not been established for optimal ratoon quality of the new early-maturing and high-yielding cane cultivars.

2.5 Soil Nutrients and pH

Soil degradation is the most pervasive threats to sustainable agriculture (Yadav and Prasad, 1992). Due to mono-cropping with exhaustive and extracting sugarcane plant over many decades, sugarcane production has remained under threat (Haynes and Hamilton, 1999). Ratoon sugarcane crops remove large amounts of NPK at 205, 55 and 275kg respectively from the soil for a yield of about 100 TCH. Fertilizer Management Practice, including soil testing, is one of the important agronomic practices in cane production. This intervention helps to determine soil pH status and the availability of essential elements (Table 1), for maximum productivity of cane (Rice *et al*., 2002). While ratoon crop tolerates a pH range of 4.5 - 8.5, it grows best at pH 6.0 - 7.5 (Blackburn, 1984). Furthermore, it requires high inputs of fertilizers, e.g. N for high yields (Sreewarome *et al.*, 2007).

However, excess or continuous application of N lowers soil pH (Taiz and Zeiger, 2002). In Kenya, however, the soil pH of cane growing areas and influence of N-K_2O rates on soils have not been established. In wheat plantations (Sadej and Przekwas, 2008) increasing N rates increased total N content within the upper soil layer and soil N level decreased with increasing depth. In South Africa (Haynes and Hamilton, 1999), soil acidification and drop in soil N were recorded in the cane fields. However, Walker *et al. (*2007) reported a significant ($p \leq 0.05$) increase in soil N levels under higher N fertilization in rice. In the converse, non-significant ($p \leq 0.05$) increase in soil N levels with higher N rates was observed later (Sadej and Przekwas, 2008). Similarly, non-significant responses of the soil chemical parameters (P, K, Ca, Zn and Fe) due to N fertilizer rates have been observed (Mandal *et al.,* 2012), but the results disagreed with that of Debiprasad *et al.* (2010) where N rates significantly ($p \leq 0.05$) changed the soil properties.

Soil nutritional status under the ratoon cane crops due to N fertilizer application rates has not been established in western Kenya.

Table 1: Status of some soil chemical parameters for sugarcane crop

Nutrient	Concentration (%)	Status	Nutrient	ppm	Status
N	0 - 0.05	Very Low	Fe	0 - 5	Very Low
	0.05 - 0.15	Low		5 - 10	Low
	0.15 - 0.25	Medium		10 - 15	Moderate
	0.25 - 0.50	High		15-20	Sufficient
	0.50 - Above	Very High		20-Above	Toxic
P	Conc. (ppm)	Status	Mn	<27	Very Low
	0 - 10	Very Low		27 - 275	Moderate
	10 - 16	Low		276-549	High
	16 - 20	Moderate		549 - Above	Toxic
	20 - 80	Adequate	Zn	0 - 39	Very Low
	80 - Above	Toxic		39 - 59	Low
Soil pH Guide				59- 98	Moderate
				98 - Above	Toxic
Acidity Status					
<4.5	Extreme				
4.5 - 4.9	Strong		K	0 – 78	Very Low
5.0 - 5.9	Moderate			78-117	Low
6.0 - 6.4	Slight			117-195	Moderate
6.5-6.9	Near Neutral			195 - Above	Adequate
Alkalinity Status					
7.0 - 7.4	Slight		Ca	0 - 400	Very Low
7.5 - 8.4	Moderate			401 - 601	Low
8.5 - 8.9	Strong			601 - 1510	Moderate
8.9 - Above	Extreme			1510 - Above	Adequate

Source: KESREF, 2010.

2.6 Foliar nutrients

Fertilizer trials, soil testing and foliar analysis are used for fertilization programs (Rice *et al.*, 2002). Foliar analysis together with visual evaluation of malnutrition symptoms, complement the formulation of fertilizer recommendations (Baldock and Schulte, 1996). The tissue of choice widely used for diagnostic purposes is the top visible dewlap (TVD) leaves (McCray *et al.*, 2006). The TVD tissue without midrib is metabolically active and is the site of photosynthesis, sugar and mineral storage. Therefore, the TVD tissue is used for measuring nutrient levels (Ezenwa *et al.*, 2005). Yield is highly correlated with foliar nutrient status at maximum growth, indicating that foliar nutrients may detect nutrient imbalances (Miles, 2010).

Foliar sampling is done based on the right season (adequate rainfall or irrigation) and satisfactory age, e.g. 6 weeks after fertilizer application (Schroeder *et al.*, 1999). In Queensland and New South Wales (Schroeder *et al.*, 1999), sampling ages were suggested at 3 - 5 and 4 - 7 months after ratooning respectively. However, the recommendations were based on agronomic conditions in sub-tropical regions, which are different from those in tropical areas e.g. along the equator where western Kenya is situated. Indeed, optimal sampling time for ratoon cane has not been assessed. Interpretation of analyses of foliar analyses results are based on the critical nutrient level, CNL and optimum range (Table 2). The CNL indicates the content below which the nutrient level limits production while optimum range is the level considered optimal for production (McCray and Mylavarapu, 2010). However, the interpretation of CNL depends on the cultivars, soil condition, fertilizers applied, sampled tissues and age of the sugarcane plant at sampling time (Gascho, 2000). When using CNL approach, it is vital to collect foliar samples at specified age since nutrient contents vary during the crop growth cycle (Schroeder *et al.*, 1999).

Foliar nutrient contents vary with the age of the tissue (Mengel and Kirkby, 2001). Young foliar tissues have higher water contents than the old tissues and are rich in nutrients which are dissolved in the water.

Table 2: Critical nutrient limits (CNL) and optimum ranges for foliar tissues crops

Nutrients	Florida (5th MAR)		Ethiopia (5th MAR)	India (6th MAR)
	Critical value	Optimum range	Optimum range	Optimum range
N	1.80%	2.00 - 2.60%	1.53 - 1.73%	1.99 - 2.38%
P	0.19%	0.22 - 0.30%	0.17 - 0.20%	0.10 - 0.25%
K	0.90%	1.00 - 1.60%	1.22 - 1.64%	1.23 - 1.93%
Ca	0.20%	0.20 - 0.45%	-	-
Mn	16 ppm	20 - 100 ppm	-	-
Zn	15 ppm	17 - 32 ppm	-	-
Fe	50 ppm	55 - 105 ppm	-	-

Source: Ambachew *et al.* (2012).

The nutrients levels reduce with increasing age, however, decrease in nutrients levels relates mostly to N, P and K (Mengel and Kirkby, 2001). Foliar contents of less mobile nutrients, such as Ca, Mn and Zn, are less affected by plant age, and may even increase in levels with ageing (Mengel and Kirkby, 2001). In Kenya, fertilizer application programs based on foliar diagnostic techniques have not been embraced. It has not been assessed how N-K_2O rates would vary with sampling period of the ratoon cane cultivars in western Kenya.

The recommended CNL and optimal ranges for ratoon crops in different countries are presented in Table 2. In India (Naga *et al.*, 2011), foliar tissues of different ratoon cultivars recorded nutrients peaks at about the 6^{th} month after ratooning (MAR). For Australia (Keating *et al.*, 1999), the critical nutrient levels for N ranges from 1.2 - 0.5% at ratooning and at the flowering seasons respectively. The values for Ethiopia (Ambachew *et al.*, 2012) appeared earlier at the 5^{th} MAR with N (1.53%), P (0.17%) and K (1.22%) while Florida (McCray and Mylavarapu, 2010) were N (1.80%), P (0.19%) and K (0.90%) and India (Naga *et al.*, 2011) the N (1.99%), P (0.10%) and K (1.23%). The optimal timing for foliar sampling for nutrients levels determination of late and new ratoon cultivars are not known in Kenya.

Sugarcane is a heavy consumer of N (Ezenwa *et al.*, 2008) and hence requires adequate N fertilization for satisfactory yield. Varying N rates affects foliar N levels during the growth regimes, but contents may fluctuate across the sampling period (Muchovej and Newman, 2004b). The N nutrient levels affect the levels of other nutrients (Jarrell and Beverly, 1981). For example, foliar K level of ratoon sugarcane crop significantly increased with age while that of macro and micro-nutrients were not affected by the N fertilizer rates applied (Ahmed *et al.*, 2009). A significant increase in foliar N and K concentrations was observed due to increasing N fertilizer rates (Ahmed *et al.*, 2009). In another study (Kumar and Verma, 1997) foliar N, P and K contents were significantly correlated with cane yield. Among the micronutrients, only leaf Zn contents had significant correlation with cane yield. However, foliar nutrient contents were analyzed only at maximum growth stage. Moreover, no finding was made on the influence of N fertilizer rates on ratoon cane yield and quality. In other related studies (Owuor, 1997, Kwach *et al.*, 2012) on tea plants, rates of N significantly affected the foliar nutrients levels of other nutrients. This is not well documented for ratoon sugarcane crops in western Kenya.

The potash application rates have increased foliar nutrient levels in many studies (Singh and Jha, 1994). The 100 - 120 kg K_2O/ha, resulted in a significant increase in N, K, P, Ca and micro-nutrients (Fe, Mn and Zn) levels during the active growth of plant crop (Ezenwa *et al.*, 2008). This could be attributed to the role of K in water uptake which in turn solubilizes the nutrients for upward absorption through the xylem tissues (Rice *et al.*, 2002). However, in Kenya, it is not known how K_2O rates may affect foliar nutrients levels of early maturing ratoon crops.

2.7 Optimal harvesting age for ratoon sugarcane

Maturity refers to the time when the cane has accumulated maximum sucrose during the growth period (Chang, 1995). Maturity curves of sucrose versus time have been developed for cane cultivars in South Africa (Bond, 1982), Louisiana (Legendre, 1985) and Mauritius (Mamet and Galwey, 1999). However, in Kenya, maturity analytical procedures have not been developed. Instead, sugar factories give cutting orders to farmers based on the crop age. Farmers harvest canes on self - initiatives driven by crop visual maturity indices e.g. yellowing and drying of leaves, metallic sound of mature canes when tapped and presence of glistening sugar crystals when a mature cane is cut in a slanting angle and held against the sun. Indeed, the indices are mere physiological properties which are not scientific since factors including the emergence time, cultivars, crop management practice affect the plant maturity. During the initial stages, the sucrose and fibre contents are small but increase steadily towards maturity when vegetative growth drops and pol% values range from 10.49 - 17.86% (Blackburn, 1984). Early maturing cultivars accumulate maximum sucrose and ready for harvesting within 8 - 10 MAR in India (BSES, 1991), 10 - 11 MAR in Indonesia (Gonzales *et al.*, 1998). Others are 9 - 10 months in Mauritius (Das *et al.*, 1997), 9 months in the Kenyan Coast (Ong'injo and Olweny, 2011) and 15 - 19 months after ratooning (MAR) in the sugar belt of western Kenya region (KESREF, 2005).

However, in western Kenya, harvesting time cuts across both old late maturing and new early maturing ratoon cultivars in disregard of possible variations the agronomic inputs, including N and K_2O rates, may have on yield and quality now enshrined in the proposed payment system (Sugar Act, 2001). It is not documented how N, K_2O rates and harvesting time may influence quality and yield of the new early maturing and high-yielding cultivars in western Kenya.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site description

The study was a continuation of an experiment conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) at Sugar Research Institute (SRI), formerly Kenya Sugar Research Foundation (KESREF) - Kibos, situated 16 km North East of Kisumu City on Kisumu - Miwani Road. More of the description of the site is in Table 3.

Table 3: Description of the study site

Parameter	**Description**
Position	16 km North East of Kisumu City
Altitude	1184 m above sea level
Latitude	0^{o} 04' S
Longitude	34^{o} 48' E
Mean annual rainfall (av. of 12 years, 2001-2013)	1464 mm
Mean monthly temperature	21.5 - 23.5 ^{o}C
Relative humidity (mean)	70.1%
Soil type	Vertisolic (black cracking clay with high shrinking and swelling potential)
Climate	Warm sub-humid
Major agricultural activity	Sugarcane cultivation
Agro ecological zone	LM_1

Source: Jaetzold *et al.* (2007)

3.2 Experimental layout and treatments

The experiment was set up as a split-split plot (3x4x2) design arranged in a Randomized Complete Block Design (RCBD) with four replications (Annex 1). Three cultivars were used as the main plots: Old and late maturing cultivar CO421 (control) with stable quality and two new early maturing and high-yielding cultivars KEN82-472 and KEN83-737 as the test cultivars. Each sub-plot was supplied with N fertilizer [urea - CO $(NH_2)_2$] at the 3rd month after rationing (MAR) at the rates of 0, 50, 100, and 150 kg N/ha). For potash, each sub-sub plot received 0 and 100 kg K_2O/ha at the 3rd MAR. The 45 kg P_2O_5/ha was uniformly applied as basal treatment.

3.3 Site preparation, planting and crop maintenance

The land was 1st ploughed (November 2007) using a mould board plough and harrowed 30 cm deep with a disc plough. After 3 months (February 2008), it was re-ploughed, furrowed (with a double-edged tractor with 1.2 m inter-row spacing). The 12 - 16 months old cane stalks were cut into three-budded sets discarding either end of the stalk and planting them in each sub-sub plot (6 m x 10 m) consisting of 8 rows of 1.2 m apart. The base had over-mature buds with reduced germinability while the tip had active meristematic cells which could be easily damaged. Within 24 hours after preparation, the sets were placed in the opened furrows and buried with thin layer of 15cm soil depth. The 1st and 8th rows were guard rows, 2nd and 7th for destructive sampling for the purposes of quality (pol% and brix %) determination. The 3rd - 6th rows were used for both foliar analysis and yield determination (just once at harvest) determination. After 1st MAP, a pre-emergence herbicide (Velpar 75 DF at 1 kg/ha), was applied to control both grass and broad foliar weeds for about 3 months. Weeds that emerged after the 3rd month after planting (MAP) were removed by hand weeding.

At the 4th MAP, fertilizers were applied in the form of urea [CO $(NH_2)_2$], di-ammonium phosphate $(NH_4)_2HPO_4$ - (DAP) and murrate of potash (K_2O). By the 6th MAP, the plants had formed adequate canopy. The smut disease, the most deleterious sugarcane disease in Kenya (Nzioki *et al.,* 2010), was monitored and then removed to avoid spreading to other sub-sub plots. The harvesting of the plant crop was done where the cane stalks were cut slightly above the ground in a V-shaped pattern, de-trashed and the trash spread all over the entire plots. However, the current study was based on ratoon sugarcane crop. Therefore, after harvesting of plant crop, the N, P_2O and K_2O fertilizers were applied and ratoon management procedures maintained (Muhammad *et al*, 2013). Weeds in areas adjacent to ratoon cane paddocks were slashed and the fence lines sprayed with herbicide (Velpar 75 DF at 1 kg/ha). Green cane trash blanketing was used to reduce the amount of weeds germinating among the ratoon canes. However, any weeds that emerged after the 3rd month after ratooning (MAR) were removed through hand weeding. Pest monitoring was done and any pests expelled by application of integrated pest management strategy. Appropriate timing of fertilizer application for ratoon cane, being an important tool in reducing the risk of fertilizer losses due to leaching, run-off and or de-nitrification (Schroeder *et al.*, 2007), was done at the 3rd MAR. The urea-based N was applied into the soil below the trash to prevent volatilization. The K, P and S were applied in the form of potash (K_2O), diammonium phosphate - $(NH_4)_2HPO_4$ and ammonium sulphate, $(NH_4)_2SO_4$.

3.4 Data Collection

3.4.1 Soil Sampling and Analysis

Initial sampling was done before ratooning while final sampling was conducted after the harvest of the first ratoon crops to determine the treatment effects on soil pH and nutrients. From sub-sub plot, ten cores were taken randomly at 0 - 15 cm and 15 - 30 cm using stainless-steel augers.

Plant and other debris were removed and the soil sample air-dried and ground to pass through a 2 mm sieve. A scoupe of 10g of fine powder was analyzed for estimation of physico-chemical properties (pH, N, P, K, Ca, Fe, Mn, and Zn) according to Okalebo *et al*. (2002). The soil pH was determined in a 1:2 soil-water suspension by a systronic digital pH meter (Elico-331- Germany). Total N was done by Kjeldahl method while P by chloro-stannous reduced phosphor-molybdate blue-colour method using a UV-vis (660 nm) spectrophotometer (UVO76S-Germany). Available soil Ca and K were determined using a flame photometer (FP056-Germany). The levels of micro-nutrients (Fe, Mn, and Zn) were determined by Atomic Absorption Spectrophotometry (Model Shimadzu AA-6200).

3.4.2 Foliar Sampling and Analysis

Twenty 3rd top visible dewlap (TVD) leaves from each sub - sub plot were randomly selected from the 2nd - 6th rows monthly at 3rd - 10th month after ratooning (MAR). Samples were prepared for analysis according to Okalebo *et al*. (2002). The foliar samples were oven dried at 70^{o}C for 72 hours; ground and 0.3g weighed for digestion in 100 ml tube with 2.5 ml of digestion mixture (3.2 g of salicylic acid in 100 ml of concentrated sulphuric (VI) acid - selenium mixture) and the blank reagent. The tube was placed in a block digester set at 110^{o}C for 1 hour, removed and cooled before adding 3 successive 1ml portions of 30% H_2O_2. The tube contents were thoroughly agitated, placed on the block digester and heated gradually to 330^{o}C until a colorless solution was formed. The tube was removed, cooled and plant digest filtered through Whatman No. 91 filter paper. The filtrate was collected into a 50 ml volumetric flask, diluted to the mark with de-ionized H_2O and settled to a clear solution. The solution was then subjected to analyses of N (KB 49 Gerhardt Kjeldalh equipment). The nutrients levels were compared with the values in Table 2.

3. 5 Yield determination

At harvest, the yield was determined by cutting all the ratoon sugarcane stalks from the four central furrows in sub-sub plot, de-trashing and weighing them (kg) using a crane scale. The sub-sub plot measured 1.2 m x 10 m = 12 m^2 (therefore yielding total area of 4 x 12 m^2 = 48 m^2). To calculate the total yield, formula (i) was used to generate each paddock yield and thereafter extrapolated to ton cane per hectare (TCH), (Annex 3).

Formula (i): Yield (TCH) = $\frac{\text{Weight of all stalks (tons) x 10,000}}{\text{Sub-sub plot area in sq. meters}}$; (1 Ha = 10,000 m^2)

3.6 Quality Parameters

Ten stalks at 10^{th} to 24^{th} MAR were taken from each sub-sub plot. The canes, from the 2^{nd} and 7^{th} rows, were randomly selected with tops, green and brown leaves removed, de-trashed and cut at the base just above the soil surface. The stalks were crushed in a three roller mill and the juice prepared for the quality parameters (pol% and brix %) analyses as described by ICUMSA (1994). The pol % was measured by using Anton PAAR - MCP 250 (GERM) Sucromat while brix by an index instrument GPR - 53X (UK) refractometer. The two quality parameters were fitted in the calculation for the commercial cane sugar CCS % as shown in formula (ii):

Formula (ii): CCS % = pol % - 0.5 (brix% - pol %); (BSES, 1991).

3.7 Effect of age on sugarcane quality

To estimate the effect of age on sugarcane quality, bi-monthly commercial cane sugar percentage (CCS %) data were subjected to simple quadratic regression. The data was fitted into quadratic response curves for each cultivar, at different N and K treatment doses. The coefficient of determination (R^2) as parameter was used as an indicator of the model's precision. The maximum sugar production age was determined at the maxima where $dy/dx = 0$.

3.8 Statistical Analyses

The data was analyzed statistically using Statistical Analysis Software (SAS) system for Windows, Version 9.2 (SAS, 2002) as a 3x4x2 split-split plot treatment arrangement within randomized complete block design (RCBD). Analysis of variance (ANOVA), least significant differences (LSD) tests and general linear models (GLM) procedures were performed to determine significant treatment effects at $p \leq 0.05$. Quadratic regression was done through Microsoft Office Excel 2013 (Window 8).

CHAPTER FOUR

RESULTS AND DISCUSSION

4. Variations in soil pH and nutrients due to cultivars, N and K_2O fertilizer rates

4.1 Soil pH

Table 4: Variation in soil pH with cultivars, N and K_2O rates at 0 - 15 cm depth

Cultivar	N Rates kg/ha	Before Ratooning: K_2O Rates kg/ha 0	Before Ratooning: K_2O Rates kg/ha 100	Before Ratooning: Mean N Rate	Before Ratooning: Mean Cultivar pH	Post-Harvest: K_2O Rates kg/ha 0	Post-Harvest: K_2O Rates kg/ha 100	Post-Harvest: Mean N Rate	Post-Harvest: Mean Cultivar pH
CO421	0	5.98	5.89	5.99		5.20	5.57	5.39	
	50	5.96	5.58	5.77		5.62	5.47	5.54	
	100	6.25	5.87	6.06		5.75	5.64	5.70	
	150	5.79	5.51	5.65	5.87.	5.68	5.21	5.45	
	Mean K rate	6.00	5.74			5.56	5.47		5.52
	C V (%)	4.45				2.99			
	LSD ($p \leq 0.05$)	NS		NS		NS			
KEN 82-472	0	5.89	5.54	5.72		5.16	4.49	4.82	
	50	5.81	5.25	5.53		5.03	4.29	4.66	
	100	5.71	5.56	5.64		5.14	4.26	4.70	
	150	4.43	4.25	4.34	5.31	4.03	4.09	4.06	
	Mean K	5.46	5.15			4.84	4.28		4.56
	C V (%)	6.67				10.57			
	LSD ($p \leq 0.05$)	0.30		NS		0.56		NS	
KEN 83-737	0	5.78	5.45	5.62		5.57	4.89	5.23	
	50	5.79	5.27	5.53		5.43	4.69	5.06	
	100	5.61	5.66	5.64		5.61	4.96	5.29	
	150	4.43	4.36	4.39	5.29	5.41	4.59	5.00	
	Mean K	4.84	4.28			5.51	4.78		5.15
	C V (%)	10.56				12.52			
	LSD ($p \leq 0.05$)	0.55		NS		0.69		NS	
Overall Means	0	5.88	5.63	5.78		5.31	4.98	5.15	
	50	5.85	5.37	5.61		5.36	4.82	5.09	
	100	5.86	5.70	5.78		5.50	4.95	5.23	
	150	4.88	4.71	4.79		5.04	4.63	4.84	
	Mean K	5.62	5.35			5.30	4.84		
	C V (%)	4.89				6.97			
	LSD ($p \leq 0.05$)	NS		NS		0.46		NS	0.34

Legend: NS -Non significant; Old cultivar -CO421; New cultivar- KEN82-472 and KEN83-737

Table 5: Variation in soil pH with cultivars, N and K_2O rates at 0 - 15 cm depth

Cultivar	N Rates kg/ha	Before Ratooning: K_2O Rates kg/ha 0	100	Mean N	Mean Cultivar pH	Post-Harvest: K_2O Rates kg/ha 0	100	Mean N	Mean Cultivar pH
CO421	0	5.29	5.20	5.24		5.26	4.88	5.07	
	50	5.28	4.87	5.07		5.18	5.11	5.15	
	100	5.57	5.19	5.38		5.21	5.07	5.14	
	150	5.00	4.83	4.97		5.04	4.92	4.98	
	Mean K	5.21	5.12		5.17	5.17	5.00		5.08
	C V (%)	4.06				3.46			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 82-472	0	5.46	4.87	5.16		5.01	4.83	4.92	
	50	5.44	4.66	5.05		5.14	4.71	4.93	
	100	5.55	4.72	5.14		4.72	4.61	4.67	
	150	4.43	4.57	4.50		4.66	4.51	4.59	
	Mean K	5.12	4.88		5.00	4.88	4.67		4.77
	C V (%)	4.69				4.52			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 83-737	0	4.89	4.79	4.84		4.69	4.42	4.56	
	50	4.79	4.74	4.77		4.51	4.36	4.44	
	100	4.88	4.68	4.78		4.60	4.42	4.51	
	150	4.85	4.66	4.75		4.47	4.37	4.42	
	Mean K	4.81	4.75		4.78	4.57	4.39		4.48
	C V (%)	2.74				4.11			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	5.25	4.94	5.09		4.99	4.71	4.85	
	50	5.20	4.73	4.97		4.94	4.73	4.84	
	100	5.33	4.93	5.13		4.84	4.70	4.77	
	150	4.77	4.59	4.68		4.72	4.60	4.66	
	Mean K	5.11	4.85			4.87	4.68		
	C V (%)	5.09				4.06			
	LSD ($p \leq 0.05$)	NS		NS	NS	NS		NS	0.28

Legend: NS- Non significant; Old cultivar- CO421; New cultivars -KEN82-472 and KEN83-737

Cultivars significantly ($p \leq 0.05$) affected pH within both depths only after harvesting. Despite the plots receiving similar treatments at plant cycle, the KEN82-472 and KEN83-737 recorded lower soil pH than the old CO421 cultivars before ratooning, after harvest and in the two soil - depths.

The variations could be attributed to the more superior extracting abilities of soil bases such as Ca^{2+} by ratoon sugarcane crops compared to the plant canes. The findings corroborated with the foliar soil Ca^{2+} levels in this report (Tables 32 and 33). However, the results contradicted the report by Muhammad *et al*. (2010) that cultivars had no significant effects on soil pH. Indeed, new cultivars could also have higher potentials to extract soil bases that might have induced soil acidification. However, the results indicate that at start of ratooning and harvest, the soil pH remained within the sufficiency range (Table 1) that suitable for the ratoon sugarcane crop cultivation (Blackburn, 1984).

The N rates had non-significant ($p \leq 0.05$) influence on pH (Tables 4 - 5) in both depths and stages. A general decline of soil pH with high N rates, although it did not reach significance. Increasing rates from 100 to 150 kg N/ha did not significantly affect soil pH. The results agreed with other reports (Haynes and Hamilton, 1999; Graham *et al*., 2000; Koochekzadeh *et al*., 2009; Muhammad *et al*., 2010) where N rates had insignificant influence on pH. In this study the soil is vertisolic (Jaetzold *et al*., 2007) with high soil compaction thus hindered significant nitrification within soil layers (Hartemink, 1998). These results suggest that prolonged N application may be unnecessary as it lowers soil pH which is unsuitable for ratoon sugarcane production.

The K_2O rates significantly ($p \leq 0.05$) influence the soil pH within 0 - 15 cm layer in new early maturing cultivars (KEN82-472 and KEN83-737) but not the old and late maturing CO421. The result may indicate that the root systems of the new cultivars are concentrated within the top layer. The variation could be due to different cultivar genetic ability to absorb soil K. However, there was non-significant ($p \leq 0.05$) effect of K_2O rates on the soil pH within the lower 15 - 30 cm layer. This could be attributed possibly due to poor soil porosity within the 15 - 30 cm soil horizon which led to generally slow leaching of K to induce acidification in the soils.

4.2 Soil Nitrogen

The variations in soil N levels due to cultivars, N and K_2O rates are presented in Tables 6 and 7.

Table 6: Variations in soil %N due to cultivars, N and K_2O rates at 0 - 15 cm depth

Cultivar	Before Ratooning					Post-Harvest			
	N Rates kg/ha	K_2O Rates kg/ha 0	100	Mean N	Mean Cultivar %N	K_2O Rates kg/ha 0	100	Mean N	Mean Cultivar %N
CO421	0	0.30	0.33	0.32		0.34	0.40	0.37	
	50	0.32	0.37	0.35		0.39	0.47	0.43	
	100	0.33	0.44	0.39		0.45	0.49	0.47	
	150	0.37	0.46	0.42		0.50	0.53	0.52	0.45
	Mean K	0.33	0.40		0.37	0.42	0.47		
	C V (%)	10.76				9.69			
	LSD ($p \leq 0.05$)	0.05		NS		0.04		NS	
KEN 82-472	0	0.32	0.35	0.34		0.40	0.47	0.44	
	50	0.33	0.39	0.36		0.49	0.53	0.51	
	100	0.35	0.47	0.41		0.58	0.59	0.59	
	150	0.39	0.49	0.44		0.53	0.55	0.54	0.52
	Mean K	0.35	0.43		0.39	0.50	0.54	0.52	
	C V (%)	12.32				10.23			
	LSD ($p \leq 0.05$)	0.05		NS		0.06		NS	
KEN 83-737	0	0.33	0.37	0.35		0.39	0.46	0.42	
	50	0.36	0.42	0.39		0.48	0.54	0.51	
	100	0.37	0.49	0.43		0.57	0.58	0.57	
	150	0.40	0.50	0.45		0.51	0.54	0.52	0.51
	Mean K	0.37	0.45		0.41	0.49	0.53		
	C V (%)	13.17				11.73			
	LSD ($p \leq 0.05$)	0.05		NS		0.05		NS	
Overall Means	0	0.32	0.35	0.33		0.38	0.44	0.41	
	50	0.34	0.39	0.37		0.45	0.51	0.48	
	100	0.35	0.47	0.41		0.53	0.55	0.54	
	150	0.39	0.48	0.44		0.51	0.54	0.53	
	Mean K	0.35	0.42			0.47	0.51		
	C V (%)	12.08				10.56			
	LSD ($p \leq 0.05$)	0.06		NS	NS	0.04		NS	NS

Legend: NS - Non significant; Old cultivar -CO421; New cultivars: KEN82-472 and KEN83-737

Table 7: Variations in soil %N due to cultivars, N and K_2O rates at 15 - 30 cm depth

Cultivar	N Rates kg/ha	Before Ratooning K_2O Rates kg/ha 0	100	Mean N	Mean Cultivar % N	Post-Harvest K_2O Rates kg/ha 0	100	Mean N	Mean Cultivar % N
CO421	0	0.31	0.33	0.32		0.38	0.47	0.43	
	50	0.33	0.48	0.41		0.49	0.55	0.52	
	100	0.35	0.47	0.41		0.58	0.59	0.59	
	150	0.44	0.56	0.50		0.52	0.55	0.54	
	Mean K	0.36	0.46		0.41	0.49	0.54		0.52
	C V (%)	10.71				11.07			
	LSD ($p \leq 0.05$)	0.06		NS		0.05		NS	
KEN 82-472	0	0.34	0.40	0.37		0.49	0.51	0.50	
	50	0.42	0.48	0.45		0.51	0.62	0.56	
	100	0.46	0.50	0.48		0.56	0.66	0.61	
	150	0.50	0.54	0.52		0.60	0.67	0.64	
	Mean K	0.43	0.48		0.46	0.54	0.61		0.58
	C V (%)	12.07				12.46			
	LSD ($p \leq 0.05$)	0.05		NS		0.06		NS	
KEN 83-737	0	0.35	0.42	0.39		0.48	0.50	0.49	
	50	0.42	0.49	0.45		0.49	0.61	0.55	
	100	0.47	0.52	0.50		0.55	0.65	0.60	
	150	0.50	0.55	0.53		0.59	0.65	0.62	
	Mean K	0.44	0.50		0.47	0.53	0.60		0.57
	C V (%)	12.46				13.15			
	LSD ($p \leq 0.05$)	0.04		NS		0.07		NS	
Overall Means	0	0.33	0.38	0.36		0.45	0.49	0.47	
	50	0.39	0.48	0.44		0.50	0.59	0.55	
	100	0.43	0.50	0.46		0.56	0.63	0.60	
	150	0.48	0.55	0.52		0.57	0.62	0.60	
	Mean K	0.41	0.48			0.52	0.59		
	C V (%)	11.75				12.23			
	LSD ($p \leq 0.05$)	0.06		NS	NS	0.05		NS	NS

Legend: NS - Non significant; Old cultivar: CO421; New cultivars- KEN82-472 and KEN83-737

Cultivars did not significantly ($p \leq 0.05$) influence soil N contents as CO421, KEN82-472 and KEN83-737 recorded statistically similar N values. The results concurred with the reports (Haynes and Hamilton, 1999, Walker *et al.*, 2007), but contradicted the findings (Muhammad *et al.*, 2010; Abou-Khalifa, 2012) where cultivars significantly influenced soil N levels.

The N application rates caused non-significant ($p \leq 0.05$) effect on soil N contents within both depths. This agreed with studies by Sadej and Przekwas (2008) and Abou-Khalifa (2012) where N levels remained non-significant ($p \leq 0.05$). The initial %N ranges at 0 - 15 cm and 15 - 30 cm depths were 0.37 - 0.41 and 0.41 - 0.47 respectively, which were considered high (Table 1). However, there was a noticeable accumulation of N in both soil layers. This could have resulted from incorporation of sugarcane trash during ratoon and stubble cultivation. However, the lower initial %N compared to the test values indicate the lack of application of N in the control. The higher %N before ratooning was from the N fertilization in the plant crop and residual N that contributed to the N mineralization potential of the soils.

The K_2O rates significantly ($p \leq 0.05$) increased soil N levels at both stages and depths. This observation agreed with the report (Wood, 1990) that potash application increased soil N availability. However, the data was in variance with other study (Lee and Jose, 2005) where potash application had insignificant influence on soil N. The results demonstrate that K_2O application is necessary to improve N availability in the vertisolic soils.

4.2.2 Soil Phosphorus

Cultivars (Table 8 - 9) did not significantly ($p \leq 0.05$) vary soil P. At 0 - 15 cm, the P levels were moderate (Table 1). The results agreed with the findings of Malavolta (1994), Shukla *et al.* (1995), Graham *et al.* (2000), Das (2000) and Ige *et al. (*2005) that regular application of P, which is relatively immobile and strongly adsorbed by soil particles, results in its accumulation within the top soil. The results contrasted other reports (Schroeder *et al.*, 1993; Morris *et al.*, 2005; Walker *et al.*, 2007; Abou - Khalifa, 2012) where cultivars markedly affected soil P levels.

Table 8: Variations in soil % P due to cultivars, N and K_2O rates at 0 - 15 cm depth

Cultivar	N Rates kg/ha	Before Ratooning K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % P	Post-Harvest K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % P
CO421	0	16.2	16.8	16.5		15.7	16.7	16.2	
	50	17.6	18.4	18.0		16.9	17.9	17.4	
	100	18.0	19.0	18.5		16.6	18.8	17.7	
	150	16.2	17.5	16.7		15.7	17.6	16.7	
	Mean K rate	17.0	17.9		17.5	16.2	17.8		17.0
	C V (%)	9.6				10.8			
	LSD (p≤0.05)	0.8		NS		1.5		NS	
KEN 82-472	0	16.9	18.8	17.8		16.8	18.7	17.8	
	50	18.7	19.0	18.9		18.6	19.0	18.8	
	100	19.0	20.0	19.5		18.9	19.0	19.0	
	150	18.0	19.7	18.8		17.9	19.6	18.8	
	Mean K	18.1	19.4		18.8	18.1	19.1		18.6
	C V (%)	10.5				11.4			
	LSD (p≤0.05)	1.2		NS		0.9		NS	
KEN 83-737	0	16.4	17.2	16.8		16.6	17.2	16.9	
	50	17.2	18.1	17.6		17.2	18.1	17.7	
	100	18.2	19.2	18.7		18.3	19.3	18.8	
	150	16.1	18.1	17.5		16.2	18.1	17.2	
	Mean K	17.0	18.1		17.6	17.1	18.2		17.6
	C V (%)	10.7				11.9			
	LSD (p≤0.05)	1.0		NS		1.0			
Overall Means	0	16.5	17.6	17.0		16.4	17.6	17.0	
	50	17.8	18.7	18.7		17.6	18.3	18.0	
	100	18.4	19.4	18.9		17.9	19.1	18.5	
	150	16.7	18.4	17.6		16.6	18.4	17.5	
	Mean K	17.4	18.5			17.1	18.4		
	C V (%)	10.2				11.4			
	LSD (p≤0.05)	0.9		NS	NS	1.2		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 9: Variations in soil %P due to cultivars, N and K_2O rates at 15 - 30 cm depth

Cultivar	N Rates kg/ha	Before Ratooning K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % P	Post-Harvest K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % P
CO421	0	11.7	13.7	12.7		9.6	11.0	10.3	
	50	13.2	14.9	14.0		10.7	11.4	11.0	
	100	14.0	16.0	15.0		10.4	12.4	11.4	
	150	12.9	15.5	14.2		9.6	11.1	10.4	
	Mean K	12.9	15.0		14.0	10.1	11.5		10.8
	C V (%)	11.9				12.3			
	LSD (p≤0.05)	1.9		NS		1.2		NS	
KEN 82-472	0	9.6	11.9	10.8		13.6	15.0	14.3	
	50	11.0	12.7	11.8		14.7	15.4	15.0	
	100	12.5	13.8	13.1		14.4	16.4	15.4	
	150	10.9	10.2	10.5		13.6	15.1	14.4	
	Mean K	11.0	12.2		11.6	14.0	15.5		14.8
	C V (%)	11.2				12.0			
	LSD (p≤0.05)	1.1		NS		1.3		NS	
KEN 83-737	0	9.2	10.3	9.7		12.2	13.5	12.8	
	50	10.1	10.5	10.3		13.2	15.1	14.1	
	100	10.2	12.1	11.2		13.9	16.3	15.1	
	150	10.1	11.0	10.6		13.0	15.0	14.0	
	Mean K	9.9	11.0		10.4	13.1	15.0		14.0
	C V (%)	12.7				11.2			
	LSD (p≤0.05)	0.7		NS		0.5		NS	
Overall Means	0	10.2	12.0	11.1		11.8	13.2	12.5	
	50	11.4	12.7	12.0		12.8	13.9	13.4	
	100	12.2	14.0	13.1		12.9	15.0	14.0	
	150	11.3	12.2	11.8		12.0	13.8	12.9	
	Mean K	11.3	12.7			12.4	14.0		
	C V (%)	11.9				11.9			
	LSD (p≤0.05)	0.57		NS	NS	0.57		NS	NS

Legend: NS -Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

The new cultivars registered lower, though statistically insignificant P soil levels at 0 - 15 cm depth after plant crop harvest. However, the P contents were within the sufficiency limits (Table 1). The data implies that cultivars had same ability to utilize soil P.

There were non-significant ($p \leq 0.05$) variations on P levels due to N rates within both depths and stages. The outcome may indicate that the applied N was not sufficient to cause any marked change on the content of soil P. The non-significant responses of the soil P to N application rates observed in this study, had also been reported in other studies (Muhammad *et al.*, 2010; Abou-Khalifa 2012). The data disagreed with previous reports (Debiprasad *et al.*, 2010) where they found significant ($p \leq 0.05$) significant variation in the soil P contents due to N treatments. The results demonstrate that soil P availability was not affected by N fertilizer application.

The K_2O rates significantly ($p \leq 0.05$) varied soil P at both stages and two soil depths. Despite the low soil P, the results show that 100 kg K/ha improved P availability in the soil. The data may indicate that K_2O fertilizer application should accompany P application to improve P uptake in sugarcane cultivation. These results corroborate the foliar P results (Tables 24 - 27).

4.2.3 Soil Potassium

The cultivars (Tables 10 - 11) significantly ($p \leq 0.05$) varied K levels after ratooning at 0 - 15 cm depth. The K levels were below the sufficiency range (KESREF, 2010) and are linked to the lower foliar K levels (Tables 28 - 31). The results agree with report (Kumar and Verma, 1997) that cultivars influence K levels causing different K availability.

The N rates insignificantly ($p \leq 0.05$) influenced soil K levels and concur with report of Muhammad *et al.* (2010). However, the data contradicts that of Abou-Khalifa (2012) on some rice cultivars under different N rates and could be due to the ability of the cultivars to absorb the K nutrient. The N rates applied were not within the levels that could affect the soil K levels.

Table 10: Variation in soil K (ppm) due to cultivars, N and K_2O rates at 0 - 15 cm depth

Cultivar	N Rates kg/ha	Before Ratooning				Post-Harvest			
		K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar K, ppm	K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar K, ppm
CO421	0	85.9	89.7	87.8		70.0	84.9	77.5	
	50	86.9	90.8	88.9		78.5	91.7	85.1	
	100	88.8	97.0	92.9		82.8	98.6	90.7	
	150	85.8	95.7	90.8		79.9	89.8	84.8	
	Mean K	86.9	93.3		90.1	77.8	91.3		84.5
	C V (%)	7.37				17.3			
	LSD ($p \leq 0.05$)	6.3		NS		13.3		NS	
KEN 82-472	0	62.0	84.9	73.5		57.3	72.0	64.7	
	50	67.1	88.9	78.0		69.4	75.6	72.5	
	100	74.5	98.0	86.2		71.1	84.6	77.8	
	150	70.7	82.1	76.4		64.6	78.1	71.3	
	Mean K	68.6	88.5		78.5	65.6	77.6		71.6
	C V (%)	26.4				18.3			
	LSD ($p \leq 0.05$)	19.7		NS		11.8		NS	
KEN 83-737	0	82.0	93.5	87.7		64.3	77.4	70.8	
	50	83.2	95.1	89.1		76.4	81.6	79.0	
	100	84.9	98.0	91.5		77.5	94.8	86.1	
	150	82.9	85.0	84.0		70.8	89.1	79.9	
	Mean K	83.3	92.9		88.1	72.2	85.7		79.0
	C V (%)	11.4				18.3			
	LSD ($p \leq 0.05$)	9.3		NS		13.2		NS	
Overall Means	0	76.7	89.4	83.0		63.9	78.1	71.0	
	50	79.1	91.6	85.3		74.7	83.0	78.9	
	100	82.7	97.6	90.2		77.1	92.7	84.9	
	150	79.8	87.6	83.7		71.7	85.6	78.7	
	Mean K	79.6	91.6			71.9	84.8		
	C V (%)	14.9				17.6			
	LSD ($p \leq 0.05$)	11.9		NS	NS	12.7		NS	5.4

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 11: Variation in soil K (ppm) to cultivars, N and K_2O rates at 15 - 30cm depth

Cultivar	N Rates kg/ha	Before Ratooning K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar K, ppm	Post-Harvest K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar K, ppm
CO421	0	72.3	97.1	84.7		69.2	86.1	77.6	
	50	79.4	98.1	88.7		72.7	87.8	80.2	
	100	82.9	99.2	91.1		75.0	89.5	82.2	
	150	79.5	96.5	88.0		71.2	81.5	76.4	
	Mean K	78.5	97.7		88.1	72.0	86.2		79.1
	C V (%)	24.2				19.7			
	LSD ($p \leq 0.05$)	19.2		NS		14.2		NS	
KEN 82-472	0	70.3	83.6	77.0		51.1	66.1	58.6	
	50	72.0	85.2	78.6		64.2	69.3	66.8	
	100	73.9	87.5	80.7		69.1	79.1	74.1	
	150	70.2	75.7	73.0		65.1	72.1	68.6	
	Mean K	71.6	83.0		77.3	62.4	71.7		67.0
	C V (%)	15.8				14.9			
	LSD ($p \leq 0.05$)	11.4		NS		9.3		NS	
KEN 83-737	0	81.1	93.1	87.1		52.3	77.1	64.7	
	50	82.0	95.2	88.6		59.4	78.1	68.7	
	100	83.3	97.3	90.3		62.9	79.2	71.1	
	150	80.2	87.2	83.7		59.5	76.5	68.0	
	Mean K	81.7	93.2		87.4	58.5	77.7		68.1
	C V (%)	13.9				27.7			
	LSD ($p \leq 0.05$)	11.3		NS		19.2		NS	
Overall Means	0	74.6	91.3	82.9		57.5	76.4	67.0	
	50	77.8	92.8	85.3		65.4	78.4	71.9	
	100	80.1	94.7	87.4		69.0	82.6	75.8	
	150	76.6	86.5	81.6		65.3	76.7	71.0	
	Mean K	77.3	91.3			64.3	78.5		
	C V (%)	18.1				21.8			
	LSD ($p \leq 0.05$)	13.6		NS	NS	14.1		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Potash application increased ($p \leq 0.05$) soil K at both layers, before ratooning and after harvest. The results imply that K deficiencies may be overcome by application of K_2O fertilizer.

4.2.4 Soil Calcium

Cultivars did not have any significant ($p \leq 0.05$) influence on soil Ca availability (Tables 12 - 13).

Table 12: Changes in soil Ca levels due to cultivars, N and K_2O rates at 0 - 15 cm depth

Cultivar	N Rates kg/ha	Before Ratooning				Post-Harvest			
		K_2O Rates kg/ha		Mean N Rate	Mean Cultivar Ca, ppm	K_2O Rates kg/ha		Mean N Rate	Mean Cultivar Ca, ppm
		0	100			0	100		
CO421	0	468	618	543		428	564	496	
	50	486	653	569		393	602	498	
	100	489	692	591		428	651	540	
	150	457	672	564		417	617	517	
	Mean K	475	659		567	417	609		513
	C V (%)	37				44			
	LSD ($p \leq 0.05$)	181		NS		191		NS	
KEN 82-472	0	437	578	507		427	568	497	
	50	445	613	529		435	612	524	
	100	456	660	558		436	651	543	
	150	457	641	549		447	630	538	
	Mean K	449	623		536	436	615		526
	C V (%)	32				40			
	LSD ($p \leq 0.05$)	173		NS		171		NS	
KEN 83-737	0	439	579	509		402	577	490	
	50	449	616	533		403	622	513	
	100	459	663	561		435	660	547	
	150	461	644	553		425	631	528	
	Mean K	452	626		539	416	623		520
	C V (%)	37				48			
	LSD ($p \leq 0.05$)	170		NS		205		NS	
Overall Means	0	436	591	513		431	570	501	
	50	445	629	537		426	610	518	
	100	460	670	565		441	655	548	
	150	446	648	547		442	630	536	
	Mean K	447	635			435	617		
	C V (%)	41				41			
	LSD ($p \leq 0.05$)	187		NS	NS	180		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 13: Variation in soil Ca (ppm) due to cultivars, N and K_2O at 15 - 30 cm depth

Cultivar	N Rates kg/ha	Before Ratooning: K_2O Rates kg/ha 0	Before Ratooning: K_2O Rates kg/ha 100	Before Ratooning: Mean N Rate	Before Ratooning: Mean Cultivar Ca, ppm	Post-Harvest: K_2O Rates kg/ha 0	Post-Harvest: K_2O Rates kg/ha 100	Post-Harvest: Mean N Rate	Post-Harvest: Mean Cultivar Ca, ppm
CO421	0	451	602	526		453	593	523	
	50	469	636	553		462	638	550	
	100	473	675	574		452	688	570	
	150	441	655	548		447	660	553	
	Mean K	459	642		550	453	645		549
	C V (%)	38				42			
	LSD ($p \leq 0.05$)	182		NS		192		NS	
KEN 82-472	0	463	594	528		423	564	494	
	50	470	638	554		432	608	520	
	100	492	685	588		422	658	540	
	150	477	667	572		417	630	523	
	Mean K	475	646		561	423	615		519
	C V (%)	33				41			
	LSD ($p \leq 0.05$)	170		NS		189		NS	
KEN 83-737	0	459	597	528		420	561	491	
	50	472	639	555		429	606	517	
	100	487	684	586		420	658	539	
	150	466	662	564	558	415	626	520	
	Mean K	471	646			421	613		517
	C V (%)	36				45			
	LSD ($p \leq 0.05$)	172		NS		191		NS	
Overall Means	0	458	598	528		432	573	503	
	50	470	638	554		441	617	529	
	100	484	681	583		431	668	550	
	150	461	661	561		426	638	532	
	Mean K	468	645			433	624		
	C V (%)	37				43			
	LSD ($p \leq 0.05$)	176		NS	NS	189		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

The data illustrates similarity with the pH levels (Tables 4 - 5) since an increase in pH is associated with availability of soil Ca. Similar results were reported by Lal and Pierce (1991) and Hartermink (1998). The results differ with Graham *et al.* (2000) where cultivars influenced soil Ca availability. The soil Ca levels were moderate (Table 1) for the ratoon cane production. The results therefore indicate that the soils contained relatively stable available Ca and the cultivars had equal ability to extract it from the soil.

The N rates (Tables 12 - 13) did not have significant ($p \leq 0.05$) effects on exchangeable soil Ca within the soil depths, before ratooning and during post-harvest. The soil Ca levels increased with 0 - 100 kg N/ha, but leveled down, though insignificantly, with 150 kg N/ha. However, the data was in variance with earlier findings (Muhammad *et al.*, 2010; Walker *et al.* 2007) where N rates significantly varied soil Ca levels. The applied N might not have been sufficient to cause significant effects on soil Ca availability.

The K_2O rates (Tables 12 - 13) increased soil Ca levels significantly ($p \leq 0.05$). However, after the post-harvest, lower Ca levels were recorded. Furthermore, the Ca pattern was similar to that of pH since a decrease in the latter declines accumulation of exchangeable Ca in the soil. The results agree with earlier work by Schroeder *et al.* (1993) and Graham *et al.*, (2000). The current study outcome suggests Ca availability to ratoon cane can be improved by K_2O application.

4.2.5 Soil Iron

The cultivars did not have any significant ($p \leq 0.05$) effects on the soil Fe levels (Tables 14 - 15). The non-responses could be due to equal abilities of the cultivars to absorb Fe. The findings agreed with those published by Schroeder *et al.* (1993). Therefore, cultivars used may not be of great concern to the uptake of Fe by the ratoon sugarcane.

Table 14: Variation in soil Fe (ppm) due to cultivars, N and K_2O rates at 0 - 15 cm depth

Cultivar	N Rates kg/ha	Before Ratooning K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Fe, ppm	Post-Harvest K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Fe, ppm
CO421	0	13.7	15.8	14.8		11.7	15.7	13.7	
	50	14.6	18.9	16.8		12.9	17.7	15.3	
	100	17.9	20.9	19.4		16.3	18.2	17.3	
	150	15.7	19.0	17.3		13.7	17.8	15.8	
	Mean K	15.5	18.7		17.1	13.7	17.4		15.5
	C V (%)	20.5				13.6			
	LSD (p≤0.05)	3.1		NS		3.7		NS	
KEN 82-472	0	10.8	14.3	12.6		8.5	12.3	10.4	
	50	11.7	16.2	13.9		9.3	14.3	11.8	
	100	15.0	18.0	16.5		12.3	15.3	13.8	
	150	12.9	16.0	14.4		10.5	14.4	12.5	
	Mean K	12.6	16.1		14.4	10.7	13.1		11.9
	C V (%)	27.6				22.3			
	LSD (p≤0.05)	3.5		NS		2.3		NS	
KEN 83-737	0	12.7	16.9	14.8		6.6	9.4	8.0	
	50	13.9	18.9	16.4		7.3	10.0	8.7	
	100	17.0	20.0	18.5		12.3	15.3	13.8	
	150	14.9	18.8	16.9		10.5	13.7	12.1	
	Mean K	14.6	18.7		16.7	9.2	12.1		10.7
	C V (%)	28.0				31.3			
	LSD (p≤0.05)	4.0		NS		2.8		NS	
Overall Means	0	12.4	15.7	14.1		8.9	12.5	10.7	
	50	13.4	18.0	15.7		9.8	14.0	11.9	
	100	16.6	19.6	18.1		13.6	16.3	15.0	
	150	14.5	17.9	16.2		11.6	15.3	13.5	
	Mean K	14.2	17.8			11.0	14.5		
	C V (%)	14.2				31.7			
	LSD (p≤0.05)	3.6		NS	NS	3.5		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 15: Variation in soil Fe (ppm) due to cultivars, N and K_2O rates at 15 - 30 cm depth

Cultivar	N Rates kg/ha	Before Ratooning: K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Fe, ppm	Post-Harvest: K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Fe, ppm
CO421	0	11.3	13.1	12.2		9.8	12.0	10.9	
	50	12.2	15.0	13.6		10.5	14.0	12.2	
	100	17.0	19.6	18.3		15.5	18.0	16.8	
	150	15.2	17.4	16.3		13.0	15.3	14.2	
	Mean K	13.9	16.3		15.1	12.2	14.9		13.5
	C V (%)	16.9				22.0			
	LSD (p≤0.05)	2.3		NS		2.7		NS	
KEN 82-472	0	9.7	11.2	10.5		7.8	11.0	9.4	
	50	10.5	15.0	12.8		9.2	12.0	10.6	
	100	15.0	17.6	16.3		13.5	16.0	14.8	
	150	13.2	15.3	14.3		12.3	13.1	12.7	
	Mean K	12.1	14.8		13.5	10.7	13.1		11.9
	C V (%)	22.2				22.3			
	LSD (p≤0.05)	2.7		NS		2.4		NS	
KEN 83-737	0	8.8	11.3	10.0		8.0	10.3	9.1	
	50	9.6	13.3	11.4		9.2	11.1	10.2	
	100	14.6	17.3	15.9		11.5	13.3	12.4	
	150	12.2	14.8	13.5		11.8	12.0	11.9	
	Mean K	11.3	14.2		12.7	10.1	11.7		10.9
	C V (%)	25.6				15.7			
	LSD (p≤0.05)	2.9		NS		1.6		NS	
Overall Means	0	9.9	11.9	10.9		8.5	11.1	9.8	
	50	10.8	14.4	12.6		9.6	12.4	11.0	
	100	15.5	18.1	16.8		13.5	15.8	14.6	
	150	13.5	15.9	14.7		12.4	13.5	12.9	
	Mean K	12.4	15.1			11.0	13.2		
	C V (%)	21.6				20.0			
	LSD (p≤0.05)	2.6			NS	2.2			NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

The N rates did cause any significant effects on the soil Fe levels and the findings were in agreement with reports by Das (2000) and Debiprasad *et al.* (2010). These results indicate that N rates did not cause loss of Fe through other means such as e.g. leaching.

Potash rates (Tables 14 - 15) significantly ($p \leq 0.05$) influenced on the soil Fe levels within the two depths, before ratooning and after harvest. This could have been attributed to K enhancing adsorption of Fe on the soil particles therefore causing the increase in soil Fe observed in this study. The results were similar to that of lowering soil pH and possibly due to Fe being more soluble in lower pH media. From the current data, the soil Fe can be improved by potash (K_2O) fertilizer application.

4.2.6 Soil Manganese

The cultivars (Tables 16 - 17) did not significantly ($p \leq 0.05$) influence soil Mn levels. This could be possibly mean that the cultivars have relatively equal potentialities to extract manganese and a characteristic attributed to cane cultivar genotypic similarities as reported by Keerio *et al.* (2003). However, the results disagree with another study finding (El-Geddway, *et al.,* 2001) where cultivars significantly affected Mn levels. Indeed, the Mn contents were below the recommended Mn levels (Table 1), thus the soil was deficient of Mn possibly due to low pH making Mn fixed.

Nitrogen rates increased Mn levels, but the difference did not reach significant ($p \leq 0.05$) levels before and after ratooning. Similar results were reported in other studies Das, 2000 and Debiprasad (2010) where Mn was sensitive to the changes in soil pH due to N rates. The Mn contents dropped under 150kg N/ha rate. However, the data does not agree with Muhammad *et al.* (2013) and Walker *et al.* (2007) where N rates markedly declined soil Mn. The results indicate that N applied was not high enough to cause soil Mn variations in a vertisolic soil.

Table 16: Variation in soil Mn (ppm) due to cultivars, N and K_2O at 0 - 15 cm depth

Cultivar	N Rates kg/ha	Before Ratooning K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Mn, ppm	Post-Harvest K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Mn, ppm
CO421	0	178	180	179		162	173	168	
	50	179	181	180		172	180	176	
	100	181	183	182		179	185	182	
	150	182	182	182		178	181	180	
	Mean K	180	182		181	173	180		176
	C V (%)	8.0				9.7			
	LSD ($p \leq 0.05$)	NS		NS		4		NS	
KEN 82-472	0	180	182	181		164	176	170	
	50	182	182	182		175	185	180	
	100	183	186	184		183	188	185	
	150	182	183	183		177	184	180	
	Mean K	182	183		183	175	183		179
	C V (%)	9.6				9.8			
	LSD ($p \leq 0.05$)	NS		NS		8		NS	
KEN 83-737	0	165	179	172		159	171	165	
	50	175	183	179		162	181	171	
	100	182	187	185		176	187	181	
	150	180	182	181		174	182	178	
	Mean K	176	183		179	168	180		174
	C V (%)	4.2				10.2			
	LSD ($p \leq 0.05$)	NS		NS		11		NS	
Overall Means	0	174	181	177		162	173	168	
	50	179	182	180		170	182	176	
	100	182	185	184		179	186	183	
	150	181	182	182		176	182	179	
	Mean K	179	183			172	181		
	C V (%)	9				9.9			
	LSD ($p \leq 0.05$)	NS		NS	NS	9		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars -KEN82-472 and KEN83-737

Table 17: Variation in soil Mn (ppm) due to cultivars, N and K_2O rates at 15 - 30 cm depth

Cultivar	N Rates kg/ha	Before Ratooning K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Mn, ppm	Post-Harvest K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Mn, ppm
CO421	0	163	174	168		157	169	163	
	50	170	183	177		168	178	173	
	100	180	187	184		176	185	181	
	150	177	183	180		173	178	176	
	Mean K	173	182		177	169	178		173
	C V (%)	5.3				5.3			
	LSD (p≤0.05)	9		NS		9		NS	
KEN 82-472	0	159	171	165		158	170	164	
	50	170	179	175		169	179	174	
	100	177	186	181		177	186	182	
	150	174	180	177		174	177	176	
	Mean K	170	179		174	170	178		174
	C V (%)	5.3				4.8			
	LSD (p≤0.05)	9		NS		8		NS	
KEN 83-737	0	157	168	162		153	167	160	
	50	168	177	172		164	176	170	
	100	174	183	179		172	183	178	
	150	171	177	174		170	174	172	
	Mean K	167	176		172	165	175		170
	C V (%)	5.2				5.4			
	LSD (p≤0.05)	9		NS		9		NS	
Overall Means	0	160	171	165		156	169	163	
	50	169	180	175		167	177	172	
	100	177	185	181		175	185	180	
	150	174	180	177		172	177	175	
	Mean K	170	179			168	177		
	C V (%)	5.2				5.3			
	LSD (p≤0.05)	9		NS	NS	9		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Potash (K_2O) rates (Tables 16 - 17) significantly increased Mn ($p \leq 0.05$) levels within the layers, before ratooning and after harvest. The pattern followed the pH trend (Table 4 - 5). The data agreed with reports (Hadi *et al.*, 1997) where K enhanced Mn availability. The results suggest that it is necessary to apply K to improve the availability of Mn in the vertisolic soils.

4.2.7 Soil Zn levels

The variations of Zn levels due to cultivars, N and K_2O rates are illustrated in the Tables 18 - 19. The cultivars did not significantly ($p \leq 0.05$) affect Zn levels. The cultivar data indicate that the Zn levels were moderate (Table 1). These results may suggest that despite cultivar differences in ability to extract soil Zn, Zn levels would still be maintained during cane cultivation.

There were linear increments in soil Zn contents due to N fertilizer rates, but did not reach significant ($p \leq 0.05$) levels. The data concurred with the report (Debiprasad *et al.,* 2010) that application of inorganic N significantly raised soil Zn levels. In a related study (Marinho and Albuquerque, 1981) Zn occurred in calcareous and phosphate applied soils while Hadi *et al.* (1997) reported that soil zinc levels reduced with the declining soil pH levels. However, the results contrasted with studies (Abou-Khalifa, 2012; Walker *et al.,* 2007) where N rates reduced Zn levels in soils under rice cultivation. This observation could be attributed to differences in the types of the soils in the different studies. The results may imply that the application of N fertilizer might not be the correct way to restore soil Zn.

The potash fertilizer application rates significantly ($p \leq 0.05$) increased soil Zn levels at both stages and soil layers. The results concur with earlier report (Filho, 1985) that reported significant increase in soil Zn due to K_2O fertilization. These findings suggest that K_2O application is crucial for Zn availability for ratoon cane crop production.

Table 18: Variations in soil Zn due to cultivars, N and K_2O rates 0 - 15 cm depth

Cultivar	N Rates kg/ha	Before Ratooning K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Zn, ppm	Post-Harvest K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Zn, ppm
CO421	0	63.4	88.3	75.9		43.9	49.8	46.9	
	50	72.3	92.8	82.5		42.3	58.8	50.6	
	100	82.4	94.1	88.3		61.4	74.1	67.8	
	150	80.2	84.4	82.3		56.2	68.4	62.3	
	Mean K	74.6	89.9		82.3	51.0	62.8		56.9
	C V (%)	20.5				23.0			
	LSD (p≤0.05)	15.3		NS		11.5		NS	
KEN 82-472	0	60.4	81.7	71.1		41.4	52.1	46.8	
	50	70.3	90.4	80.3		53.7	57.8	55.8	
	100	80.1	94.1	87.1		56.3	66.8	61.6	
	150	79.2	84.3	81.8		51.3	61.4	56.4	
	Mean K	72.5	87.6		80.1	50.7	59.5		55.1
	C V (%)	20.8				17.1			
	LSD (p≤0.05)	15.1		NS		8.7		NS	
KEN 83-737	0	60.8	81.7	71.3		44.7	52.8	48.8	
	50	71.0	90.7	80.8		53.9	65.2	59.5	
	100	80.8	94.9	87.8		56.3	69.6	63.0	
	150	79.7	88.0	83.8		48.3	56.2	52.3	
	Mean K	73.1	88.8		80.9	50.8	61.0		55.9
	C V (%)	21.3				20.0			
	LSD (p≤0.05)	15.7		NS		9.9		NS	
Overall Means	0	61.6	83.9	72.7		43.4	51.6	47.5	
	50	71.2	91.3	81.2		50.0	60.6	55.3	
	100	81.1	94.4	87.7		58.0	70.2	64.1	
	150	79.7	85.6	82.6		51.9	62.0	57.0	
	Mean K	73.4	88.8			50.8	61.1		
	C V (%)	20.7				19.9			
	LSD (p≤0.05)	15.4		NS	NS	10.1		NS	NS

Legend: NS-Non significant; Old cultivar- CO421; New cultivars - KEN82-472 and KEN83-737

Table 19: Variations in soil Zn due to cultivars, N and K_2O rates 15 - 30 cm depth

Cultivar	N Rates kg/ha	Before Ratooning				Post-Harvest			
		K_2O Rates kg/ha		Mean N Rate	Mean Cultivar Zn, ppm	K_2O Rates kg/ha		Mean N Rate	Mean Cultivar Zn, ppm
		0	100			0	100		
CO421	0	66.7	78.1	72.4		40.2	51.0	45.6	
	50	72.8	86.2	79.5		47.6	53.7	50.6	
	100	79.8	89.8	84.8		53.1	62.8	58.0	
	150	76.2	78.8	77.5		48.1	58.2	53.2	
	Mean K	73.9	83.2		78.6	47.3	56.4		51.9
	C V (%)	12.4				19.1			
	LSD (p≤0.05)	9.1		NS		9.1		NS	
KEN 82-472	0	57.8	87.1	72.5		39.4	50.1	44.8	
	50	63.8	88.8	76.3		45.3	56.6	50.9	
	100	70.8	99.7	85.3		51.3	67.3	59.3	
	150	68.1	96.8	82.5		41.1	57.5	49.3	
	Mean K	65.1	93.1		79.1	44.3	57.9		51.1
	C V (%)	42.6				30.7			
	LSD (p≤0.05)	28.0		NS		13.6		NS	
KEN 83-737	0	57.2	77.1	67.2		34.5	51.1	42.8	
	50	68.2	88.9	78.6		47.5	54.0	50.8	
	100	69.4	99.7	84.5		51.1	66.1	58.6	
	150	67.1	96.5	81.8		47.1	55.2	51.2	
	Mean K	65.5	90.5		78.0	45.1	56.6		50.8
	C V (%)	37.9				25.3			
	LSD (p≤0.05)	24.8		NS		11.3		NS	
Overall Means	0	60.6	80.8	70.7		38.1	50.7	44.4	
	50	68.3	88.0	78.1		46.8	54.8	50.8	
	100	73.3	96.4	84.9		51.9	65.4	58.6	
	150	70.5	90.7	80.6		45.4	57.0	51.2	
	Mean K	68.2	89.0			45.5	57.0		
	C V (%)	30.3				25.1			
	LSD (p≤0.05)	20.6		NS	NS	11.4		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

From the observations made on the effects of treatments on soil pH, N, P, K, Ca, Fe, Mn and Zn levels at 0 - 15 cm and 15 - 30 cm before ratooning and at post-harvest (Tables 3-19), it can be concluded that, only soil K (Table 10) significantly ($p \leq 0.05$) changed due to cultivars at 0 - 15 cm soil depth at post-harvest. This may suggest that ratoon canes have greater K extracting potentialities than the plant crops. Although, both N and potash rates altered soil physicochemical characteristics, only K_2O treatments caused significant ($p \leq 0.05$) increase on all of the soil properties. The results demonstrate that the soils are grossly in need of K to ensure availability of these nutrients.

4. 3 Variation in foliar nutrients levels due to cultivars, N and K_2O fertilizer rates

The results for variations in foliar nutrients levels in different months after ratooning (MAR) due to cultivars, N and potash fertilization rates are represented in Figures 2 - 22 and Tables 20 - 47.

4.3.1 Foliar Nitrogen

Foliar N levels (Figure 2) varied significantly ($p \leq 0.05$) with cultivars between the 5^{th} - 7^{th} MAR.

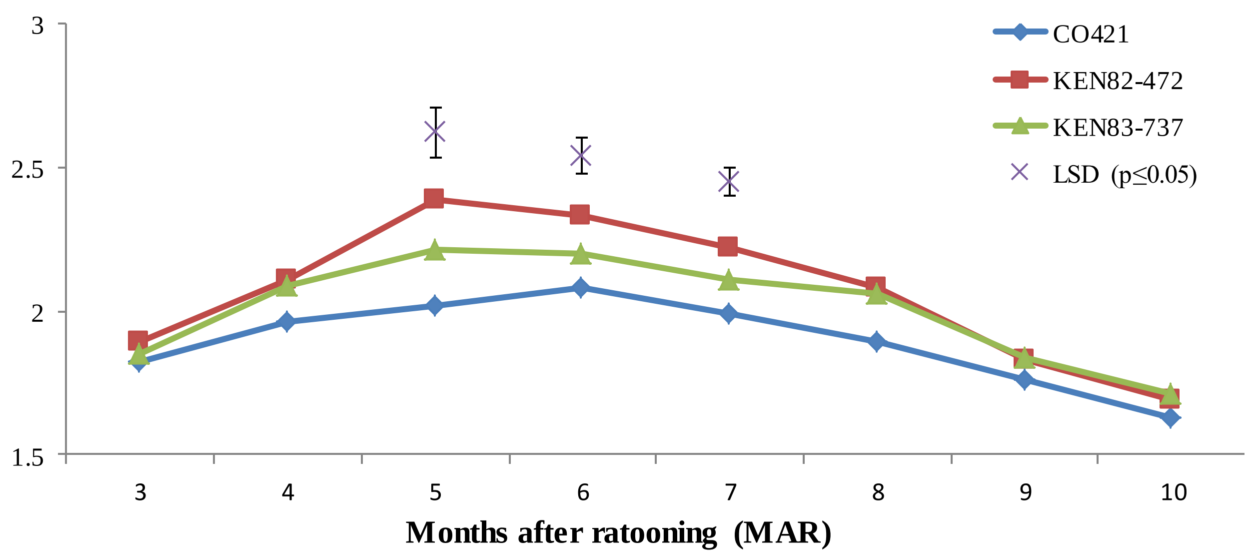

Figure 2: Variations in foliar N levels of cultivars at different ages.

The new cultivars had higher N % than CO421 throughout the period. The difference be due to genetic makeup of the cultivars to extract N from the soil. Prior to 5^{th} MAR and after peaks, the cultivar differences were non-significant ($p \leq 0.05$). There was a decline in foliar %N after the peaks and could be attributed to rapid growth and dry matter accumulation that resulted in the foliar N dilution. The data concurred with study finding (Oindo, 2015) where significant differences in foliar N levels of ratoon crops of both early and late maturing cultivars were recorded the 5^{th} to 10^{th} MAR. Moreover, the data agreed with other reports (Ambachew and Abiy, 2012; Ochola, 2013) where foliar N % in plant cane crops differed significantly between 5^{th} and 8^{th} month after planting (MAP). However, the results contrasted reports by Panwar and Katyal (1986) and Yadava (1993) that illustrated late maturing cultivars recorded higher foliar N % than early maturing cultivars. Significant differences in this study imply that from the 5^{th} MAR onwards, individual cultivars require specific recommendations on N fertilizer rates if these were to be used in foliar analysis. Therefore, the data suggest that foliar sampling for estimation of N levels should be done in Kenya before the 5^{th} MAR when the levels have not started responding to different cultivars.

There were significant ($p \leq 0.05$) differences in foliar N (Figure 3) with N rates from 5^{th} - 7^{th} MAR. The results agreed with reports (Stranack and Miles, 2011; Ambachew and Abiy, 2012) where increasing N rates markedly elevated foliar %N in TVD plants. In Kenya, the data agreed with Ochola (2013) where N rates significantly affected foliar N contents in plant crops of early and late maturing cultivars. The foliar %N was within optimal range (Table 2) at the 5^{th} MAR, but below critical level at the 10^{th} MAR. This indicated that N fertilization was adequate during the growth stage but reduced as the cane matured. The 100 kg N/ha recorded higher significant ($p \leq 0.05$) responses in foliar N at the 5^{th} MAR in all the cultivars than other N fertilizer rates.

This indicated that optimal uptake time and rate for cane production. The data suggests that in the use of foliar N to predict the N deficiency sampling should be before the 4th MAR.

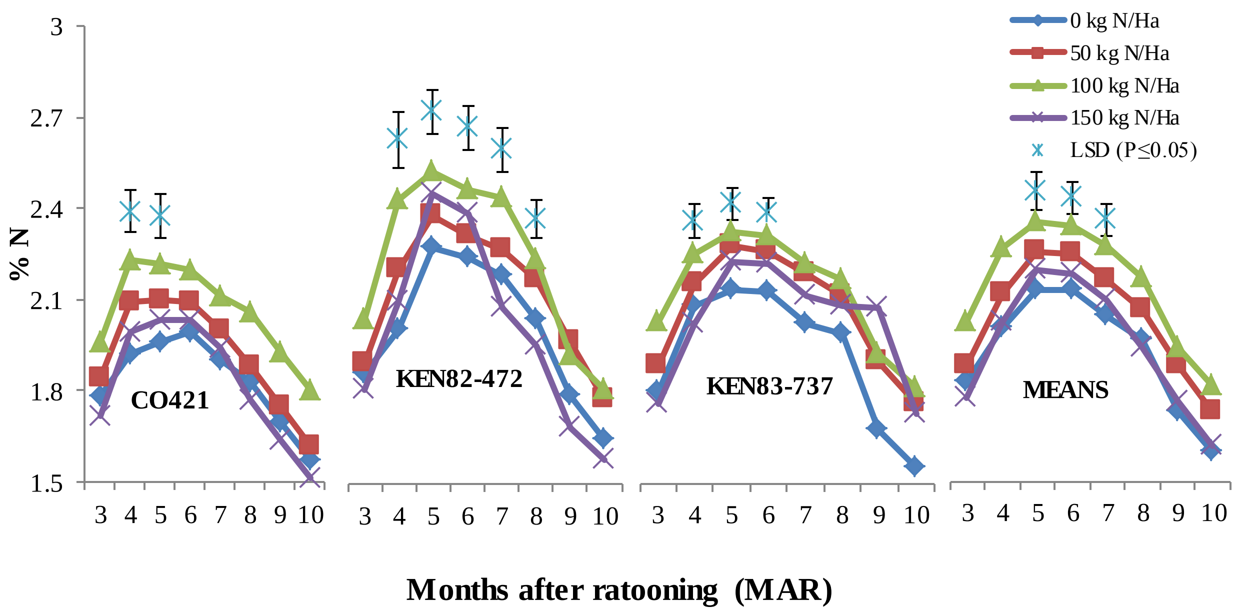

Figure 3: Variations in foliar N content with N rates (kg/ha) in cultivars

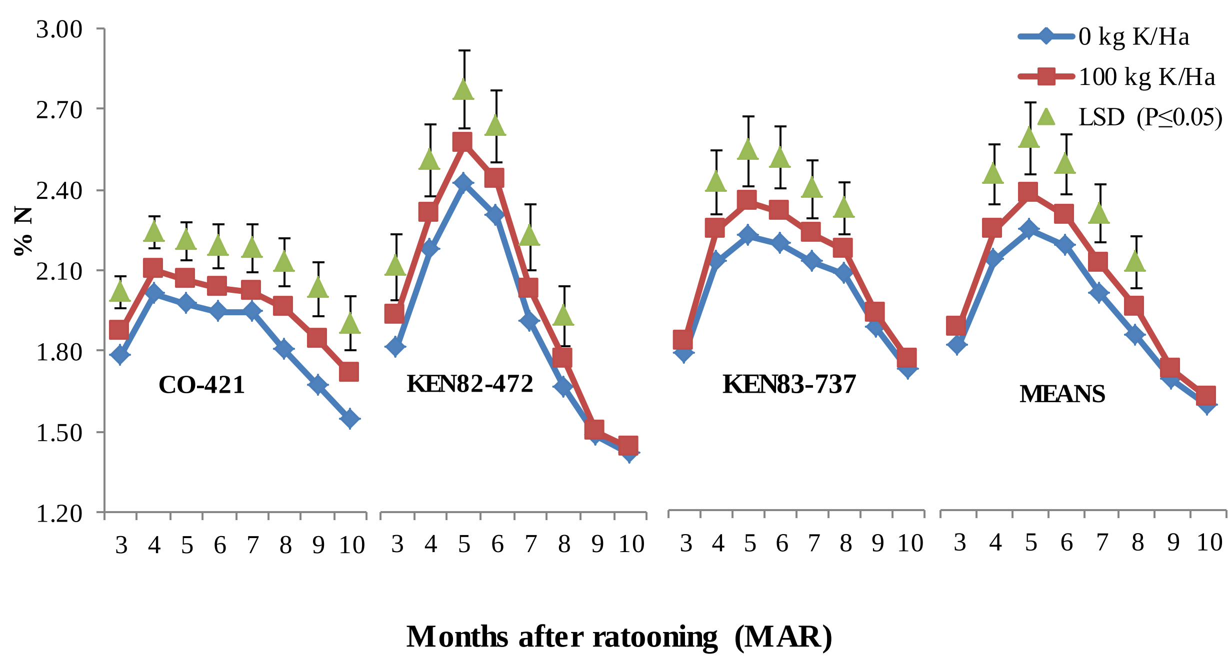

Figure 4: Foliar N levels due to K_2O rates in CO421, KEN82-472 and KEN83-737

Increasing potash rates significantly ($p \leq 0.05$) increased foliar N from 4th to 8th MAR (Figure 4). These results are in line with reports (Rice *et al*., 2002; Ezenwa *et al*., 2008) where increasing potash rates increased foliar N%. The K trans-location is fast and effects may show up as early as the 3rd MAR, when the nutrient was applied. Therefore foliar K status can be monitored using foliar analysis before 4th MAR.

In conclusion, higher ($p \leq 0.05$) foliar N responses were recorded with the new early maturing ratoon cultivars than the old and late maturing cultivars. The 100kg N/ha rate recorded higher significant ($p \leq 0.05$) responses in foliar N at the 5th MAR in all the cultivars than other N rates. Increasing K_2O rates from 0 to the 100 kg K_2O/ha increased foliar N significantly ($p \leq 0.05$) from 4th to 8th MAR.

Table 20: Variations in foliar %N due to cultivars, N and K_2O rates from 3 - 4[th] MAR

Cultivar	N Rates kg/ha	3rd MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % N	4th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % N
CO421	0	1.74	1.82	1.78		1.91	1.93	1.92	
	50	1.79	1.89	1.84		2.05	2.12	2.09	
	100	1.87	2.05	1.96		2.13	2.32	2.23	
	150	1.71	1.73	1.72		1.93	2.04	1.99	
	Mean K	1.78	1.87		1.82	2.01	2.10		2.05
	C V (%)	5.06				4.51			
	LSD (p≤0.05)	0.09		NS		0.09		0.07	
KEN 82-472	0	1.82	1.87	1.85		1.93	2.05	1.99	
	50	1.85	1.91	1.88		2.07	2.28	2.18	
	100	1.99	2.05	2.02		2.31	2.48	2.40	
	150	1.73	1.87	1.8		2.19	1.97	2.08	
	Mean K	1.85	1.93		1.89	2.13	2.20		2.16
	C V (%)	4.33				3.31			
	LSD (p≤0.05)	0.08		NS		0.07		0.09	
KEN 83-737	0	1.74	1.84	1.79		2.01	2.11	2.06	
	50	1.84	1.89	1.87		2.10	2.16	2.13	
	100	1.99	2.04	2.01		2.24	2.19	2.22	
	150	1.71	1.79	1.75		1.96	2.04	2.00	
	Mean K	1.82	1.89		1.85	2.08	2.13		2.11
	C V (%)	3.85				2.41			
	LSD (p≤0.05)	0.07		NS		0.05		0.06	
Overall Means	0	1.77	1.84	1.81		1.94	2.02	1.98	
	50	1.83	1.9	1.86		2.04	2.15	2.09	
	100	1.95	2.05	2.00		2.18	2.28	2.23	
	150	1.72	1.80	1.76		2.01	1.99	2.00	
	Mean K	1.82	1.90			2.04	2.11		
	C V (%)	4.41				3.43			
	LSD (p≤0.05)	0.08		NS	NS	0.07		0.05	0.05

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 21: Variations in foliar %N due to cultivars, N and K_2O rates from 5 - 6th MAR

Cultivar	N Rates kg/ha	5th MAR K_2O Rates kg/ha 0	5th MAR K_2O Rates kg/ha 100	5th MAR Mean N Rate	5th MAR Mean Cultivar % N	6th MAR K_2O Rates kg/ha 0	6th MAR K_2O Rates kg/ha 100	6th MAR Mean N Rate	6th MAR Mean Cultivar % N
CO421	0	1.92	1.94	1.93		1.98	2.00	1.99	
	50	1.98	2.06	2.02		2.06	2.12	2.09	
	100	2.05	2.24	2.15		2.11	2.18	2.20	
	150	1.94	2.00	1.97		2.00	2.06	2.03	
	Mean K	2.01	2.06		2.02	2.01	2.06		2.08
	C V (%)	9.14				8.74			
	LSD ($p \leq 0.05$)	0.04		0.06		0.04		NS	
KEN 82-472	0	2.17	2.33	2.25		2.14	2.29	2.22	
	50	2.29	2.40	2.35		2.24	2.33	2.29	
	100	2.43	2.55	2.49		2.37	2.49	2.43	
	150	2.37	2.47	2.42		2.32	2.39	2.36	
	Mean K	2.33	2.43		2.38	2.27	2.38		2.32
	C V (%)	10.31				9.69			
	LSD ($p \leq 0.05$)	0.09		0.07		0.10		0.07	
KEN 83-737	0	2.09	2.13	2.11		2.07	2.12	2.10	
	50	2.19	2.31	2.25		2.18	2.29	2.23	
	100	2.23	2.35	2.29		2.22	2.33	2.28	
	150	2.17	2.24	2.20		2.16	2.23	2.19	
	Mean K	2.17	2.26		2.21	2.16	2.24		2.20
	C V (%)	8.29				7.41			
	LSD ($p \leq 0.05$)	0.09		0.05		0.08		0.05	
Overall Means	0	2.06	2.13	2.10		2.06	2.14	2.10	
	50	2.16	2.27	2.22		2.17	2.25	2.21	
	100	2.24	2.38	2.31		2.23	2.37	2.30	
	150	2.16	2.24	2.16		2.16	2.23	2.15	
	Mean K	2.16	2.26			2.16	2.25		
	C V (%)	9.29				8.61			
	LSD ($p \leq 0.05$)	0.09		0.06	0.15	0.08		0.05	0.11

Legend: NS-Non significant; Old cultivar- CO421; New cultivars - KEN82-472 and KEN83-737

Table 22: Variations in foliar %N due to cultivars, N and K_2O rates from 7 - 8th MAR

Cultivar	N Rates kg/ha	7th MAR K_2O Rates kg/ha 0	100	Mean N rate	Mean Cultivar % N	8th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % N
CO421	0	1.88	1.92	1.90		1.77	1.89	1.83	
	50	1.97	2.02	2.00		1.78	1.99	1.88	
	100	2.01	2.21	2.11		1.91	2.21	2.06	
	150	1.91	1.96	1.94		1.76	1.79	1.77	
	Mean K	1.94	2.02		1.98	1.80	1.97		1.89
	C V (%)	4.14				9.44			
	LSD ($p\leq0.05$)	0.08		NS		0.16		NS	
KEN 82-472	0	2.03	2.29	2.16		1.93	2.12	2.02	
	50	2.13	2.35	2.24		2.05	2.25	2.15	
	100	2.38	2.44	2.41		2.14	2.29	2.21	
	150	1.73	2.39	2.06		1.73	2.14	1.94	
	Mean K	2.08	2.36		2.22	1.97	2.19		2.08
	C V (%)	13.46				11.18			
	LSD ($p\leq0.05$)	0.27		0.07		0.22		0.06	
KEN 83-737	0	1.97	2.03	2.00		1.91	2.03	1.97	
	50	2.09	2.23	2.16		2.05	2.13	2.09	
	100	2.13	2.25	2.19		2.13	2.15	2.14	
	150	2.07	2.11	2.09		2.05	2.07	2.06	
	Mean K	2.07	2.15		2.11	2.03	2.09		2.06
	C V (%)	9.59				10.13			
	LSD ($p\leq0.05$)	0.08		NS		0.06		NS	
Overall Means	0	1.96	2.08	2.02		1.87	2.01	1.94	
	50	2.06	2.20	2.13		1.96	2.12	2.04	
	100	2.16	2.32	2.24		2.06	2.22	2.14	
	150	1.90	2.15	2.07		1.85	2.00	1.92	
	Mean K	2.02	2.19			1.93	2.09		
	C V (%)	8.42				8.29			
	LSD ($p\leq0.05$)	0.16		0.05	0.11	0.16		0.05	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 23: Variations in foliar N due to cultivars, N and K_2O rates from 9 - 10th MAR

Cultivar		9th MAR				10th MAR			
	N Rates kg/ha	K_2O Rates kg/ha 0	100	Mean N rate	Mean Cultivar % N	K_2O Rates kg/ha 0	100	Mean N rate	Mean Cultivar % N
CO421	0	1.64	1.76	1.70		1.51	1.63	1.57	
	50	1.65	1.86	1.75		1.52	1.73	1.62	
	100	1.78	2.08	1.93		1.65	1.96	1.80	
	150	1.63	1.66	1.64		1.50	1.53	1.51	
	Mean K	1.67	1.84		1.76	1.54	1.71		1.63
	C V (%)	10.18				11.04			
	LSD (p≤0.05)	0.10		NS		0.10		NS	
KEN 82-472	0	1.69	1.87	1.78		1.55	1.73	1.56	
	50	1.81	2.09	1.95		1.63	1.91	1.76	
	100	1.79	2.04	1.91		1.58	2.01	1.90	
	150	1.48	1.88	1.68		1.42	1.74	1.68	
	Mean K	1.69	1.97		1.83	1.54	1.85		1.69
	C V (%)	10.57				11.56			
	LSD (p≤0.05)	0.13		NS		0.14		NS	
KEN 83-737	0	1.61	1.73	1.67		1.48	1.63	1.55	
	50	1.83	1.93	1.88		1.70	1.80	1.75	
	100	1.86	1.95	1.91		1.73	1.87	1.80	
	150	1.79	2.05	2.05		1.66	1.79	1.72	
	Mean K	1.77	1.92		1.84	1.64	1.77		1.71
	C V (%)	8.47				7.93			
	LSD (p≤0.05)	NS		NS		NS		NS	
Overall Means	0	1.65	1.79	1.72		1.51	1.66	1.56	
	50	1.76	1.96	1.86		1.62	1.81	1.71	
	100	1.81	2.02	1.92		1.65	1.95	1.83	
	150	1.63	1.86	1.75		1.53	1.69	1.64	
	Mean K	1.71	1.91			1.58	1.78		
	C V (%)	9.74				10.18			
	LSD (p≤0.05)	NS		NS	NS	NS		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars -KEN82-472 and KEN83-737

4.3.2 Foliar Phosphorus

The uptake of P is vital for sugarcane growth and root development (Ambachew *et al.*, 2012). The variations in the foliar P contents with cultivars, N and K_2O rates are shown in Figures 5 - 7.

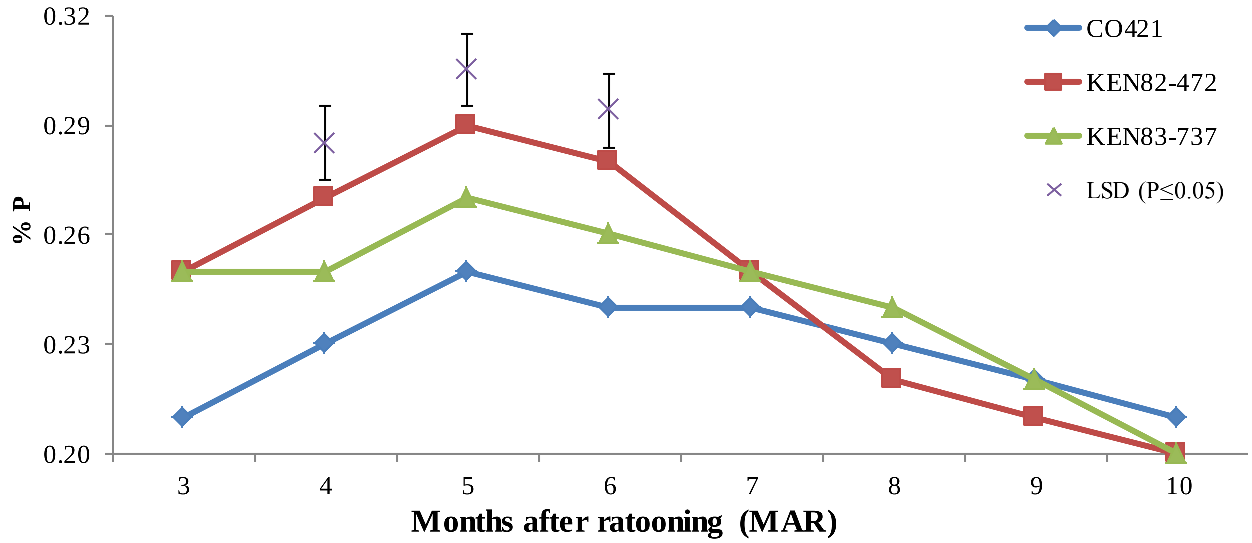

Figure 5: Foliar % P of cultivars at different ages (MAR)

There were significant ($p \leq 0.05$) cultivar differences in foliar P from 4 - 6th MAR (Figure 5; Tables 24 - 27). The results were similar to other reports (Ambachew *et al.*, 2012) that nutrients uptake in sugarcane vary with cultivars. The foliar P pattern was similar to that of N in this study (Figure 2). The peaks were achieved at the 5th MAR in all the cultivars. The differences could have been due to genotypic differences. The early maturing sugarcane cultivars absorbed more P from the soil than the old cultivar. After the the 6th MAR, however, there were non-significant ($p \leq 0.05$) differences in foliar P levels, but declined with intermittent crosses towards the 10th MAR. This observation contradicted the studies (Yadava, 1993; Ambachew *et al.*, 2012) that foliar levels of P in ratoon sugarcane increased with crop age. Generally the foliar P values were optimal (Table 2) and may suggest that the basal P application was sufficient for the three cultivars and did not limit ratoon cane productivity. Furthermore, the data indicated that successful foliar sampling and analysis for prediction of P nutrient be done before the 4th MAR.

Nitrogen rates significantly (p≤0.05) affected foliar P contents (Figure 6). The lowest foliar %P was obtained at zero N rate and interestingly, was still optimal (Table 2). This is an indication that the soil P uptake could have been sourced from the basal P treatment (45kg P/ha) without much help from N application. The results concur with other studies (Franco *et al.*, 2010; Stranack and Miles, 2011; Ambachew and Abiy, 2012; Ochola, 2013). After the peaks, the foliar P levels under all the N rates declined with insignificant differences being observed. Similar pattern was reported by Muchovej and Newman (2004a, b) and Debiprasad *et al.* (2010) where organic N was applied. The results demonstrate that sensitivity of P to N fertilizer application can be tested before the 3rd MAR. The foliar P levels were within the optimum range 0.22 - 0.30 % (Table 2). This suggested that nutrient P may not be a limiting factor in this study.

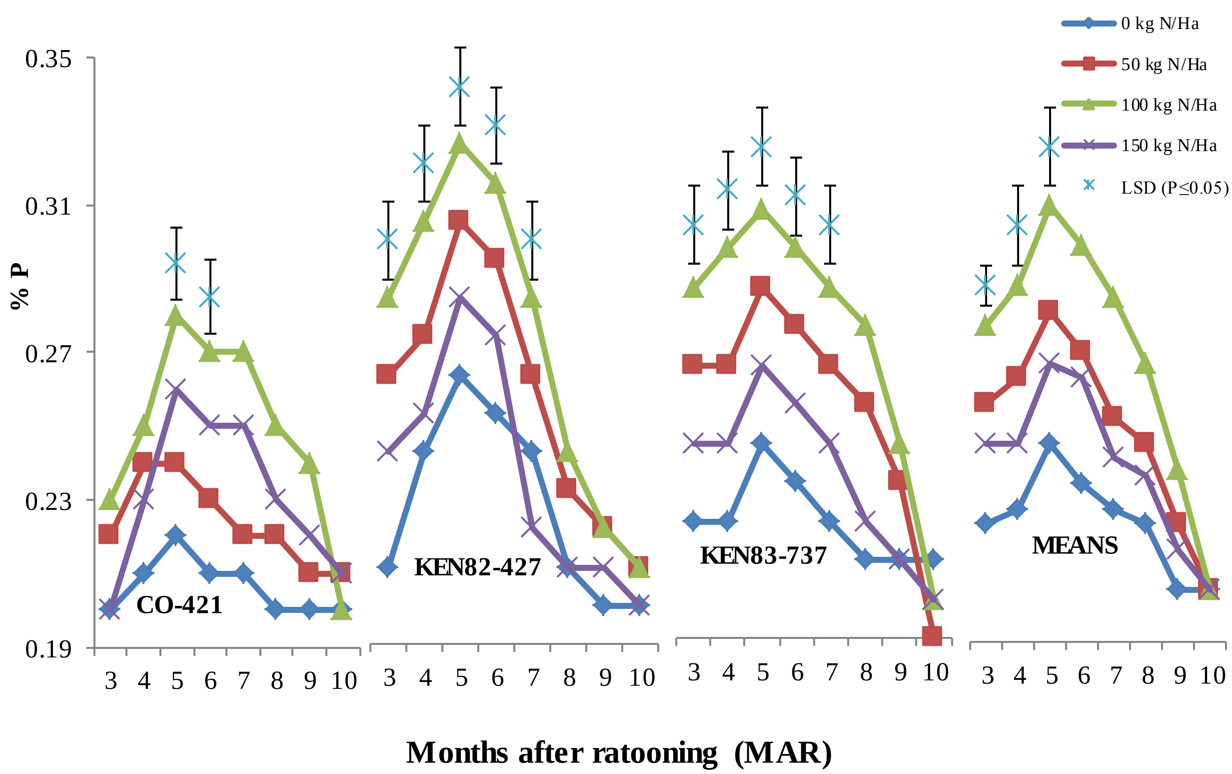

Figure 6: Foliar P levels due to N rates in CO421, KEN82-472 and KEN83-737

Potash (K_2O) rates (Figure 7) caused significant ($p \leq 0.05$) variation on foliar P levels in KEN83-737 from 3 - 8th MAR. The peaks occurred at the 5th MAR irrespective of the K_2O applied rate. However, during the 9 - 10th MAR, there was a decline in foliar P availability with non-significant ($p \leq 0.05$) response in P in CO421 and KEN83-737 cultivars. The results compare effectively with soil data (Tables 8 and 9) where potash rates increased soil available P. These observations suggest that potash application should be a recommended practice in the Kenya Sugar Industry to improve plant nutrition and productivity. The foliar P levels were maintained within the optimum reference range i.e. 0.22 - 0.30 %, (Table 2).

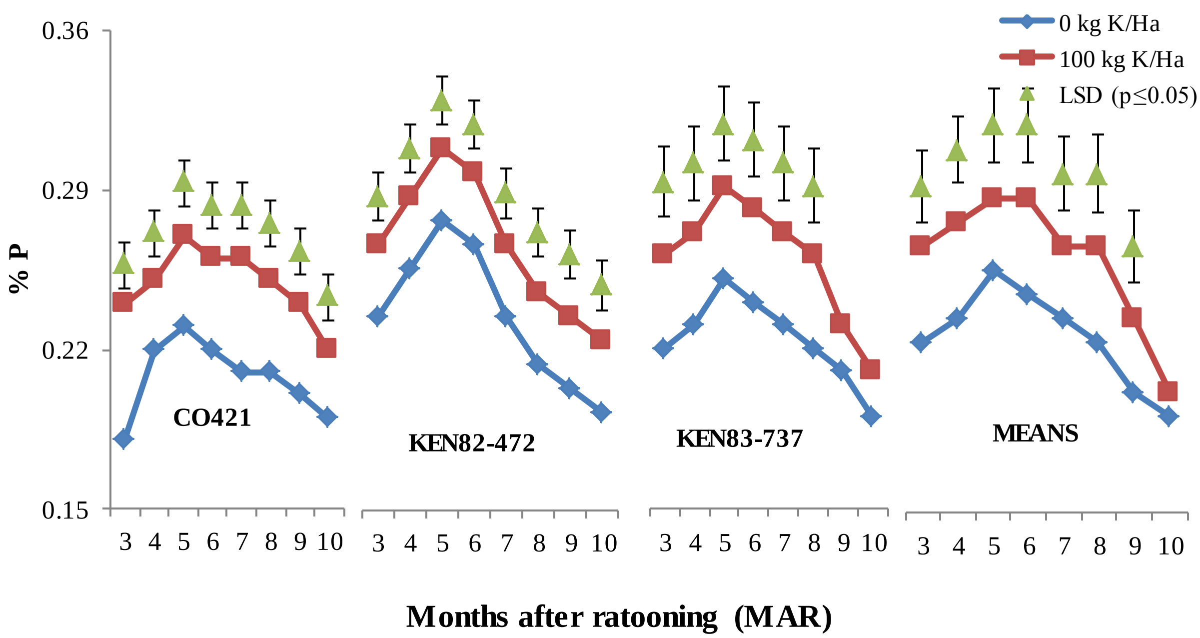

Figure 7: Variations in foliar %P with potash rates in CO421, KEN82-472 and KEN83-737

Table 24**:** Variations in foliar P due to cultivars, N and K_2O rates from 3 - 4th MAR

Cultivar	N Rates kg/ha	3rd MAR: K_2O Rates kg/ha 0	3rd MAR: K_2O Rates kg/ha 100	3rd MAR: Mean N Rate	3rd MAR: Mean Cultivar % P	4th MAR: K_2O Rates kg/ha 0	4th MAR: K_2O Rates kg/ha 100	4th MAR: Mean N Rate	4th MAR: Mean Cultivar % P
CO421	0	0.17	0.23	0.20		0.18	0.24	0.21	
	50	0.18	0.25	0.22		0.22	0.25	0.24	
	100	0.20	0.26	0.23		0.24	0.26	0.25	
	150	0.17	0.22	0.20		0.22	0.24	0.23	
	Mean K	0.18	0.24		0.21	0.22	0.25		0.23
	C V (%)	33.07				13.64			
	LSD ($p \leq 0.05$)	0.05		NS		0.03		0.02	
KEN 82-472	0	0.17	0.24	0.21		0.20	0.27	0.24	
	50	0.25	0.27	0.26		0.26	0.28	0.27	
	100	0.26	0.29	0.28		0.28	0.31	0.30	
	150	0.23	0.25	0.24		0.25	0.27	0.25	0.27
	Mean K	0.23	0.26		0.25	0.25	0.28		
	C V (%)	13.04				12.00			
	LSD ($p \leq 0.05$)	0.03		0.02		0.03		0.02	
KEN 83-737	0	0.18	0.25	0.22		0.18	0.25	0.22	
	50	0.23	0.27	0.25		0.24	0.28	0.26	
	100	0.25	0.28	0.27		0.26	0.29	0.28	
	150	0.23	0.25	0.24		0.23	0.25	0.24	0.25
	Mean K	0.22	0.26		0.25	0.23	0.27		
	C V (%)	18.18				13.04			
	LSD ($p \leq 0.05$)	0.04		0.02		0.03		0.02	
Overall Means	0	0.18	0.25	0.22		0.19	0.25	0.22	
	50	0.23	0.27	0.25		0.24	0.27	0.26	
	100	0.25	0.29	0.27		0.26	0.29	0.28	
	150	0.22	0.25	0.24		0.23	0.25	0.24	
	Mean K	0.22	0.26			0.23	0.27		
	C V (%)	18.19				17.39			
	LSD ($p \leq 0.05$)	0.04		NS	NS	0.04		0.02	0.02

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 25: Variations in foliar P due to cultivars, N and K rates from 5 - 6th MAR

Cultivar	N Rates kg/ha	5th MAR K₂O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % P	6th MAR K₂O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % P
CO421	0	0.19	0.25	0.22		0.18	0.24	0.21	
	50	0.22	0.26	0.24		0.21	0.25	0.23	
	100	0.26	0.29	0.28		0.25	0.28	0.27	
	150	0.25	0.27	0.26		0.23	0.26	0.25	0.24
	Mean K	0.23	0.27		0.25	0.22	0.26		
	C V (%)	11.11				18.18			
	LSD ($p \leq 0.05$)	0.04		NS		0.04		NS	
KEN 82-472	0	0.22	0.29	0.26		0.21	0.29	0.25	
	50	0.29	0.3	0.30		0.28	0.29	0.29	
	100	0.31	0.32	0.32		0.30	0.31	0.31	
	150	0.27	0.29	0.28		0.26	0.28	0.27	0.28
	Mean K	0.27	0.30		0.29	0.26	0.29		
	C V (%)	11.11				11.54			
	LSD ($p \leq 0.05$)	0.03		NS		0.03		NS	
KEN 83-737	0	0.20	0.27	0.24		0.19	0.26	0.23	
	50	0.25	0.28	0.27		0.24	0.27	0.26	
	100	0.28	0.31	0.30		0.27	0.31	0.29	
	150	0.26	0.28	0.27		0.25	0.27	0.26	0.26
	Mean K	0.25	0.29		0.27	0.24	0.28		
	C V (%)	16.01				16.67			
	LSD ($p \leq 0.05$)	0.04		NS		0.04		NS	
Overall Means	0	0.20	0.27	0.24		0.19	0.26	0.23	
	50	0.25	0.28	0.27		0.24	0.27	0.26	
	100	0.28	0.31	0.30		0.27	0.30	0.29	
	150	0.26	0.28	0.27		0.25	0.27	0.26	
	Mean K	0.25	0.28			0.24	0.28		
	C V (%)	12.00				16.67			0.02
	LSD ($p \leq 0.05$)	0.03		NS	0.02	0.04		NS	

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 26: Variations in foliar P due to cultivars, N and K_2O rates from 7 - 8th MAR

Cultivar	7th MAR					8th MAR			
	N Rates kg/ha	K_2O Rates kg/ha 0	K_2O Rates kg/ha 100	Mean N Rate	Mean Cultivar % P	K_2O Rates kg/ha 0	K_2O Rates kg/ha 100	Mean N Rate	Mean Cultivar % P
CO421	0	0.18	0.23	0.21		0.18	0.22	0.20	
	50	0.20	0.24	0.22		0.21	0.23	0.22	
	100	0.24	0.29	0.27		0.23	0.27	0.25	
	150	0.23	0.27	0.25		0.20	0.26	0.23	
	Mean K	0.21	0.26		0.24	0.21	0.25		0.23
	C V (%)	23.81				19.04			
	LSD ($p \leq 0.05$)	0.05		NS		0.04		NS	
KEN 82-472	0	0.20	0.28	0.24		0.17	0.25	0.21	
	50	0.25	0.26	0.26		0.22	0.23	0.23	
	100	0.27	0.28	0.28		0.23	0.24	0.24	
	150	0.21	0.23	0.22		0.20	0.22	0.21	
	Mean K	0.23	0.26		0.25	0.21	0.24		0.22
	C V (%)	13.04				14.29			
	LSD ($p \leq 0.05$)	0.03		NS		0.03		NS	
KEN 83-737	0	0.18	0.25	0.22		0.18	0.25	0.22	
	50	0.23	0.26	0.25		0.22	0.26	0.24	
	100	0.26	0.30	0.28		0.24	0.28	0.26	
	150	0.23	0.25	0.24		0.22	0.24	0.23	
	Mean K	0.23	0.27		0.25	0.22	0.26		0.24
	C V (%)	17.39				18.18			
	LSD ($p \leq 0.05$)	0.04		NS		0.04		NS	
Overall Means	0	0.19	0.25	0.22		0.18	0.24	0.22	
	50	0.23	0.26	0.25		0.22	0.24	0.24	
	100	0.26	0.29	0.28		0.23	0.26	0.26	
	150	0.22	0.25	0.24		0.21	0.24	0.23	
	Mean K	0.23	0.26			0.22	0.26		
	C V (%)	13.04				18.18			
	LSD ($p \leq 0.05$)	0.03		NS	NS	0.04		NS	NS

Legend: NS- Non significant; Old cultivar- CO421; New cultivars- KEN82-472 and KEN83-737

Table 27: Variations in foliar P due to cultivars, N and K_2O rates from 9 - 10th MAR

Cultivar	N Rates kg/ha	9th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % P	10th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % P
CO421	0	0.18	0.21	0.20		0.18	0.21	0.20	
	50	0.20	0.22	0.21		0.19	0.22	0.21	
	100	0.22	0.26	0.24		0.19	0.23	0.21	
	150	0.19	0.25	0.22		0.18	0.22	0.20	
	Mean K	0.20	0.24		0.22	0.19	0.22		0.21
	C V (%)	20.0				15.7			
	LSD ($p \leq 0.05$)	0.04		NS		0.03		NS	
KEN 82-472	0	0.17	0.23	0.20		0.17	0.22	0.20	
	50	0.20	0.23	0.22		0.19	0.23	0.21	
	100	0.21	0.23	0.22		0.20	0.22	0.21	
	150	0.20	0.22	0.21		0.19	0.21	0.20	
	Mean K	0.20	0.23		0.21	0.19	0.22		0.20
	C V (%)	15.0				15.8			
	LSD ($p \leq 0.05$)	0.03		NS		0.03		NS	
KEN 83-737	0	0.18	0.22	0.20		0.18	0.20	0.19	
	50	0.21	0.23	0.22		0.19	0.21	0.20	
	100	0.22	0.24	0.23		0.20	0.22	0.21	
	150	0.20	0.22	0.21		0.19	0.21	0.20	
	Mean K	0.21	0.23		0.22	0.19	0.21		0.20
	C V (%)	9.0				7.9			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	0.18	0.22	0.20		0.18	0.21	0.20	
	50	0.20	0.23	0.22		0.19	0.22	0.20	
	100	0.22	0.24	0.23		0.20	0.22	0.20	
	150	0.20	0.23	0.21		0.19	0.21	0.20	
	Mean K	0.20	0.23			0.19	0.22		
	C V (%)	9.3				15.8			NS
	LSD ($p \leq 0.05$)	0.03		NS	NS	0.03		NS	

Legend: NS- Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

4.3.3 Foliar K levels

Poatassium is vital for cane growth as it is aids in sucrose synthesis and phloem loading (Malavolta, 1994; Kumar and Verma, 1997; Garcia *et al.*, 2001; Mengel and Kirby, 2001). The variations due to cultivars, N and K_2O fertilizer rates on foliar % K are shown in Figures 8 - 10.

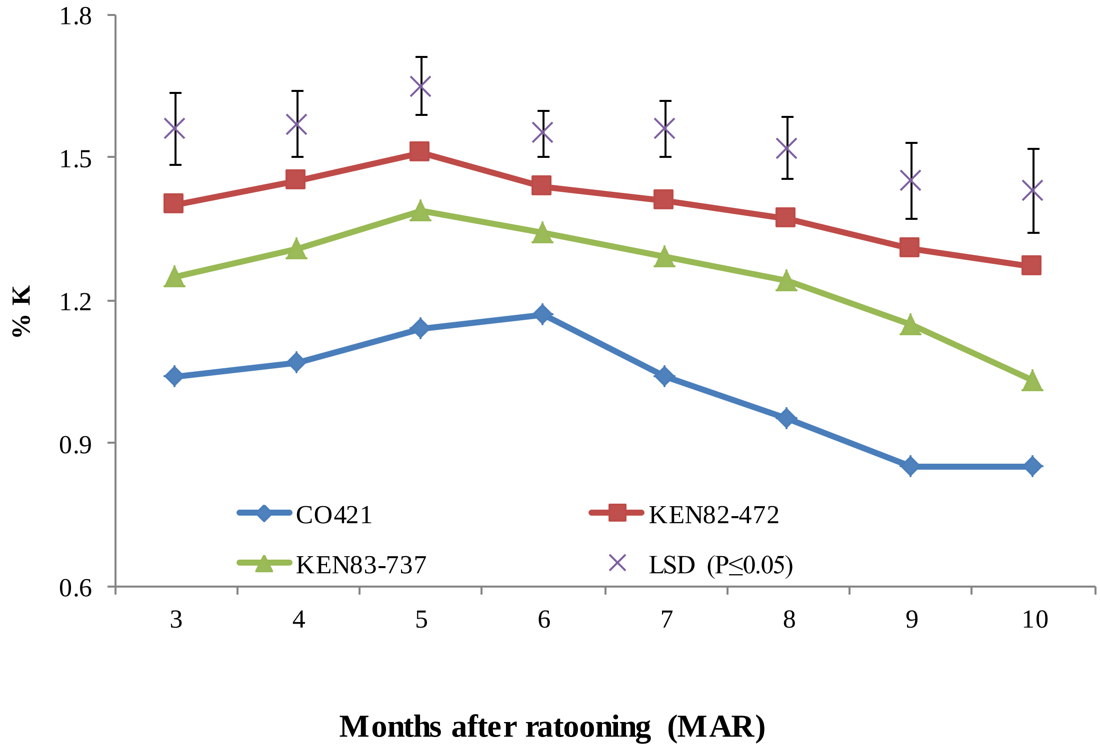

Figure 8: Variation of foliar % K with age in CO421, KEN82-472 and KEN83-737

The cultivars significantly ($p \leq 0.05$) influenced foliar K contents throughout the sampling period (Figures 8; Tables 28 - 31). The old cultivar CO421 recorded lower % K than the new cultivars from 3 - 10th MAR. The lower foliar K values could have been due to the different cultivar K absorption abilities since all cultivars received similar treatments. From 3rd - 5th MAR, there was fairly uniform increment in cultivar foliar K contents. This could have been due to the potash applied being taken up adequately during the active growth period (Ambachew and Abiy, 2012).

The variations in foliar K levels with cultivars are not unique as Schroeder *et al.* (1993) in South Africa had observed similar variations. The KEN82-472 and KEN83-737 attained peaks at the 5th MAR while the old CO421 peaked later at the 6th MAR. After the peaks, the foliar potassium contents declined to lower and critical concentrations (Table 2) from 9 - 10th MAR. This trend was also observed in another study by Stranack and Miles (2011) where foliar K levels dropped after the peaks. Despite the earlier peak of the new cultivars at 5th MAR, it was still later than those observed elsewhere (Whitehead, 2000) and possibly due to differences in genotypes or the conditions of growth. After the peak, there was decline in foliar levels of potassium as the ratoon crops approached maturity. This outcome indicates that optimal foliar K sampling age ought to be before the 5th MAR which agrees with those suggested ages of 3rd - 5th and 4th - 7 MAR in Queensland and New South Wales respectively (Schroeder *et al.*, 1999). The sampling time for foliar K, therefore, does not vary with geographical area of production.

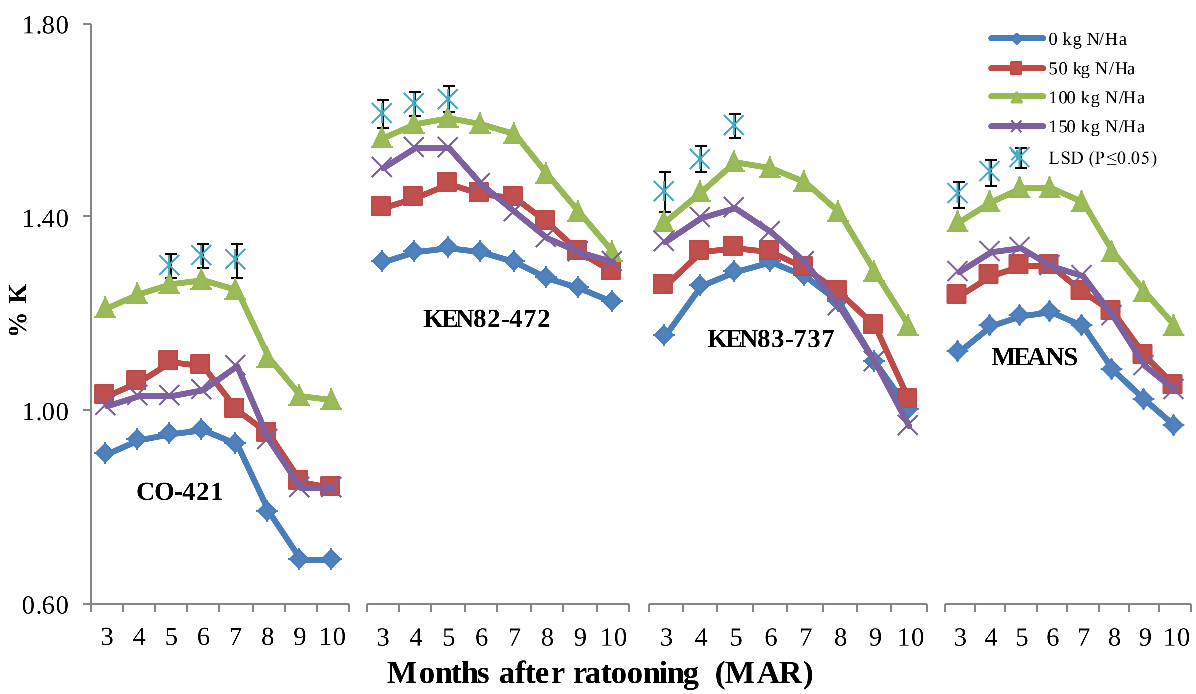

Figure 9: Variation in foliar K due to N fertilizer rates

There were significant ($p \leq 0.05$) effects of N rates (Figure 9) on foliar K from 3rd - 5th MAR in the cultivars. The variations that occurred after the 5th MAR due to N rates were insignificant. Zero and 50 kg N/ha produced lowest % K throughout the trial. Higher 100 kg N/ha reduced foliar K levels. In another study (Debiprasad *et al.*, 2010), foliar K peaks were observed earlier than the 5th MAR. This can be attributed to environmental variations in the responses or differences in cultivars used. However, the results demonstrate that responses in foliar K due to N rates can only be recorded from 3rd - 5th MAR in the new cultivars and 5 - 7th in the old CO421 cultivar. From the cultivar means, the results suggest that the best time for testing for adequacy of foliar K levels should be before 4th MAR.

Potassium rates (Figure 10) significantly ($p \leq 0.05$) increased foliar K levels during the entire trial period. The results agreed with the findings (Singh and Jha, 1994; Ahmed, *et al.*, 2009) where absorption of K by ratoon cane was significantly increased with increasing the K_2O.

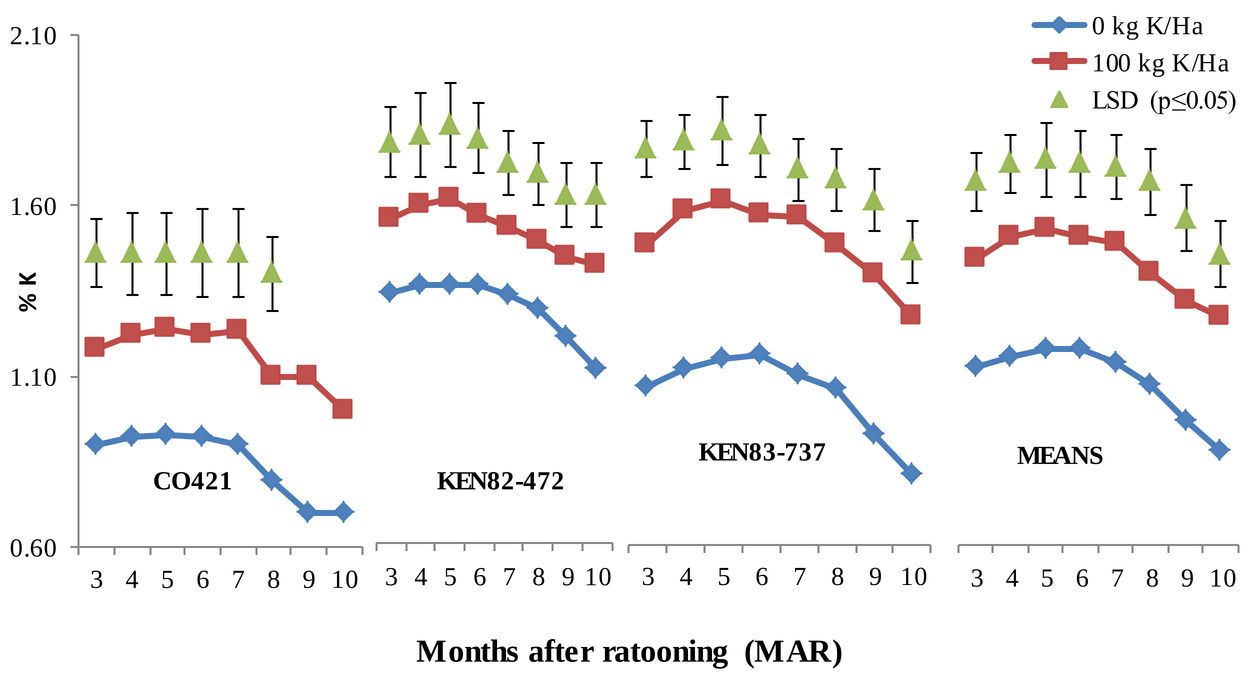

Figure 10: Variations in foliar K levels due to K_2O rates in CO421, KEN82-472 and KEN83-737

The results contradicted a report by Akhtar and Akhtar (2002) where K_2O application rates did not affect foliar K levels. The responses of cultivar foliar K indicate that 100 kg K/ha attained the peaks earlier at the 5^{th} MAR while the 0 kg K/ha rate was at the 6^{th} MAR. However, after the attainment of the peaks, there was a general decline in the foliar K levels possibly due to the additional role of K in phloem loading of assimilates (Cavalot *et al*., 1990) as the ratoon crop approached maturity.

The foliar K contents were within the sufficiency range under the test treatment while the control recorded critical foliar K (Table 2). The results demonstrate that applied K is taken up by the plant as reflected by soil K data (Tables 10 - 11). Furthermore, the outcome indicates that application of potash fertilizers will benefit ratoon cane plants.

Table 28: Changes in foliar % K with cultivars, N and K_2O rates from 3rd - 4th MAR

Cultivar	N Rates kg/ha	3rd MAR K_2O Rates kg/ha 0	3rd MAR K_2O Rates kg/ha 100	3rd MAR Mean N Rate	3rd MAR Mean Cultivar % K	4th MAR K_2O Rates kg/ha 0	4th MAR K_2O Rates kg/ha 100	4th MAR Mean N Rate	4th MAR Mean Cultivar % K
CO421	0	0.79	1.03	0.91		0.81	1.06	0.94	
	50	0.84	1.21	1.03		0.86	1.25	1.06	
	100	0.99	1.42	1.21		1.01	1.47	1.24	
	150	0.96	1.05	1.01		0.98	1.08	1.03	
	Mean K	0.90	1.18		1.04	0.92	1.22		1.07
	C V (%)	15.0				15.3			
	LSD ($p \leq 0.05$)	0.27		NS		0.30		NS	
KEN 82-472	0	1.09	1.49	1.29		1.10	1.52	1.31	
	50	1.27	1.52	1.40		1.28	1.55	1.42	
	100	1.48	1.59	1.54		1.52	1.62	1.57	
	150	1.43	1.52	1.48		1.46	1.57	1.52	
	Mean K	1.32	1.53		1.42	1.34	1.57		1.45
	C V (%)	14.9				15.2			
	LSD ($p \leq 0.05$)	0.21		0.06		0.23		0.05	
KEN 83-737	0	0.89	1.38	1.14		0.93	1.54	1.24	
	50	0.98	1.49	1.24		1.06	1.56	1.31	
	100	1.22	1.51	1.37		1.28	1.57	1.43	
	150	1.16	1.49	1.33		1.17	1.59	1.38	
	Mean K	1.06	1.47		1.27	1.11	1.57		1.34
	C V (%)	15.2				15.9			
	LSD ($p \leq 0.05$)	0.17		0.04		0.19		0.05	
Overall Means	0	0.92	1.30	1.11		0.95	1.37	1.16	
	50	1.03	1.41	1.22		1.07	1.45	1.26	
	100	1.23	1.51	1.37		1.27	1.55	1.41	
	150	1.18	1.35	1.27		1.20	1.41	1.31	
	Mean K	1.09	1.39			1.12	1.45		
	C V (%)	15.1				15.4			
	LSD ($p \leq 0.05$)	0.30		NS	0.15	0.33		NS	0.09

Legend: NS- Non significant; Old cultiva- CO421; New cultivars - KEN82-472 and KEN83-737

Table 29: Foliar %K with cultivars, N and K_2O rates at 5 - 6th MAR

Cultivar	N Rates kg/ha	5th MAR K_2O Rates kg/ha 0	5th MAR K_2O Rates kg/ha 100	5th MAR Mean N Rate	5th MAR Cultivar Mean	6th MAR K_2O Rates kg/ha 0	6th MAR K_2O Rates kg/ha 100	6th MAR Mean N Rate	Mean Cult. % K
CO421	0	0.82	1.07	0.95		0.83	1.08	0.96	
	50	0.88	1.29	1.09		0.88	1.29	1.09	
	100	1.03	1.49	1.26		1.04	1.5	1.27	
	150	0.97	1.09	1.03		0.93	1.14	1.04	
	Mean K	0.93	1.24		1.08	0.92	1.22		1.09
	C V (%)	15.3				16.5			
	LSD ($p \leq 0.05$)	0.30		0.05		0.30		0.05	
KEN 82-472	0	1.10	1.53	1.32		1.15	1.47	1.31	
	50	1.33	1.57	1.45		1.31	1.55	1.43	
	100	1.51	1.65	1.58		1.51	1.62	1.57	
	150	1.43	1.61	1.52		1.39	1.5	1.45	
	Mean K	1.34	1.59		1.47	1.34	1.54		1.44
	C V (%)	18.7				14.9			
	LSD ($p \leq 0.05$)	0.25		0.05		0.20		NS	
KEN 83-737	0	0.93	1.60	1.27		1.05	1.53	1.29	
	50	1.07	1.56	1.32		1.07	1.55	1.31	
	100	1.35	1.62	1.49		1.32	1.63	1.48	
	150	1.20	1.6	1.40		1.16	1.54	1.35	
	Mean K	1.14	1.60		1.37	1.15	1.56		1.36
	C V (%)	19.9				15.9			
	LSD ($p \leq 0.05$)	0.34		0.05		0.17		NS	
Overall Means	0	0.95	1.40	1.18		1.01	1.36	1.19	
	50	1.09	1.47	1.28		1.09	1.46	1.28	
	100	1.30	1.59	1.45		1.29	1.58	1.44	
	150	1.20	1.43	1.32		1.16	1.39	1.28	
	Mean K	1.14	1.47			1.14	1.45		
	C V (%)	14.9				14.3			
	LSD ($p \leq 0.05$)	0.34		0.05	0.10	0.31		NS	0.08

Legend: NS-Non significant; Old cultivar - CO421; New cultivars- KEN82-472 and KEN83-737

Table 30: Variations in foliar K due to cultivars, N and K_2O rates at 7 - 8th MAR

Cultivar	N Rates kg/ha	7th MAR: K_2O Rates kg/ha 0	7th MAR: K_2O Rates kg/ha 100	7th MAR: Mean N Rate	7th MAR: Mean Cultivar % K	8th MAR: K_2O Rates kg/ha 0	8th MAR: K_2O Rates kg/ha 100	8th MAR: Mean N Rate	8th MAR: Mean Cult. % K
CO421	0	0.78	1.07	0.93		0.67	0.91	0.79	
	50	0.82	1.17	1.00		0.77	1.13	0.95	
	100	1.02	1.47	1.25		0.88	1.34	1.11	
	150	0.99	1.19	1.09		0.84	1.03	0.94	
	Mean K	0.90	1.23		1.08	0.79	1.10		0.95
	C V (%)	14.2				14.1			
	LSD ($p \leq 0.05$)	0.32		0.07		0.29		NS	
KEN 82-472	0	1.12	1.45	1.29		1.01	1.44	1.23	
	50	1.30	1.53	1.42		1.29	1.49	1.39	
	100	1.48	1.61	1.55		1.41	1.47	1.44	
	150	1.33	1.44	1.39		1.37	1.46	1.42	1.37
	Mean K	1.31	1.51		1.41	1.27	1.47		
	C V (%)	14.4				13.7			
	LSD ($p \leq 0.05$)	0.19		NS		0.20		NS	
KEN 83-737	0	0.92	1.59	1.26		0.88	1.53	1.21	
	50	1.01	1.54	1.28		0.97	1.49	1.23	
	100	1.32	1.58	1.45		1.28	1.50	1.39	
	150	1.1	1.48	1.29		1.05	1.34	1.20	1.26
	Mean K	1.09	1.55		1.32	1.05	1.47		
	C V (%)	13.65				13.07			
	LSD ($p \leq 0.05$)	0.19		NS		0.18		NS	
Overall Means	0	0.94	1.37	1.16		0.85	1.29	1.07	
	50	1.04	1.41	1.23		1.01	1.37	1.19	
	100	1.27	1.55	1.41		1.19	1.44	1.32	
	150	1.14	1.37	1.26		1.09	1.28	1.19	
	Mean K	1.10	1.43			1.04	1.35		
	C V (%)	14.1				14.1			
	LSD ($p \leq 0.05$)	0.33		NS	0.09	0.31		NS	0.09

Legend: NS- Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 31: Changes in foliar K due to cultivars, N and K_2O rates at 9 - 10th MAR

Cultivar	N Rates kg/ha	9th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % K	10th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. % K
CO421	0	0.57	0.81	0.69		1.02	0.84	0.69	
	50	0.68	1.02	0.84		0.67	1.01	0.84	
	100	0.81	1.24	1.02		0.80	1.23	1.02	
	150	0.74	0.94	0.84		0.74	0.94	0.84	
	Mean K	0.70	1.10		0.84	0.70	1.00		0.85
	C V (%)	10.2				10.1			
	LSD ($p \leq 0.05$)	0.29		NS		0.28		NS	
KEN 82-472	0	1.03	1.39	1.21		0.98	1.43	1.21	
	50	1.17	1.37	1.27		1.02	1.52	1.27	
	100	1.30	1.47	1.31		1.2	1.42	1.31	
	150	1.27	1.34	1.29		1.19	1.39	1.29	
	Mean K	1.19	1.42		1.31	1.10	1.44		1.27
	C V (%)	9.8				9.3			
	LSD ($p \leq 0.05$)	0.24		NS		0.34		NS	
KEN 83-737	0	0.77	1.40	0.99		0.70	1.27	0.99	
	50	0.9	1.41	1.01		0.72	1.29	1.01	
	100	1.12	1.42	1.16		0.99	1.33	1.16	
	150	0.9	1.02	0.96		0.77	1.14	0.96	
	Mean K	0.92	1.38		1.15	0.80	1.26		1.03
	C V (%)	10.4				13.3			
	LSD ($p \leq 0.05$)	0.18		NS		0.18		NS	
Overall Means	0	0.79	1.22	1.01		0.75	1.17	0.96	
	50	0.92	1.29	1.11		0.80	1.27	1.04	
	100	1.08	1.38	1.23		1.00	1.33	1.17	
	150	0.97	1.19	1.08		0.90	1.16	1.03	
	Mean K	0.94	1.27			0.86	1.23		
	C V (%)	10.1				11.2			
	LSD ($p \leq 0.05$)	0.31		NS	0.16	0.31		NS	0.18

Legend: NS- Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

4.3.4 Foliar Calcium

The variations in foliar Ca levels due to cultivars, N and K_2O rates are shown in Figures 11 - 13 and Tables 32 - 35. Cultivars significantly ($p \leq 0.05$) influenced foliar Ca levels from 3 - 7th MAR.

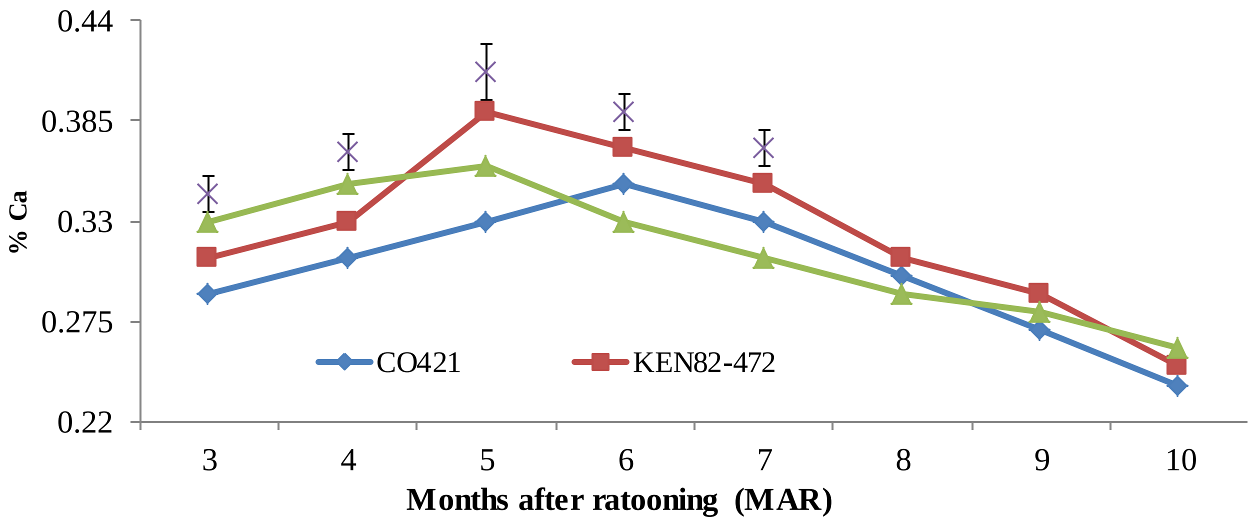

Figure 11: Variations in foliar % Ca with age in cultivars

The KEN8-472 and KEN83-737 had the peak at 5th MAR while and CO421 was later at 6th MAR (Figure 11). The Ca levels were within the optimal range (Table 2) for the cultivars during the experiment. After the peaks, the foliar calcium levels declined to the 10th MAR. Similar variations had been observed in New South Wales (Schroeder *et al.*, 1993). The results illustrate that Ca response is cultivar dependent.

Nitrogen rates significantly ($p \leq 0.05$) affected foliar Ca levels. In CO421, KEN82-472 and KEN83-737, significant responses were observed from 3 - 6th, 5 - 7th and 4 - 6th MAR respectively (Figure 12). The results contrasted another study (Stranack and Miles, 2011) where the results were sporadic. Similar responses were also reported (Muchovej and Newman, 2004a).

The 100 kg N/ha had highest % Ca throughout the period. This suggested that it would not be necessary to apply more than 100 kg N/ha to ratoon crops. Indeed, all the Ca values were within the sufficiency range (Table 2) indication that the soils had steady source of Ca.

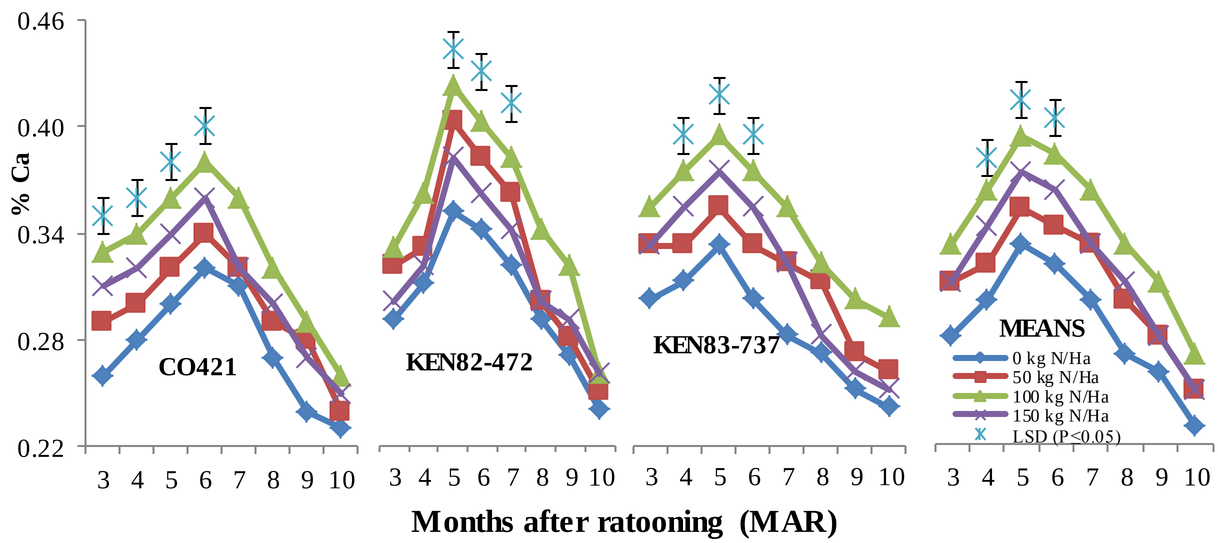

Figure 12: Effects of N rates on foliar Ca content in CO421, KEN8-472 and KEN83-737

There was appreciably high % Ca with zero N rate application, suggesting that the sugarcane farms received stable supply of Ca needed for ratoon plant uptake. This can be explained by the moderate availability of Ca in the soil (Tables 12; 13). Therefore, application of N fertilizer to the crops in Western Kenya may have no predictable effect on the ratoon cane foliar Ca levels.

Potash fertilizer application rates significantly ($p \leq 0.05$) increased foliar Ca contents of the ratoon crops from 3rd - 6th MAR (Figure 13). The foliar Ca peaks were obtained between the 5th and 7th MAR, at 100 and 0 kg K_2O/ha respectively. However, after the attainment of the peaks, there was decline in foliar Ca levels and lack of response in the foliar Ca levels due to K_2O rates. The results demonstrate that K_2O application promotes Ca uptake in ratoon sugarcane crops.

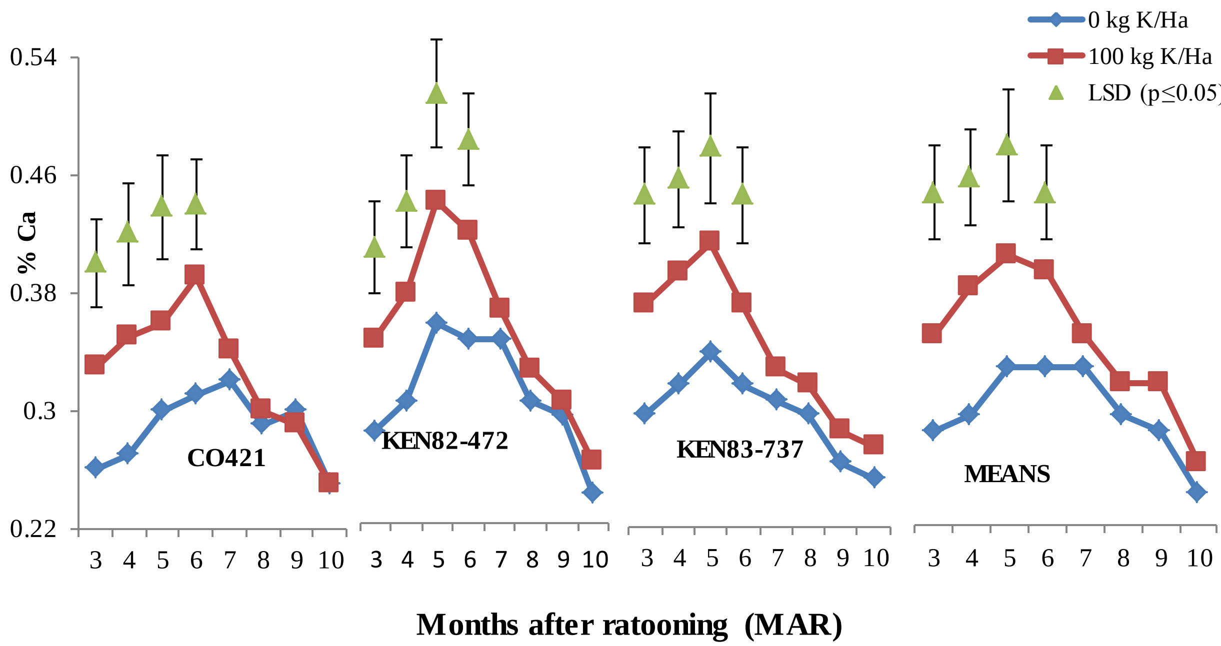

Figure 13: Variations of foliar Ca due to K_2O rates in CO421, KEN82-472 and KEN83-7

Table 32: Variations in foliar Ca % due to cultivars, N and K_2O rates from 3rd - 4th MAR

Cultivar	N Rates kg/ha	3rd MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % Ca	4th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. % Ca
CO421	0	0.24	0.27	0.26		0.24	0.32	0.28	
	50	0.25	0.32	0.29		0.26	0.34	0.30	
	100	0.28	0.37	0.33		0.31	0.37	0.34	
	150	0.27	0.34	0.31		0.27	0.36	0.32	
	Mean K	0.26	0.33		0.29	0.27	0.35		0.31
	C V (%)	11.54				12.96			
	LSD ($p \leq 0.05$)	0.06		0.02		0.07		0.02	
KEN 82-472	0	0.25	0.33	0.29		0.27	0.35	0.31	
	50	0.28	0.35	0.32		0.29	0.37	0.33	
	100	0.30	0.36	0.33		0.32	0.40	0.36	
	150	0.28	0.32	0.30		0.30	0.34	0.32	
	Mean K	0.28	0.34		0.31	0.30	0.37		0.33
	C V (%)	10.71				10.01			
	LSD ($p \leq 0.05$)	0.06		NS		0.06		NS	
KEN 83-737	0	0.26	0.34	0.30		0.27	0.35	0.31	
	50	0.28	0.37	0.33		0.30	0.40	0.35	
	100	0.31	0.38	0.35		0.33	0.40	0.37	
	150	0.3	0.36	0.33		0.32	0.38	0.38	
	Mean K	0.29	0.36		0.33	0.31	0.38		0.34
	C V (%)	10.34				11.29			
	LSD ($p \leq 0.05$)	0.06		NS		0.07		0.02	
Overall Means	0	0.25	0.31	0.28		0.26	0.34	0.30	
	50	0.27	0.35	0.31		0.28	0.37	0.33	
	100	0.30	0.37	0.33		0.32	0.39	0.36	
	150	0.28	0.34	0.31		0.30	0.36	0.34	
	Mean K	0.28	0.34			0.29	0.37		
	C V (%)	10.87				11.42			
	LSD ($p \leq 0.05$)	0.06		NS	0.02	0.07		0.02	0.02

Legend: NS- Non significant; Old cultivar -CO421; New cultivars -KEN82-472 and KEN83-737

Table 33: Variations in foliar Ca % due to cultivars, N and K_2O rates from 5 - 6th MAR

Cultivar	N Rates kg/ha	5th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % Ca	6th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. % Ca
CO421	0	0.26	0.34	0.30		0.28	0.36	0.32	
	50	0.28	0.36	0.32		0.30	0.38	0.34	
	100	0.33	0.39	0.36		0.35	0.41	0.38	
	150	0.32	0.36	0.34		0.31	0.40	0.36	
	Mean K	0.30	0.36		0.33	0.31	0.39		0.35
	C V (%)	10.0				11.3			
	LSD (p≤0.05)	0.05		0.02		0.07		0.02	
KEN 82-472	0	0.32	0.38	0.35		0.30	0.38	0.34	
	50	0.36	0.44	0.40		0.34	0.42	0.38	
	100	0.37	0.46	0.42		0.36	0.44	0.40	
	150	0.34	0.42	0.38		0.34	0.38	0.36	
	Mean K	0.35	0.43		0.39	0.34	0.41		0.37
	C V (%)	11.43				10.3			
	LSD (p≤0.05)	0.07		0.02		0.06		NS	
KEN 83-737	0	0.31	0.35	0.33		0.29	0.31	0.30	
	50	0.32	0.37	0.35		0.31	0.34	0.33	
	100	0.35	0.43	0.39		0.32	0.41	0.37	
	150	0.32	0.42	0.37		0.37	0.36	0.35	
	Mean K	0.33	0.40		0.36	0.31	0.36		0.33
	C V (%)	10.61				8.1			
	LSD (p≤0.05)	0.06		0.02		0.05		0.02	
Overall Means	0	0.30	0.36	0.33		0.29	0.35	0.32	
	50	0.32	0.39	0.36		0.31	0.38	0.35	
	100	0.35	0.42	0.39		0.34	0.42	0.38	
	150	0.33	0.40	0.37		0.32	0.38	0.36	
	Mean K	0.32	0.39			0.32	0.38		
	C V (%)	10.7				9.9			
	LSD (p≤0.05)	0.07		0.02	0.02	0.05		0.02	0.02

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 34: Variations in foliar Ca % due to cultivars, N and K_2O rates from 7 - 8[th] MAR

Cultivar	N Rates kg/ha	7th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % Ca	8th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. % Ca
CO421	0	0.29	0.32	0.31		0.26	0.28	0.27	
	50	0.30	0.34	0.32		0.28	0.30	0.29	
	100	0.35	0.36	0.36		0.32	0.32	0.32	
	150	0.32	0.32	0.32		0.29	0.31	0.30	
	Mean K	0.32	0.34		0.33	0.29	0.30		0.30
	C V (%)	6.3				5.5			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 82-472	0	0.31	0.32	0.32		0.27	0.3	0.29	
	50	0.34	0.37	0.36		0.28	0.32	0.30	
	100	0.35	0.42	0.39		0.34	0.34	0.34	
	150	0.34	0.33	0.34		0.29	0.30	0.30	
	Mean K	0.34	0.36		0.35	0.30	0.32		0.31
	C V (%)	5.9				5.7			
	LSD ($p \leq 0.05$)	NS		0.02		NS		NS	
KEN 83-737	0	0.27	0.29	0.28		0.25	0.28	0.27	
	50	0.30	0.34	0.32		0.29	0.33	0.31	
	100	0.34	0.35	0.35		0.30	0.33	0.32	
	150	0.31	0.32	0.32		0.27	0.28	0.28	
	Mean K	0.30	0.32		0.31	0.28	0.31		0.29
	C V (%)	6.3				6.5			
	LSD ($p \leq 0.05$)	NS		NS		0.05		NS	
Overall Means	0	0.29	0.30	0.30		0.26	0.29	0.27	
	50	0.31	0.35	0.33		0.28	0.32	0.30	
	100	0.35	0.38	0.36		0.32	0.33	0.33	
	150	0.32	0.32	0.32		0.28	0.30	0.29	
	Mean K	0.32	0.34			0.29	0.31		
	C V (%)	6.1				5.9			
	LSD ($p \leq 0.05$)	NS		NS	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 35: Variations in foliar Ca levels with cultivars, N and K_2O rates from 9 - 10th MAR

Cultivar	N Rates kg/ha	9th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar % Ca	10th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. % Ca
CO421	0	0.24	0.24	0.24		0.22	0.23	0.23	
	50	0.27	0.28	0.28		0.23	0.25	0.24	
	100	0.28	0.30	0.29		0.25	0.26	0.26	
	150	0.26	0.27	0.27		0.24	0.25	0.25	
	Mean K	0.26	0.27		0.27	0.24	0.25		0.24
	C V (%)	4.96				4.2			
	LSD (p≤0.05)	NS		NS		NS		NS	
KEN 82-472	0	0.25	0.28	0.27		0.23	0.24	0.24	
	50	0.26	0.29	0.28		0.24	0.25	0.25	
	100	0.33	0.32	0.33		0.25	0.27	0.26	
	150	0.28	0.29	0.29		0.24	0.28	0.26	
	Mean K	0.28	0.30		0.29	0.24	0.26		0.25
	C V (%)	4.99				4.9			
	LSD (p≤0.05)	NS		NS		NS		NS	
KEN 83-737	0	0.24	0.26	0.25		0.22	0.25	0.24	
	50	0.26	0.27	0.27		0.26	0.26	0.26	
	100	0.29	0.31	0.30		0.27	0.31	0.29	
	150	0.26	0.27	0.27		0.25	0.25	0.25	
	Mean K	0.26	0.28		0.27	0.25	0.27		0.26
	C V (%)	5.16				5.1			
	LSD (p≤0.05)	NS		NS		NS		NS	
Overall Means	0	0.25	0.29	0.27		0.22	0.24	0.23	
	50	0.28	0.31	0.29		0.24	0.25	0.25	
	100	0.31	0.34	0.32		0.26	0.28	0.27	
	150	0.28	0.31	0.30		0.24	0.26	0.25	
	Mean K	0.28	0.31			0.24	0.26		
	C V (%)	5.04				4.7			
	LSD (p≤0.05)	NS		NS	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

4.3.5 Foliar iron contents

The variations in foliar Fe (ppm) due to cultivars, N and K_2O rates are presented in Figures 14 - 16 and Tables 36 - 39. There were significant ($p \leq 0.05$) increments in foliar Fe levels in cultivars from 3rd - 6th MAR (Figure 14) followed by declines after the peaks. Similar observations had been made by Schroeder *et al.* (1993) and Gascho *et al.* (2000). From 3rd - 6th MAR, the new cultivars had higher ($p \leq 0.05$) foliar Fe than the CO421 indicating that cultivars have different Fe storage ability. The levels of Fe nutrient remained within the optimum limits (Table 2) hence Fe was not a limiting factor for ratoon sugarcane production in western Kenya.

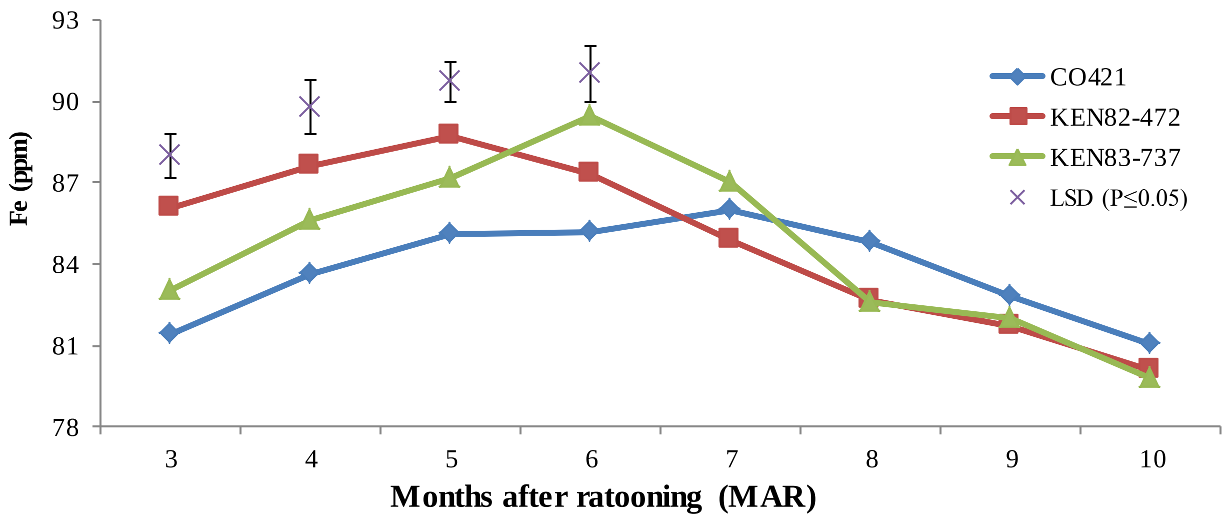

Figure 14: Variations in foliar Fe (ppm) with age due to cultivars

The N rates caused significant ($p \leq 0.05$) responses in foliar Fe levels upto 5th MAR in early maturing canes (Figure 15). The results agree with the finding (Duhan and Singh, 2002) that increasing N rate significantly increased foliar Fe. The results contradicted the findings of Muchovej and Newman (2004a; b) where N rates had no significant effects on foliar Fe contents. Despite the N application, the foliar Fe remained optimal (Table 2). The zero and 150 kg N/ha application rates recorded low responses of foliar Fe whereas 100 kg N/ha had highest Fe levels. The data shows that soil Fe is available with or without N fertilizer application.

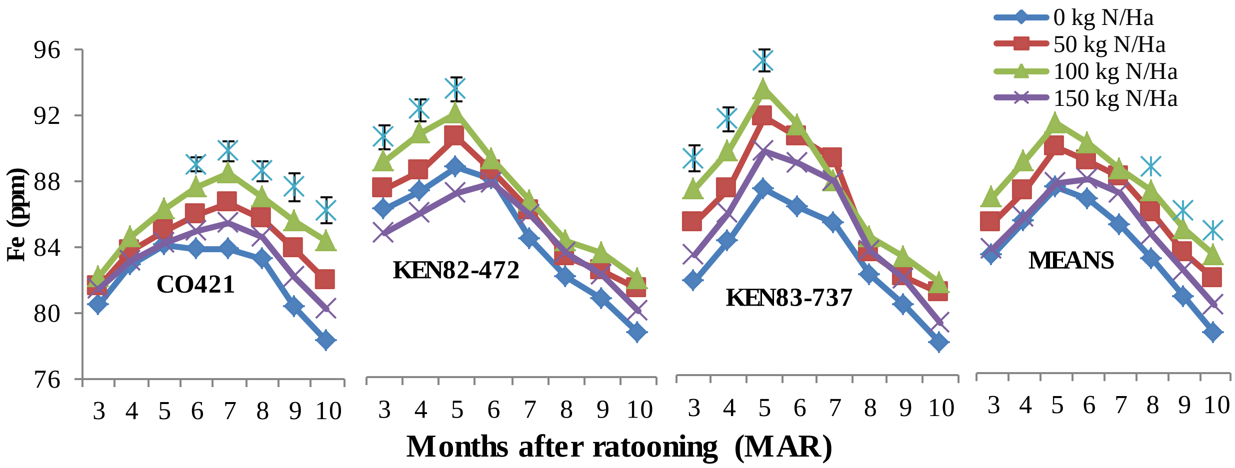

Figure 15: Effect of N rates on foliar Fe levels (ppm) in CO421, KEN82 - 472 and KEN83 – 737

Foliar Fe contents of changed significantly ($p \leq 0.05$) with K_2O rates (Figure 16; Tables 36 - 39). The results agree with soil data (Tables 14 and 15) and the findings by (Malavolta, 1994; Singh and Jha, 1994) where K_2O application significantly increased foliar Fe levels in ratoon cane crop. The zero rates had lower foliar Fe than 100 kg K_2O/ha during the entire sampling process. Despite the responses, Fe levels were within the acceptable limits (Table 2) and K_2O fertilization may be core to soil Fe availability in western Kenya.

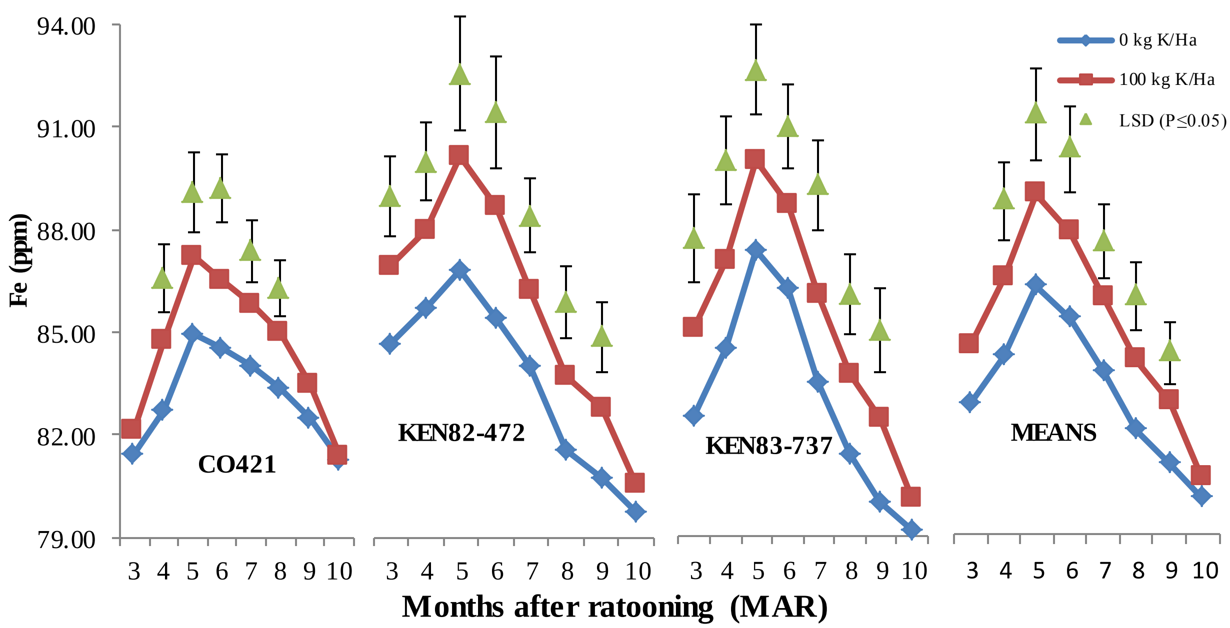

Figure 16: Variations in foliar Fe (ppm) with age due to K fertilizer rates in the three cultivars

Table 36: Variations in foliar Fe (ppm) due to cultivars, N and K_2O rates from 3rd - 4th MAR

Cultivar	N Rates kg/ha	3rd MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Fe-ppm	4th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Fe-ppm
CO421	0	79.8	81.1	80.5		82.0	83.8	82.9	
	50	80.7	82.4	81.5		82.9	84.7	83.8	
	100	81.1	83.2	82.2		83.4	85.6	84.5	
	150	80.2	82.6	81.4		81.4	84.9	83.2	
	Mean K	80.5	82.3		81.4	82.4	84.7		83.6
	C V (%)	6.8				6.3			
	LSD ($p \leq 0.05$)	1.9		NS		1.3		NS	
KEN 82-472	0	84.6	86.0	85.3		85.6	87.1	86.3	
	50	85.5	87.4	86.4		86.5	88.4	87.5	
	100	87.0	89.0	88.0		88.2	90.8	89.5	
	150	84.9	84.4	84.6		84.9	87.4	85.2	
	Mean K	85.5	86.7		86.1	86.5	88.7		87.6
	C V (%)	5.7				7.6			
	LSD ($p \leq 0.05$)	1.2		1.3		2.2		1.2	
KEN 83-737	0	80.5	83.0	81.1		82.9	85.7	83.3	
	50	83.7	84.8	84.2		84.7	87.4	86.1	
	100	84.0	88.0	86.0		87.4	88.8	88.1	
	150	81.7	83.4	82.5		83.9	86.0	84.9	
	Mean K	82.1	83.9		83.0	84.4	86.9		85.6
	C V (%)	8.6				9.0			
	LSD ($p \leq 0.05$)	1.8		1.4		2.5		1.3	
Overall Means	0	81.9	83.4	82.3		83.8	85.5	84.2	
	50	83.0	84.7	84.1		84.0	86.1	84.1	
	100	83.8	87.1	85.4		85.6	86.4	85.4	
	150	75.0	82.3	82.6		81.7	83.5	82.6	
	Mean K	82.7	84.3			84.4	86.8		
	C V (%)	7.1				7.6			
	LSD ($p \leq 0.05$)	1.6		NS	1.6	2.0		NS	2.0

Legend: NS -Non significant; Old cultivar -CO421; New cultivars -KEN82-472; KEN83-737

Table 37: Variations in foliar Fe (ppm) due to cultivars, N and K_2O rates from 5 - 6th MAR

Cultivar	N Rates kg/ha	5th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Fe-ppm	6th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Fe-ppm
CO421	0	82.5	85.7	84.1		82.5	85.3	83.9	
	50	83.4	86.4	84.9		83.4	86.0	84.7	
	100	85.4	87.1	86.3		85.2	88.9	87.1	
	150	84.4	86.1	85.3		84.0	85.8	84.9	
	Mean K	84.4	86.5		85.1	83.8	86.5		85.1
	C V (%)	7.7				6.4			
	LSD ($p \leq 0.05$)	2.1		NS		2.7		NS	
KEN 82-472	0	86.7	88.6	87.6		85.6	88.5	87.0	
	50	88.8	89.6	89.3		86.4	88.6	87.5	
	100	89.3	92.0	90.7		87.1	89.0	88.1	
	150	81.9	85.5	82.2		86.4	87.2	86.8	
	Mean K	87.6	89.8		88.7	86.3	88.3		87.3
	C V (%)	5.2				4.7			
	LSD ($p \leq 0.05$)	2.2		1.3		2.0		NS	
KEN 83-737	0	85.7	86.5	86.1		87.9	89.2	85.1	
	50	88.7	91.1	89.9		88.9	90.9	88.8	
	100	89.0	93.8	91.4		87.9	92.9	89.5	
	150	83.1	87.2	85.2		87.9	88.9	87.5	
	Mean K	86.3	88.1		87.2	88.2	90.7		89.4
	C V (%)	4.1				4.0			
	LSD ($p \leq 0.05$)	1.8		1.2		1.3		NS	
Overall Means	0	84.9	87.2	85.9		85.3	86.7	85.3	
	50	86.9	89.2	88.0		86.2	88.5	87.0	
	100	87.3	89.5	89.4		86.8	90.3	88.2	
	150	85.7	87.6	86.5		86.1	87.6	86.4	
	Mean K	85.9	88.1			86.1	88.5		
	C V (%)	5.7				5.0			
	LSD ($p \leq 0.05$)	2.1		NS	1.5	2.0		NS	2.1

Legend: NS -Non significant; Old cultivar -CO421; New cultivars - KEN82-472; KEN83-737

Table 38: Variations in foliar Fe (ppm) due to cultivars, N and K_2O rates from 7 - 8th MAR

Cultivar	N Rates kg/ha	7th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Fe-ppm	8th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Fe-ppm
CO421	0	83.5	86.3	84.9		82.4	84.2	83.3	
	50	84.4	86.3	85.4		83.6	86.2	85.7	
	100	86.7	90.2	88.4		85.5	87.5	86.0	
	150	85.1	85.7	85.4		83.1	86.0	84.5	
	Mean K	84.9	87.1		86.0	83.7	86.0		84.8
	C V (%)	5.1				5.6			
	LSD ($p \leq 0.05$)	2.2		NS		2.3		1.3	
KEN 82-472	0	82.6	84.8	83.7		80.5	82.6	81.5	
	50	83.5	87.0	85.2		81.3	84.0	82.6	
	100	85.1	86.4	85.8		82.2	85.0	83.6	
	150	83.6	86.4	85.0		81.6	84.3	82.9	
	Mean K	83.7	86.2		84.9	81.4	84.0		82.7
	C V (%)	5.9				6.3			
	LSD ($p \leq 0.05$)	2.5		NS		2.6		NS	
KEN 83-737	0	84.1	84.4	84.3		80.3	82.6	81.5	
	50	86.4	89.0	87.7		81.3	83.9	82.6	
	100	85.1	87.9	86.5		82.1	84.8	83.5	
	150	85.0	88.0	86.5		81.3	84.1	82.7	
	Mean K	85.9	88.1		87.0	81.3	83.9		82.6
	C V (%)	5.1				6.3			
	LSD ($p \leq 0.05$)	2.2		NS		2.6		NS	
Overall Means	0	83.7	85.6	84.3		81.1	83.1	82.1	
	50	84.7	87.4	86.1		83.0	86.1	84.6	
	100	86.3	88.9	86.9		83.3	86.1	85.8	
	150	84.6	86.7	85.6		82.0	84.8	83.4	
	Mean K	84.8	87.1			82.1	84.6		
	C V (%)	5.4				5.0			
	LSD ($p \leq 0.05$)	2.3		NS	NS	2.4		NS	NS

Legend: NS- Non significant; Old cultivar -CO421; New cultivars - KEN82-472; KEN83-737

Table 39: Variations in foliar Fe (ppm) due to cultivars, N and K_2O rates from 9 - 10th MAR

Cultivar	N Rates kg/ha	7th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Fe-ppm	8th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Fe-ppm
CO421	0	79.5	81.3	80.4		78.2	78.3	78.3	
	50	84.1	83.5	83.8		80.8	82.9	81.9	
	100	85.1	86.1	85.6		83.7	85.8	84.4	
	150	81.3	82.9	82.1		80.2	80.3	80.3	
	Mean K	82.5	83.5		83.0	81.3	81.4		
	C V (%)	4.7				5.4			81.3
	LSD ($p \leq 0.05$)	NS		1.7		NS		1.6	
KEN 82-472	0	79.2	81.4	80.3		78.2	78.6	78.4	
	50	81.1	82.6	81.9		80.1	81.6	80.9	
	100	81.9	83.8	82.8		80.9	82.0	81.5	
	150	80.5	82.9	81.7		79.5	79.8	79.6	
	Mean K	80.7	82.7		81.7	79.7	80.5		80.1
	C V (%)	7.4				5.0			
	LSD ($p \leq 0.05$)	2.0		NS		NS		NS	
KEN 83-737	0	78.5	81.1	79.8		77.9	77.7	77.8	
	50	80.4	82.3	81.3		79.7	80.4	80.4	
	100	81.4	83.5	82.4		81.2	80.9	81.0	
	150	79.7	82.6	81.2		78.1	79.6	78.8	
	Mean K	80.0	82.4		81.2	79.2	80.1		79.7
	C V (%)	7.5				3.4			
	LSD ($p \leq 0.05$)	2.4		NS		NS		NS	
Overall Means	0	79.1	81.3	80.1		78.1	78.2	78.2	
	50	81.9	82.8	82.5		80.2	81.9	81.1	
	100	82.8	84.5	83.7		82.6	83.6	82.3	
	150	80.5	82.8	81.5		79.3	79.9	79.6	
	Mean K	81.1	82.8			80.0	80.7		
	C V (%)	7.0				1.9			
	LSD ($p \leq 0.05$)	1.8		1.0	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars -KEN82-472 and KEN83-737

4.3.6 Foliar manganese contents

The changes in foliar Mn contents (ppm) due to cultivars, N and K fertilizer rates with age are presented in Figures 17 - 19 and Tables 40 - 43.

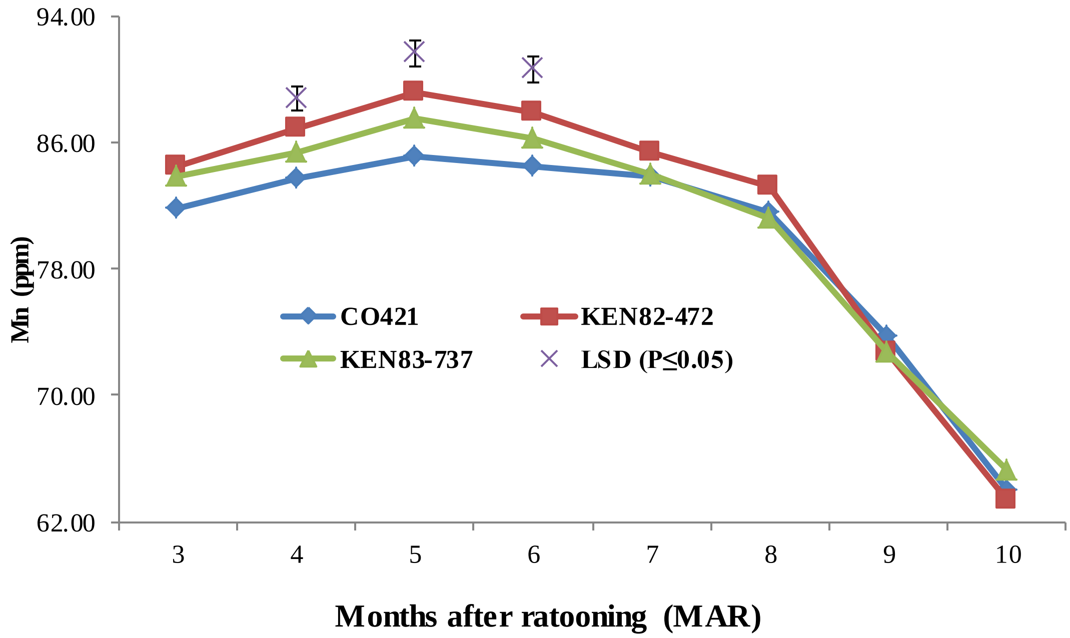

Figure 17: Variations in foliar Mn levels due to cultivars with age

There were significant ($p \leq 0.05$) differences in foliar Mn in the cultivars from 4th MAR with a peaking at the 5th MAR (Figure 17). The new cultivars KEN82-472, KEN83-737 had higher ($p \leq 0.05$) Mn levels than the old CO421 cultivar. This could have been due to genotypic differences in ability to absorb the nutrients. The foliar Mn values are within the optimal range (Table 2) and supported by the moderate soil Mn levels (Tables 5; 16 and 17) in this study. However, the results were at variance with observations by Panwar and Katyal (1986) that the foliar nutrients for late maturing cultivars were higher than early maturing crops. This could arise from cultivar genetic differences. After the 5th MAR, the foliar Mn declined in all the cultivars.

The results indicated that the cultivars had adequate Mn levels (Table 2) and varying potentials to accumulate foliar Mn before the 7th MAR. Therefore, foliar sampling and analysis for Mn may be done before this age to allow for any necessary intervention.

The N rates (Figures 18) caused quadratic and significant ($p \leq 0.05$) effect on foliar Mn levels from 4th to 6th MAR. The results agree with reports (Debiprasad *et al.*, 2010) on rice and cane (Das, 2000), but were in converse of the findings by Muchovej and Newman (2004a; b) where there were insignificant foliar manganese responses to different cultivars. The foliar Mn levels reached peaks at different ages. The newer KEN82-472 and KEN83-737 cultivars, significant ($p \leq 0.05$) differences occurred from 5th to 7th and 3rd to 4th MAR respectively. However, 150 kg N/ha recorded relatively lower Mn levels than the 100 kg N/ha. This could be due to higher N levels lowering soil pH which promotes solubility of Mn soils in the vertisolic soils. Contradicting results had been observed (Muchovej and Newman, 2004a, b) where there was no foliar Mn response to N fertilization. After the peaks, there was a decline pattern irrespective of the N rate. The data suggests that Mn levels were adequate (Table 2) despite different N rates.

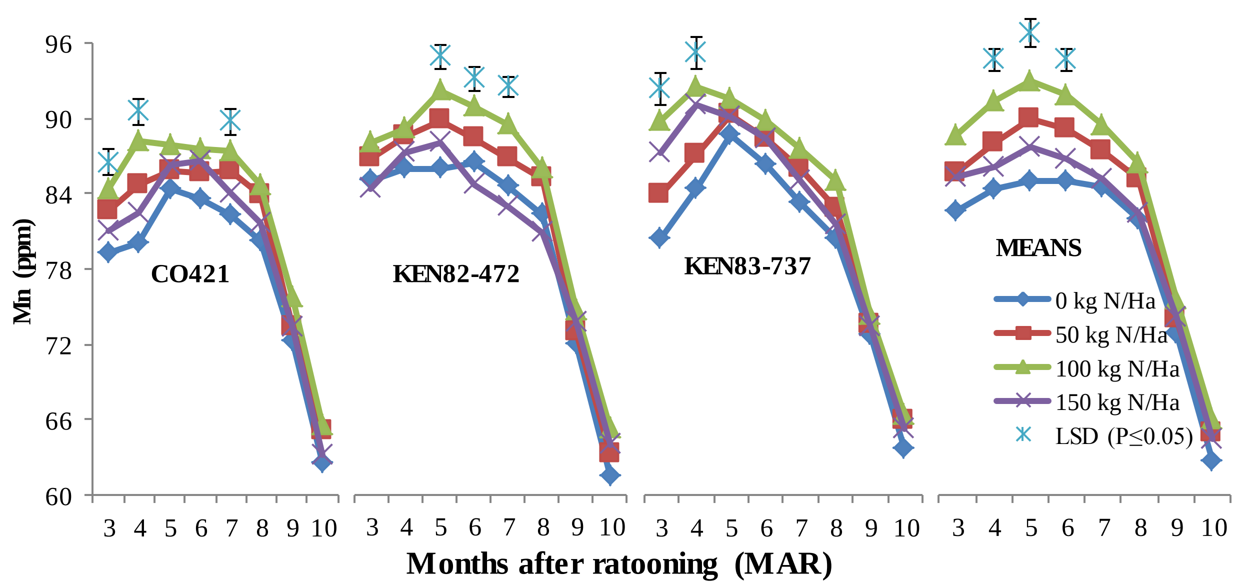

Figure 18: Variations in foliar N due to N rates with age

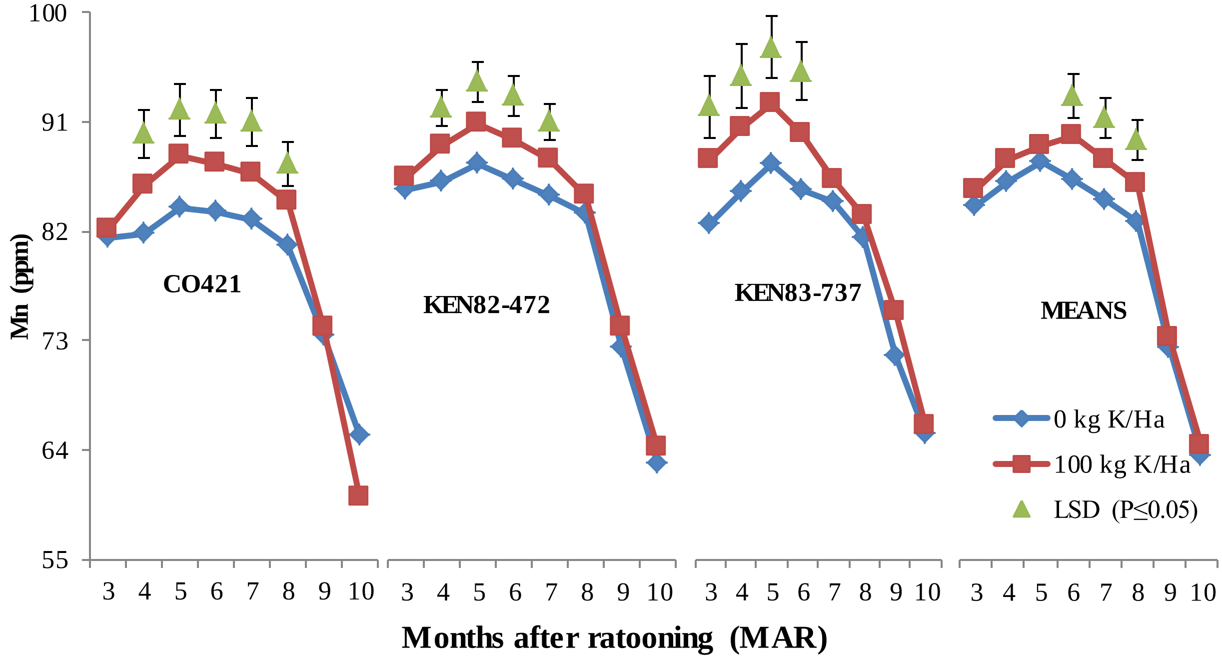

Figure 19: Variations in foliar Mn (ppm) with age due to K fertilizer rates

Increasing potash rates significantly ($p \leq 0.05$) increased foliar Mn levels (Figure 19). The data corresponded to the soil K data (Tables 10 and 11) and the study finding by Singh and Jha (1994) where foliar storage of Mn by ratoon sugarcane was markedly increased with increasing K fertilizer application levels. The results supported other studies (Marschner, 1986; Rizk *et al.*, 2002) that Mn levels increased during the growth period when photosynthetic processes are rigorous. The Mn response to potash fertilizer application recorded peaks at the 5th MAR in all cultivars. After the peaks, there were declines in foliar Mn contents; however, the levels were still within the optimum range (Table 2). The results may suggest that sampling for Mn analysis be done before the 4th MAR.

Table 40: Variations in foliar Mn levels due to cultivars, N and K_2O rates from 3rd - 4th MAR

Cultivar	N Rates kg/ha	3rd MAR K_2O Rates kg/ha 0	3rd MAR K_2O Rates kg/ha 100	3rd MAR Mean N Rate	3rd MAR Mean Cult, ppm	4th MAR K_2O Rates kg/ha 0	4th MAR K_2O Rates kg/ha 100	4th MAR Mean N Rate	4th MAR Mean Cult. Mn-ppm
CO421	0	78.4	80.0	79.2		78.7	82.7	80.7	
	50	83.1	82.2	82.7		81.3	85.3	83.3	
	100	84.0	84.7	84.4		86.2	90.2	88.2	
	150	80.3	81.6	80.9		80.7	84.7	82.7	
	Mean K	81.5	82.1		81.8	81.7	85.7		83.7
	C V (%)	8.1				9.8			
	LSD ($p \leq 0.05$)	NS		NS		4.0		NS	
KEN 82-472	0	83.4	84.7	84.0		83.7	86.1	84.9	
	50	84.5	86.7	85.6		85.6	89.1	87.4	
	100	86.0	87.9	87.0		86.4	89.6	88.0	
	150	83.9	82.9	83.4		85.0	87.3	86.2	
	Mean K	84.5	85.5		84.5	85.2	88.0		86.9
	C V (%)	12.4				6.7			
	LSD ($p \leq 0.05$)	NS		NS		2.9		NS	
KEN 83-737	0	75.4	81.1	78.3		77.1	82.9	80.0	
	50	80.1	85.1	82.6		82.2	89.0	85.6	
	100	86.0	90.1	88.1		88.6	92.9	90.7	
	150	84.3	89.1	86.7		87.8	90.8	89.3	
	Mean K	81.4	86.4		83.9	83.9	88.9		85.4
	C V (%)	9.5				10.0			
	LSD ($p \leq 0.05$)	4.9		NS		5.0		NS	
Overall Means	0	79.0	81.9	80.5		79.9	83.9	81.9	
	50	81.9	84.7	83.3		83.0	87.8	85.4	
	100	86.0	87.6	86.8		87.1	90.9	89.0	
	150	82.8	84.5	83.7		84.5	87.6	86.1	
	Mean K	82.8	84.0			84.8	86.5		
	C V (%)	10.7				9.9			
	LSD ($p \leq 0.05$)	1.2		NS	NS	1.7		NS	1.5

Legend: NS -Non significant; Old cultivar -CO421; New cultivars -KEN82-472 and KEN83-737

Table 41: Variations in foliar Mn levels due to cultivars, N and K_2O rates from 5^{th} - 6^{th} MAR

Cultivar	N Rates kg/ha	5th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Mn-ppm	6th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult., ppm
CO421	0	82.2	86.4	84.3		80.9	86.1	83.5	
	50	83.5	88.1	85.8		83.0	86.4	84.7	
	100	85.6	90.3	87.9		85.9	89.0	87.5	
	150	84.4	88.1	86.3		84.4	88.7	86.6	
	Mean K	83.9	88.2		85.1	83.5	87.6		84.6
	C V (%)	10.3				9.6			
	LSD ($p \leq 0.05$)	4.3		NS		4.0		NS	
KEN 82-472	0	84.0	85.8	84.9		83.1	88.4	85.8	
	50	86.5	90.7	88.6		85.0	89.5	87.3	
	100	88.9	92.8	90.8		89.1	90.1	89.6	
	150	87.0	90.1	88.5		83.7	85.7	84.7	
	Mean K	86.6	89.8		89.2	85.2	88.4		87.9
	C V (%)	7.4				7.4			
	LSD ($p \leq 0.05$)	3.2		NS		3.2		1.1	
KEN 83-737	0	84.5	89.7	87.1		81.7	87.8	84.8	
	50	86.4	90.8	88.6		82.7	88.8	85.8	
	100	87.5	92.0	89.7		86.5	89.6	88.1	
	150	85.8	91.1	88.5		85.4	88.0	86.7	
	Mean K	86.1	90.9		87.5	84.1	88.6		86.3
	C V (%)	10.6				8.5			
	LSD ($p \leq 0.05$)	4.9		NS		4.5		1.0	
Overall Means	0	83.6	87.3	85.4		81.9	87.4	84.7	
	50	85.5	89.9	87.7		83.6	88.2	85.9	
	100	87.3	91.7	89.5		87.2	89.6	88.4	
	150	85.7	89.8	87.8		84.5	87.5	86.0	
	Mean K	85.5	89.7			84.3	88.2	86.2	
	C V (%)	7.9				8.9			
	LSD ($p \leq 0.05$)	1.4		NS	1.7	2.5		NS	1.6

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 42: Variations in foliar Mn (ppm) due to cultivars, N and K_2O rates at 7th and 8th MAR

Cultivar	N Rates kg/ha	7th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Mn-ppm	8th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult., ppm
CO421	0	79.9	84.7	82.3		77.8	82.7	80.2	
	50	84.6	86.9	85.7		82.4	85.2	83.8	
	100	85.5	89.4	87.5		83.4	86.1	84.7	
	150	81.8	86.2	84.0		79.6	83.5	81.6	
	Mean K	82.9	86.8		83.9	80.8	84.4		81.6
	C V (%)	9.3				8.8			
	LSD ($p \leq 0.05$)	3.9		1.7		3.6			
KEN 82-472	0	82.5	84.7	83.6		80.2	82.5	81.3	
	50	84.4	86.9	85.7		83.8	84.4	84.1	
	100	85.2	89.4	87.3		84.7	85.2	84.9	
	150	83.9	86.2	85.0		81.6	83.8	82.7	
	Mean K	84.0	86.8		85.4	82.6	84.0		83.3
	C V (%)	6.7				5.7			
	LSD ($p \leq 0.05$)	2.8		NS		NS		NS	
KEN 83-737	0	81.5	82.3	81.9		79.1	79.5	79.3	
	50	83.4	85.8	84.6		80.8	82.3	81.6	
	100	84.4	87.5	86.0		82.3	84.8	83.5	
	150	83.1	84.1	83.6		79.3	81.4	80.4	
	Mean K	83.1	84.9		84.0	80.4	82.0		81.2
	C V (%)	6.6				6.1			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	81.3	83.9	82.6		79.0	81.6	80.3	
	50	84.1	86.5	85.3		82.4	84.0	83.2	
	100	85.0	88.8	86.9		83.4	85.3	84.4	
	150	82.9	85.5	84.2		80.2	82.9	81.6	
	Mean K	83.3	86.2			81.2	83.5		
	C V (%)	8.8				8.2			
	LSD ($p \leq 0.05$)	2.8		NS	NS	2.2		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 43: Variations in foliar Mn due to cultivars, N and K_2O rates at 9th and 10th MAR

Cultivar	N Rates kg/ha	9th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Mn-ppm	10th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult., ppm
CO421	0	72.1	72.5	72.3		61.2	63.7	62.5	
	50	73.2	73.6	73.4		64.2	65.8	65.0	
	100	75.0	76.5	75.8		65.1	65.9	65.5	
	150	73.0	73.7	73.4		61.5	64.9	63.2	
	Mean K	73.3	74.1		73.7	63.0	65.1		64.0
	C V (%)	4.2				6.6			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 82-472	0	70.2	72.5	71.4		61.0	61.9	61.4	
	50	71.3	73.4	72.4		62.9	63.2	63.1	
	100	73.4	74.5	74.0		64.0	66.0	65.0	
	150	72.4	73.8	73.1		62.7	64.9	63.8	
	Mean K	71.9	73.6		72.7	62.6	64.0		63.3
	C V (%)	7.2				6.5			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 83-737	0	69.8	74.2	72.0		63.5	64.3	63.5	
	50	70.9	74.6	72.7		65.6	65.9	65.6	
	100	72.1	75.0	73.6		66.1	67.0	66.1	
	150	71.0	74.4	72.7		64.6	65.0	65.0	
	Mean K	71.0	74.5		72.7	65.0	65.6		65.3
	C V (%)	8.7				6.6			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	70.7	73.1	71.9		61.9	63.3	62.6	
	50	71.8	73.9	72.9		64.2	65.0	64.6	
	100	73.5	75.4	74.4		65.1	66.3	65.7	
	150	72.2	73.9	73.0		62.9	64.9	63.9	
	Mean K	72.1	74.1			63.5	64.9		
	C V (%)	5.6				5.4			
	LSD ($p \leq 0.05$)	NS		NS	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

4.3.7 Foliar Zn

The variations of foliar Zn to cultivars, due to N and K_2O rates are shown in Figures 20 - 22. Sugarcane cultivars significantly ($p \leq 0.05$) influenced the Zn levels (ppm) from the 6 - 8th MAR. The CO421 and KEN82-472 had lower Zn levels and peaked earlier than KEN83-737 (Figure 20). After the peaks, there was a declining pattern towards the 10th MAR possibly due to minimal functions of Zn as already reported (Hadi *et al.* 1997). The trends compare favourably with other finding (Fihlo, 1985; Schroeder *et al.*, 1993) that ratoon-cane crops reduce Zn foliar levels with increasing age as the role of Zn in the tillering and growth stages diminishes. The foliar Zn contents were within the acceptable range (Table 2) and indeed, sampling for diagnostic analysis could be conducted before the 5th MAR.

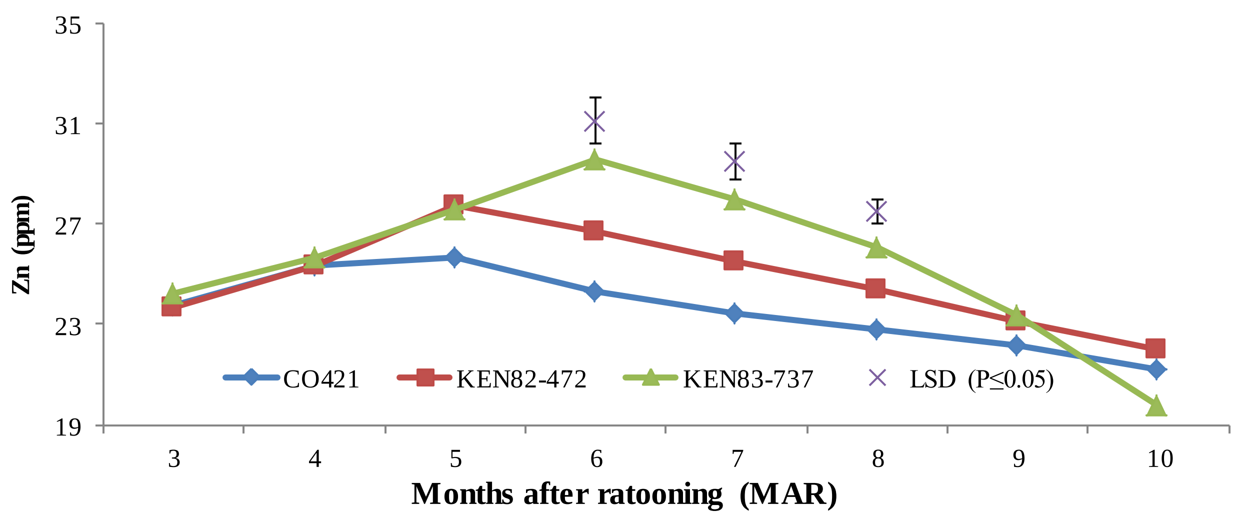

Figure 20: hanges in foliar Zn levels due to cultivars with age

The N rates significantly ($P \leq 0.05$) increased foliar Zn contents (Figure 21). The results agreed with the studies by Debiprasad *et al.* (2010), Stranack and Miles (2011) and Akhtar *et al.* (2000) that N fertilizations increased foliar Zn levels. However, the results contradicted reports (Muchovej and Newman 2004a; b) where the N rates insignificantly affected foliar Zn contents.

The zero N rate recorded foliar Zn ppm within the optimum range (Table 2), demonstrating that the study soils had sufficient Zn. After the peaks, there were declines in foliar Zn contents with age. However, new cultivars displayed faster decline than the old cultivar. The results suggest that foliar Zn contents are N dependent and may fit in Zn diagnostic norms before the 3rd MAR.

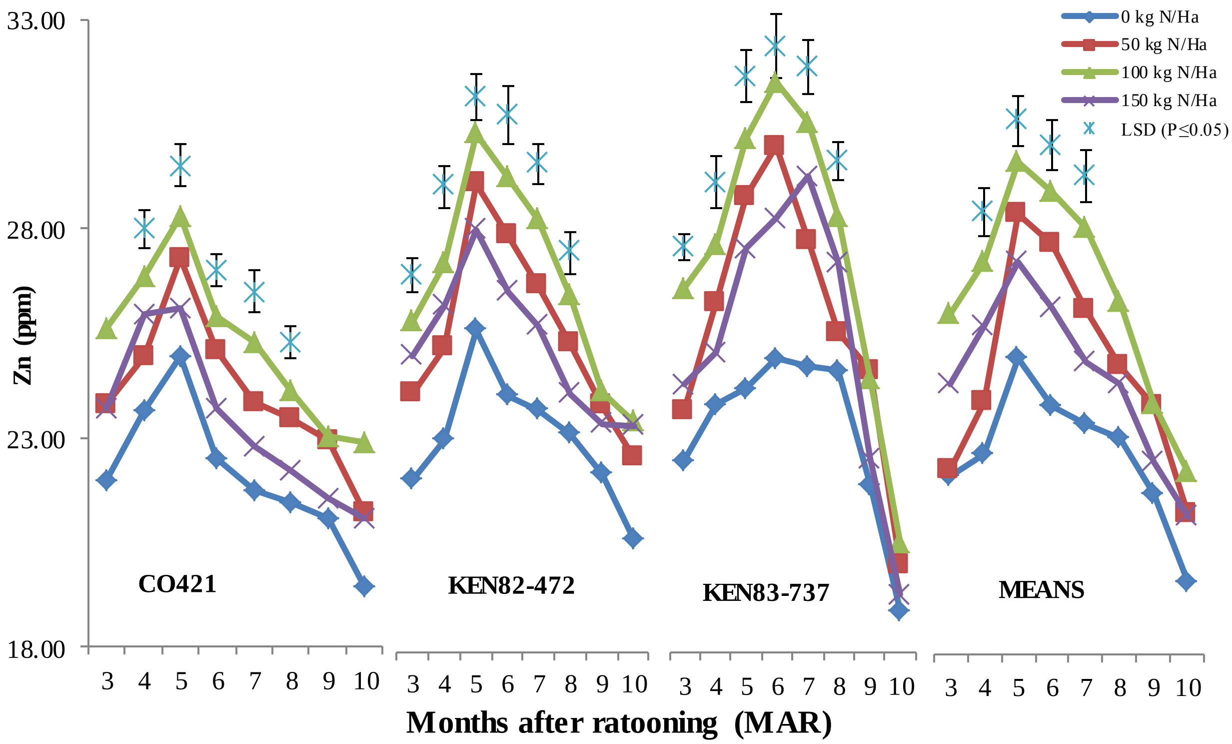

Figure 21: Variations in foliar Zn (ppm) with age due to N fertilizer rates

The potash fertilizer rates (Figure 22) significantly ($p \leq 0.05$) increased foliar Zn levels in the old and new cultivars from 3 - 5th and 3 - 7th MAR respectively. The data illustrates that K_2O application is necessary for Zn availability in the soil.

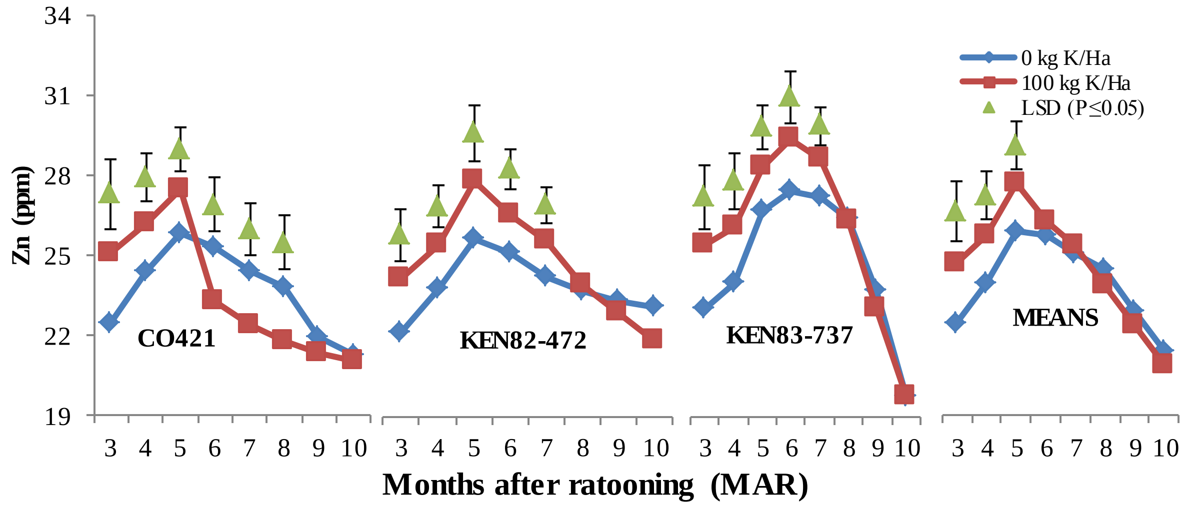

Figure 22: Variations in foliar Zn in cultivars due to K_2O rates

Cultivars had significant ($p \leq 0.05$) increments in foliar nutrients generally from the 3rd - 6th MAR in N, P, K, Ca, Fe, Mn and Zn. The increments were higher in the new and early maturing cultivars (KEN82-472 and KEN83-737) than the old and late maturing CO421. Peaks were generally attained at the 5th MAR. After the attainment of the peaks, foliar nutrients concentrations declined more rapidly in the new cultivars than in the old cultivar. Therefore, sampling conducted later than 5th MAR would give lower nutrients contents for the new cultivars. The N and potash fertilizer application rates significantly ($p \leq 0.05$) increased foliar N, P, K, Ca, Fe, Mn and Zn levels.

The 100 kg N/ha and 100 kg K_2O/ha rates recorded significant ($p \leq 0.05$) foliar levels in the foliar tissues. These results suggested that 100 kg N/ha and 100 kg K_2O/ha fertilizer rates might give the highest foliar nutrients contents.

Table 44: Variations in foliar Zn (ppm) due to cultivars, N and K_2O rates from 3rd - 4th MAR

Cultivar	N Rates kg/ha	3rd MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. ppm	4th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult., ppm
CO421	0	21.1	22.9	22.0		23.1	24.2	23.6	
	50	22.9	24.7	23.8		24.4	25.5	24.9	
	100	23.3	27.9	25.6		25.8	27.8	26.8	
	150	22.5	24.9	23.7		24.5	27.4	25.9	
	Mean K	22.5	25.1		23.8	24.4	26.2		2.53
	C V (%)	11.7				7.3			
	LSD ($p \leq 0.05$)	2.6		NS		1.8		0.9	
KEN 82-472	0	20.8	23.0	21.9		22.0	23.6	22.8	
	50	22.9	24.7	23.8		23.7	26.0	24.8	
	100	24.0	26.9	25.4		25.7	27.9	26.8	
	150	22.7	24.7	23.7		24.7	26.9	25.8	
	Mean K	22.6	24.8		23.7	24.4	26.2		25.3
	C V (%)	9.8				7.3			
	LSD ($p \leq 0.05$)	2.2		NS		1.8		1.2	
KEN 83-737	0	22.0	23.0	22.5		22.9	24.7	23.8	
	50	23.0	24.4	23.7		24.5	27.9	26.2	
	100	24.2	28.8	26.5		25.9	29.2	27.6	
	150	23.0	25.6	24.3		24.8	25.3	25.0	
	Mean K	23.1	25.4		24.2	24.5	26.8		25.6
	C V (%)	10.3				8.4			
	LSD ($p \leq 0.05$)	2.4		NS		2.1		1.2	
Overall Means	0	21.3	22.9	22.1		22.6	22.7	22.6	
	50	21.6	22.9	22.3		24.2	23.5	23.8	
	100	23.8	27.9	25.8		25.8	28.4	27.1	
	150	22.7	25.7	24.2		24.7	26.5	25.6	
	Mean K	22.7	25.1			24.3	26.2		
	C V (%)	10.6				7.7			
	LSD ($p \leq 0.05$)	2.4		1.1	NS	1.9		1.1	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 45: Variations in foliar Zn (ppm) due to cultivars, N and K_2O rates from 5 - 6th MAR

Cultivar	N Rates kg/ha	5th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Zn-ppm	6th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. ppm
CO421	0	24.7	25.2	25.0		24.0	21.0	22.5	
	50	26.6	28.1	27.3		26.4	23.9	25.1	
	100	27.2	29.5	28.3		26.5	25.3	25.9	
	150	24.9	27.4	26.1		24.3	23.2	23.7	
	Mean K	25.8	27.5		26.7	25.3	23.3		24.3
	C V (%)	6.6				7.8			
	LSD (p≤0.05)	1.7		1.0		2.0		0.8	
KEN 82-472	0	24.0	26.6	25.3		22.9	24.6	23.8	
	50	26.2	28.8	27.5		26.5	28.2	27.4	
	100	28.6	30.8	29.7		27.8	29.5	28.7	
	150	27.4	29.7	28.5		26.3	27.9	27.1	
	Mean K	26.5	29.0		27.8	25.9	27.6		26.7
	C V (%)	9.1				6.5			
	LSD (p≤0.05)	2.4		1.0		1.7		1.3	
KEN 83-737	0	24.0	24.4	24.2		25.2	26.6	25.9	
	50	26.9	30.5	28.7		29.0	32.6	30.8	
	100	28.9	31.2	30.1		31.1	33.5	32.3	
	150	27.5	27.4	27.5		29.6	28.7	29.2	
	Mean K	26.8	28.4		27.6	28.7	30.4		29.6
	C V (%)	6.1				5.7			
	LSD (p≤0.05)	1.6		1.2		1.6		1.5	
Overall Means	0	24.2	25.4	24.8		23.7	23.7	23.7	
	50	26.6	29.7	28.2		27.0	27.9	27.4	
	100	28.2	30.7	29.4		28.2	29.1	28.6	
	150	26.2	27.9	27.5		25.6	26.3	26.0	
	Mean K	26.4	28.5			26.3	26.8		
	C V (%)	7.2				3.9			
	LSD (p≤0.05)	1.9		1.2	NS	NS		1.2	1.8

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 46: Variations in foliar Zn (ppm) due to cultivars, N and K_2O rates from 7 - 8th MAR

Cultivar	N Rates kg/ha	7th MAR K_2O Rates kg/ha 0	7th MAR K_2O Rates kg/ha 100	7th MAR Mean N Rate	7th MAR Mean Cultivar Zn-ppm	8th MAR K_2O Rates kg/ha 0	8th MAR K_2O Rates kg/ha 100	8th MAR Mean N Rate	8th MAR Mean Cult. pm
CO421	0	22.8	20.7	21.7		22.6	20.3	21.5	
	50	24.7	23.0	23.8		24.5	22.4	23.5	
	100	26.3	24.3	25.3		24.8	23.5	24.1	
	150	23.8	21.8	22.8		23.2	21.3	22.2	
	Mean K	24.4	22.4		23.4	23.8	21.8		22.8
	C V (%)	8.0				8.2			
	LSD ($p \leq 0.05$)	2.0		1.0		2.0		0.8	
KEN 82-472	0	23.1	23.8	23.5		22.9	22.9	22.9	
	50	25.7	26.9	26.3		25.0	24.9	24.9	
	100	26.7	28.8	27.7		25.7	26.4	26.1	
	150	24.2	26.4	25.3		23.6	24.0	23.8	
	Mean K	24.9	26.5		25.7	24.3	24.6		24.4
	C V (%)	6.1				3.9			
	LSD ($p \leq 0.05$)	1.5		1.0		NS		0.9	
KEN 83-737	0	24.0	25.4	24.7		24.4	24.2	24.3	
	50	26.6	28.8	27.7		25.1	25.3	25.2	
	100	29.8	31.0	30.4		27.7	28.2	27.9	
	150	28.9	29.4	29.2		27.1	26.6	26.9	
	Mean K	27.3	28.7		28.0	26.1	26.0		26.1
	C V (%)	8.7				4.4			
	LSD ($p \leq 0.05$)	2.4		1.3		NS		0.9	
Overall Means	0	23.3	23.3	23.3		23.4	22.5	23.0	
	50	25.6	26.2	25.9		25.0	24.3	24.6	
	100	27.6	28.0	27.8		26.1	26.1	26.1	
	150	24.6	24.9	25.8		24.4	24.0	24.2	
	Mean K	25.6	25.8			24.8	24.2		
	C V (%)	3.4				3.5			
	LSD ($p \leq 0.05$)	NS		NS	2.1	NS		NS	1.6

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 47: Variations in foliar Zn (ppm) due to cultivars, N and K_2O rates from 9 - 10th MAR

Cultivar	N Rates kg/ha	9th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. ppm	10th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. ppm
CO421	0	21.0	21.1	21.1		19.7	19.2	19.5	
	50	22.9	23.0	23.0		21.2	21.3	21.2	
	100	22.9	23.2	23.0		22.9	23.0	22.9	
	150	21.1	22.0	21.6		21.3	20.9	21.1	
	Mean K	22.0	22.4		22.2	21.3	21.1		21.2
	C V (%)	3.6				2.8			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 82-472	0	21.7	22.4	22.0		19.7	18.9	19.3	
	50	23.5	23.6	23.6		21.7	20.7	21.2	
	100	23.7	24.0	23.9		22.3	21.6	22.0	
	150	22.8	23.5	23.1		22.0	22.8	22.4	
	Mean K	22.9	23.4		23.1	21.4	21.0		21.2
	C V (%)	3.8				3.6			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 83-737	0	20.8	23.1	22.0		18.8	19.2	19.0	
	50	25.1	24.1	24.6		20.0	20.2	20.1	
	100	25.1	23.7	24.4		20.5	20.7	20.6	
	150	23.9	21.2	22.6		19.8	18.9	19.4	
	Mean K	23.7	23.1		23.4	19.8	19.7		19.8
	C V (%)	4.2				2.0			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	21.2	22.2	21.7		19.8	19.5	19.7	
	50	23.8	23.6	23.7		21.3	21.1	21.2	
	100	23.9	23.6	23.8		22.3	22.2	22.2	
	150	22.6	22.2	22.4		21.1	21.3	21.2	
	Mean K	22.9	22.9			21.2	21.0		
	C V (%)	2.3				3.0			
	LSD ($p \leq 0.05$)	NS		NS	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

4.4 Yield responses to cultivars, N and K_2O rates at harvest

The yield (TCH) responses of the cultivars to N and K_2O fertilizer rates are presented in Table 48. The cultivars significantly ($p \leq 0.05$) influenced yields. Despite similar treatments, the new cultivars recorded higher yield than the old CO421 cultivar. The variations could be due to different genetic abilities to accumulate biomass by sugarcane cultivars. The results agreed with other study findings by Hurney and Berding (2000) and Olaoye (2006) where cultivars recorded varying cane yields.

Table 48: Cultivar yields (TCH) due to N and K_2O rates at harvest

Cultivar	K Rates kg/ha	N Rates, kg/ha 0	50	100	150	Mean K Rate	Mean Cultivar Yield-TCH
CO421	0	60.5	63.2	73.7	67.3	66.2	69.6
	100	63.0	69.6	82.2	77.6	73.1	
	Mean N	61.8	66.4	78.0	72.4		
	C V (%)	9.0					
	LSD ($p \leq 0.05$)	5.5				6.9	
KEN 82-472	0	61.7	66.7	78.6	72.3	69.8	73.5
	100	65.3	74.6	89.3	79.7	77.2	
	Mean N	63.5	70.7	83.9	76.0		
	C V (%)	8.4					
	LSD ($p \leq 0.05$)	5.3				7.4	
KEN 83-737	0	65.9	73.9	86.7	79.0	66.2	80.2
	100	68.7	78.8	95.0	93.6	73.1	
	Mean N	67.3	76.4	90.8	86.3		
	C V (%)	6.8					
	LSD ($p \leq 0.05$)	4.6				7.6	
Overall Means	0	62.7	68.0	79.6	72.9	70.8	
	100	65.7	74.3	88.8	83.6	78.1	
	Mean N	64.2	71.2	84.2	78.2		
	C V (%)	9.4					
	LSD ($p \leq 0.05$)	6.0				7.3	3.9

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

In Kenya, the data concurred with earlier criteria (Jamoza, 2005; Wawire *et al.*, 2006) that the newly developed and released cultivars were more superior in yields than the old cultivars like CO421 plant crop. The findings for the first time indicated that such yield superiority in yield was still maintained in ratoon sugarcane crops. On the contrary, Ambachew *et al.* (2012) reported insignificant yield differences in cultivars which were attributed to the difference in environmental growth conditions. Therefore, the results indicated that cultivar selection is necessary for ratoon sugarcane production in western Kenya.

The N rates significantly ($p \leq 0.05$) increased yield. Zero N rates recorded the lowest yield compared to other rates, where 100 kg N/ha had the highest yield and therefore corroborates N rate recommendation by KESREF (2002) in Kenya. However, 150 kg N/ha recorded a drop in yield in all the cultivars. Elsewhere, similar yield responses due to over-application of N fertilizer had been recorded (Martin, 1994; Muchow *et al.*, 1995; Mui *et al.*, 1996; Rizk *et al.*, 2002; Shukla, 2003; Richard, 2007; Koochekzadeh *et al.*, 2009; Ambachew *et al.*, 2012) where excessive N prolonged the vegetative growth period, leading to delayed cane maturity. In Kenya, Ong'injo and Olweny (2011), Ochola *et al.* (2014) and recently Oindo (2015) demonstrated that cane yield dropped when above 100kg N/ha fertilizer was applied. The results suggest that the current 100 kg N/ha may be optimal for old and new sugarcane cultivars in western Kenya.

The K_2O rates significantly ($p \leq 0.05$) increased ratoon cane yield. The control K_2O fertilizer rate recorded lower ($p \leq 0.05$) ratoon cane yield than 100 kg K_2O/ha. The data agreed with other reports (Malik *et al.*, 1993; Ahmed and Ferweez, 2004) that yields and K_2O rates correlated directly. In a recent study on plant crops by Ochola *et al.* (2014), increasing K_2O rates increased yield. The results indicated that K_2O is core to ratoon cane yield and 100 kg K_2O/ha would suffice the new cultivars need before the Sugar Act (2001) is implemented in Kenya.

The results from previous studies and data presented herein demonstrated that cultivar selection is vital for realization of improved ratoon-sugarcane crop yield. Ratoon sugarcane yield was significantly ($p \leq 0.05$) increased by increasing N rates. The 100 kg N/ha had the highest yield for both old and new cultivars hence might still be used for the new cultivars. The results indicated that K_2O fertilization is core to ratoon crops as potash application rates (Table 48) exhibited significant ($p \leq 0.05$) increases in yield in all cultivars.

4.5 Sugarcane quality

Sugarcane quality can be determined by pol%, brix% and commercial cane sugar percentage (CCS %) the juice (Equation 1). Pol and brix % measure the sucrose and the total dissolved solids in the juice respectively. The CCS% is a combination of both Pol% and brix%.

4.5.1 Pol % levels

The variations in pol% due to cultivars, N and K_2O rates applications are presented in Figures 23 - 25. The pol % were significantly ($p \leq 0.05$) influenced by cultivars from the 10^{th} - 14^{th} MAR.

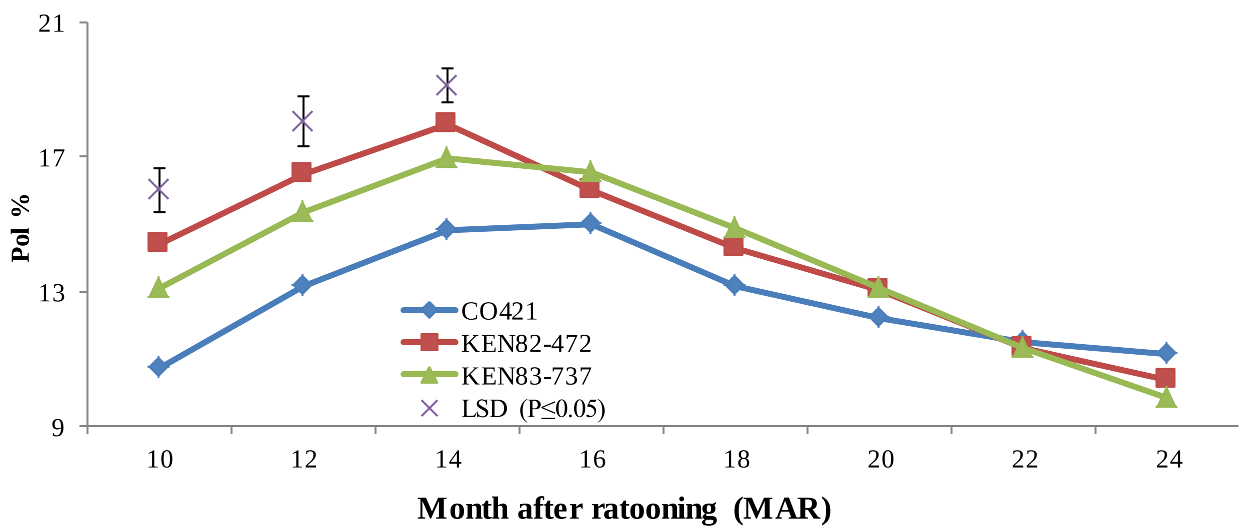

Figure 23: Pol % of ratoon cultivars with age

The new-early and late-old maturing ratoon cultivars had % pol peaks (point of maturity) at 14th and 16th MAR respectively. The data was in line with other study findings (Hurney and Berding 2000; Cock, 2001) that sugar contents increased up to the maturity and thereafter dropped. In Kenya, the results concurred with the reports (Jamoza, 2005; Wawire *et al*., 2006) that the cultivars (KEN82-472 and KEN83-737) and CO421 are early and late maturing sugarcane cultivars respectively. In a similar study on sugarcane plant crops in Kenya, Ochola (2013) and Ochola *et al*. (2014), reported significant cultivar difference in sucrose levels. The cultivars demonstrated their genetic potential to increase pol %, which implied that they have the ability to increase sugar yield, a requirement in the new proposal (Sugar Act, 2001). However, the decline was more drastic in new cultivars than the old cultivar after attaining the peaks. This trend indicated that any delay in harvesting of the new cultivars would result in lower sucrose recovery than in the old cultivar. The results suggested that for higher sucrose realization, the new and old cultivars should be harvested at the 14th and 16th MAR respectively. Therefore it is vital for Kenya Sugar Industry to move away from current harvesting policy, where all cultivars are harvested after the 20th MAR.

Increasing N rates (Figure 24) significantly ($p \leq 0.05$) increased pol % from 10th to 14th MAR. The effects were realized before and after the peaks in new and old cultivars respectively. The 0, 50, 100 and 150 kg N/ha yielded maximum sucrose contents of 15.57, 16.89, 17.66 and 16.25% respectively. The findings agree with the reports (Rizk, *et al.*, 2002; Muchovej and Newman, 2004a; Koochekzadeh *et al*., 2009; Ambachew *et al*., 2009; Naga *et al*., 2011) that high or excess N rates adversely affect pol% towards maturity. However, the results contradicted reports (Stranack and Miles, 2011; Najran *et al.*, 2012) where pol levels did not respond to the N rates.

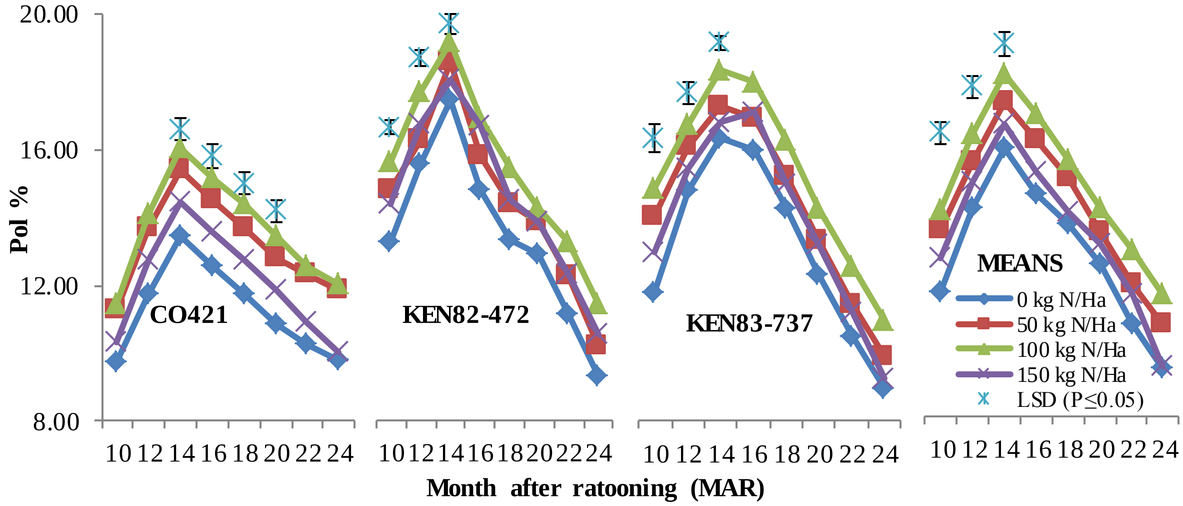

Figure 24: Variations in pol % due to N fertilizer rates in cultivars

The results illustrate that appropriate N application is required for quality improvement for increased sucrose production. Therefore, the data suggested that 100 kg N/ha rate can be applied to both new and old cultivars in western Kenya.

Potash application significantly ($p \leq 0.05$) improved ratoon-sugarcane pol % (Figure 25). From the 10th MAR, the zero K rate recorded lower pol% values compared to the test rate.

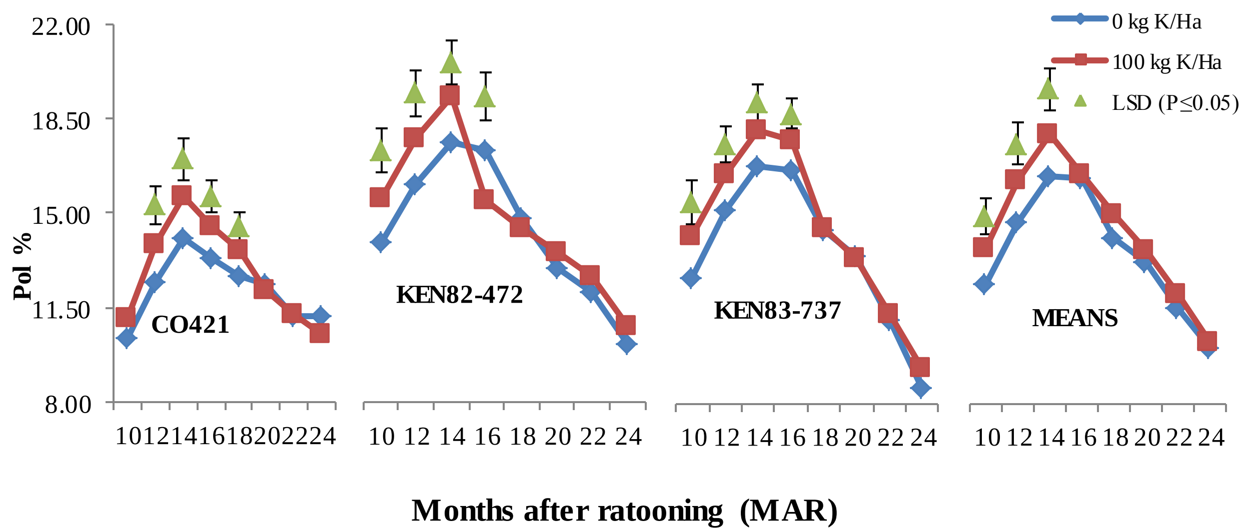

Figure 25: Pol % with K_2O fertilizer rates with age

The control and test rates recorded peaks at the 14th MAR with mean pol% values of 15.82 and 17.29 % respectively. The results agreed with the KSI recommendation (KESREF, 2008) of 100 kg K_2O/ha for both new and old cultivars. Furthermore, these findings match other reports (Malavolta, 1994; Satisha, *et al.*, 1996) that increasing K_2O level increased translocation of sucrose into storage tissue. The results demonstrate that K_2O application should be re-introduced for realization of higher sugar recovery.

Table 49: Changes in pol % due to cultivars, N and K_2O fertilizer rates from 10 - 12th MAR

Cultivar	N Rates kg/ha	10th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Pol %	12th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Pol%
CO421	0	9.6	9.8	9.7		11.2	12.3	11.8	
	50	10.9	11.6	11.3		13.2	14.2	13.7	
	100	10.9	12.4	11.6		13.2	15.5	14.1	
	150	10.1	10.5	10.3		12.2	13.3	12.8	
	Mean K	10.4	11.1		10.7	12.4	13.9		12.9
	C V (%)	6.6				11.3			
	LSD ($p \leq 0.05$)	NS		NS		1.4		0.7	
KEN 82-472	0	12.4	13.9	13.2		14.9	16.0	15.4	
	50	13.7	15.7	14.7		16.1	17.0	16.5	
	100	14.5	16.5	15.5		16.7	18.4	17.5	
	150	13.9	14.6	14.3		15.3	17.9	16.6	
	Mean K	13.6	15.2		14.4	15.7	17.3		16.5
	C V (%)	11.2				10.0			
	LSD ($p \leq 0.05$)	1.5		0.4		1.6		0.5	
KEN 83-737	0	10.5	12.8	11.7		13.6	15.3	14.5	
	50	13.6	14.1	13.8		14.7	15.9	15.3	
	100	13.4	14.8	14.1		15.8	17.0	16.4	
	150	12.0	13.6	12.8		14.8	15.7	15.7	
	Mean K	12.3	13.8		13.1	14.7	16.0		15.3
	C V (%)	12.1				8.4			
	LSD ($p \leq 0.05$)	1.5		0.6		1.2		0.4	
Overall Means	0	10.9	12.2	11.5		13.2	14.5	13.9	
	50	12.7	13.8	13.3		14.7	15.7	15.2	
	100	12.9	15.6	13.8		15.2	17.0	16.1	
	150	12.0	12.9	12.5		13.6	15.6	14.6	
	Mean K	12.1	13.4			14.3	15.7		
	C V (%)	10.2							
	LSD ($p \leq 0.05$)	1.2		0.6	1.3	1.4		0.6	1.2

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 50: Variations in pol % due to cultivars, N and K_2O rates from 14 - 16th MAR

Cultivar	N Rates kg/ha	14th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Pol %	16th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Pol%
CO421	0	12.8	14.1	13.4		13.1	14.1	13.6	
	50	14.8	16.0	15.4		15.1	16.0	15.5	
	100	14.8	17.3	16.1		15.2	17.3	16.2	
	150	13.8	15.1	14.4		14.1	15.1	14.6	
	Mean K	14.0	15.6		14.8	14.4	15.6		15.0
	C V (%)	11.2				9.0			
	LSD ($p \leq 0.05$)	1.6		0.7		1.2		0.7	
KEN 82-472	0	16.4	17.5	17.3		15.6	13.8	14.7	
	50	17.5	18.4	17.9		16.5	14.8	15.7	
	100	18.2	19.8	19.0		17.9	15.6	16.8	
	150	16.8	19.4	18.4		17.5	15.8	16.6	
	Mean K	17.2	18.8		18.0	16.9	15.2		16.5
	C V (%)	9.2				10.2			
	LSD ($p \leq 0.05$)	1.6		0.6		1.7		NS	
KEN 83-737	0	15.3	16.9	16.1		15.0	16.4	15.7	
	50	16.4	17.6	17.0		16.1	17.0	16.6	
	100	17.4	18.6	18.0		17.1	18.1	17.6	
	150	16.3	17.3	16.8		15.9	16.7	16.7	
	Mean K	16.4	17.6		17.0	16.0	17.1		15.3
	C V (%)	7.7				6.5			
	LSD ($p \leq 0.05$)	1.2		0.4		1.0		NS	
Overall Means	0	14.8	16.2	15.6		14.5	14.8	14.7	
	50	16.2	17.3	16.7		15.9	15.9	15.9	
	100	16.8	18.6	17.7		16.7	17.2	17.0	
	150	15.6	17.3	16.5		15.8	15.9	16.0	
	Mean K	15.9	17.3			15.8	15.9		
	C V (%)	9.2				4.9			
	LSD ($p \leq 0.05$)	1.3		NS	1.0	NS		NS	1.2

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 51: Variations in pol % due to cultivars, N and K_2O rates from 18 - 20[th] MAR

Cultivar	N Rates kg/ha	18[th] MAR K_2O Rates kg/ha 0	18[th] MAR K_2O Rates kg/ha 100	18[th] MAR Mean N Rate	18[th] MAR Mean Cultivar Pol %	20[th] MAR K_2O Rates kg/ha 0	20[th] MAR K_2O Rates kg/ha 100	20[th] MAR Mean N Rate	20[th] MAR Mean Cult. Pol%
CO421	0	11.4	12.1	11.8		10.6	11.1	10.9	
	50	13.4	14.0	13.7		12.5	13.1	12.8	
	100	13.4	15.3	14.4		13.8	13.1	13.5	
	150	12.4	13.1	12.8		11.6	12.1	11.9	
	Mean K	12.6	13.7		13.1	12.1	12.4		12.2
	C V (%)	7.9				1.8			
	LSD ($p \leq 0.05$)	1.0		0.7		NS		0.7	
KEN 82-472	0	13.2	13.3	13.2		11.9	12.0	14.8	
	50	14.1	14.5	14.3		13.1	13.0	15.8	
	100	15.5	15.1	15.3		13.7	14.4	17.2	
	150	15.1	13.7	14.4		12.3	13.9	16.7	
	Mean K	14.5	14.1		14.3	12.8	13.3		13.0
	C V (%)	2.5				4.5			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 83-737	0	14.0	14.1	14.0		12.1	12.2	12.2	
	50	15.1	14.8	14.9		13.2	13.1	13.1	
	100	16.1	15.8	16.0		14.2	13.8	14.0	
	150	14.9	14.5	14.7		13.0	13.0	13.0	
	Mean K	15.0	14.8		14.9	13.1	13.0		13.1
	C V (%)	3.7				4.5			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	12.8	14.1	13.5		12.3	12.3	12.3	
	50	14.2	15.3	14.7		12.9	13.5	13.2	
	100	15.0	15.4	15.2		13.9	13.9	13.9	
	150	14.1	13.4	13.8		12.3	13.4	12.9	
	Mean K	14.1	14.5			12.9	13.3		
	C V (%)	3.4				3.1			
	LSD ($p \leq 0.05$)	NS		NS	0.6	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 52: Variations in pol % due to cultivars, N and K_2O rates from 22nd - 24th MAR

Cultivar	N Rates kg/ha	22nd MAR K_2O Rates kg/ha 0	22nd MAR K_2O Rates kg/ha 100	22nd MAR Mean N Rate	22nd MAR Mean Cultivar Pol %	24tha MAR K_2O Rates kg/ha 0	24tha MAR K_2O Rates kg/ha 100	24tha MAR Mean N Rate	24tha MAR Mean Cult. Pol%
CO421	0	10.5	10.0	10.2		10.3	9.1	9.7	
	50	12.5	12.0	12.2		12.3	11.0	11.7	
	100	12.5	12.6	12.6		12.4	12.3	12.4	
	150	11.5	10.4	10.9		11.3	10.2	10.7	
	Mean K	11.7	11.3		11.5	11.6	10.7		11.1
	C V (%)	3.9				6.8			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 82-472	0	11.1	11.2	11.1		9.3	9.4	9.3	
	50	12.2	12.1	12.2		10.1	10.2	10.2	
	100	12.9	13.5	13.2		11.1	11.7	11.4	
	150	11.5	13.1	12.3		9.7	11.3	10.5	
	Mean K	11.9	12.5		12.2	10.1	10.7		10.4
	C V (%)	4.8				6.2			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 83-737	0	10.4	10.4	10.4		9.0	8.9	9.0	
	50	11.5	11.1	11.3		10.1	9.5	9.8	
	100	12.6	12.2	12.4		11.2	10.6	10.9	
	150	11.4	10.8	11.1		10.1	9.2	9.2	
	Mean K	11.5	11.1		11.3	10.1	9.5		9.8
	C V (%)	2.9				4.6			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	10.6	10.5	10.6		9.2	9.1	9.4	
	50	12.1	11.4	11.7		10.4	10.9	10.6	
	100	12.6	12.8	12.7		11.3	11.5	11.4	
	150	11.4	11.5	11.5		8.5	10.4	9.4	
	Mean K	11.1	11.8			9.9	10.3		
	C V (%)	4.8				3.4			
	LSD ($p \leq 0.05$)	NS		NS	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

4.5.2 Brix % levels

The responses of brix% to cultivars, N and K_2O fertilizer application rates are shown in Figures 26 - 28 and Tables 53 - 56. There were significant ($p \leq 0.05$) increases in brix% with sugarcane cultivars from 10 - 14th MAR. The increment was relatively uniform until the attainment of the peaks by all the cultivars at the 14th MAR. The cultivars KEN82-472 and KEN83-737 had accumulated higher brix% than the CO421. In other studies in Australia (Hurney and Berding, 2000) and Kenya (Ochola, 2013), similar results were obtained but with the cane plant crops.

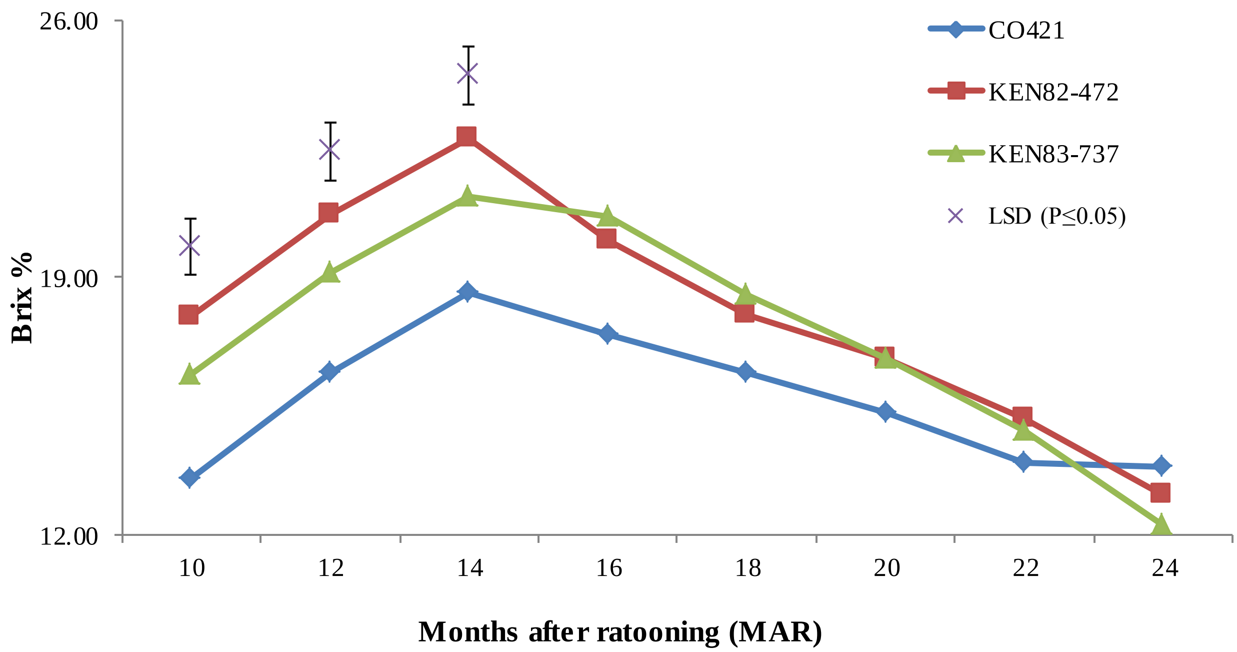

Figure 26: Variations in brix % due to cultivars

Furthermore, the results agree with the assertion (KESREF, 2002; 2007) that the new cultivars are superior in quality than the old cultivar. However, non-significant cultivar differences in brix% were observed in other studies (Srivastava *et al.*, 1992; Ahmed *et al.* (2010). After the peaks (14th MAR) however, there were declines in the brix% levels. The results suggested that the harvesting time of the ratoon crops be at the 14th MAR.

Nitrogen rates (Figures 27) significantly ($p \leq 0.05$) increased brix% in all the cultivars. The brix increased from 10th - 14th MAR with the control registering lowest brix%. Similar pattern was observed with pol levels (Figure 25) in this study. The 150 kg N/ha rate had a lower peak at the 16th MAR for KEN83-737. These results had similar pattern between other quality parameters pol% and brix% as reported by Richard (2007 and Yahaya *et al*., (2009). These findings matched other reports (Meyer and Wood, 2001; Inman-Bamber, 2004) where increasing rates from 100 to 150 kg N/ha significantly declined brix% juice. The current data upholds by the recommendation (KESREF, 2008) of a uniform 100kg N/ha rate across all cultivars. After the peaks, the brix levels declined till the 24th MAR. These findings agreed with earlier reports (El-Sogheir and Ferweez, 2009; Ong'injo and Olweny, 2011; Eman *et al*., 2013) in which brix% values reduced after peakings. On the other hand, the current results are in variance with previous studies (Koochekzadeh *et al*., 2009; Saleem *et al*. 2012; Mengistu 2013) where responses were just sporadic. The results suggested that 100 kg N/ha is the most suitable application rate for Kenya Sugar Industry while the 150 kg N/ha would be of no benefits to the ratoon canes.

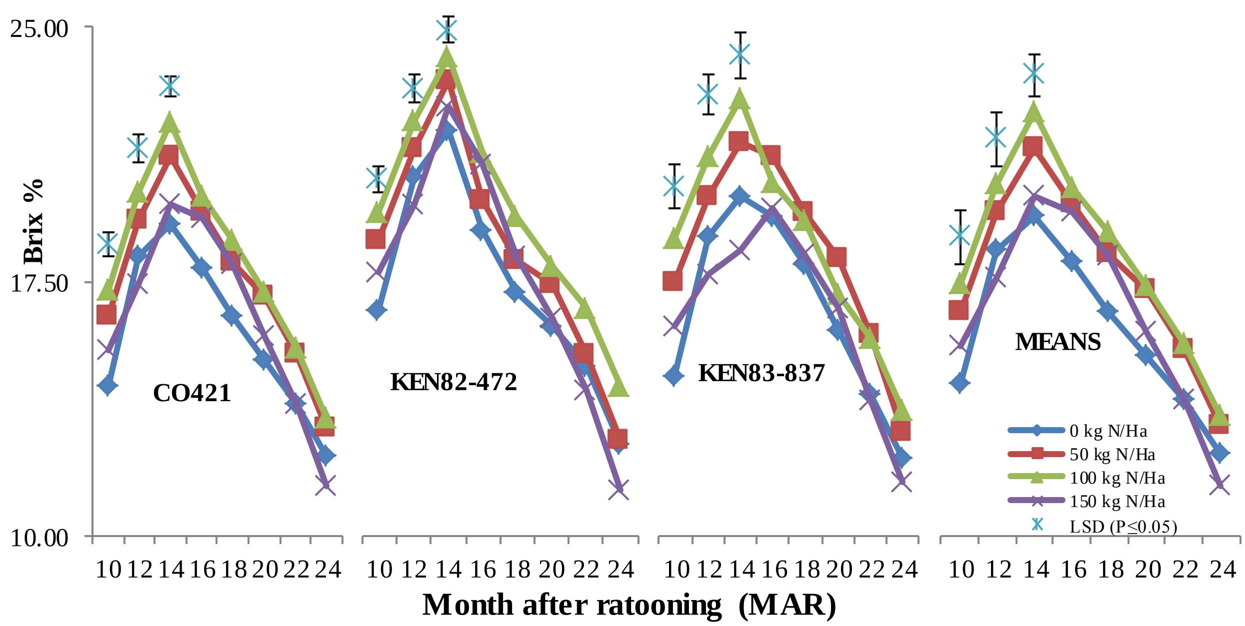

Figure 27**:** Brix % due to N rates in CO421, KEN82 - 472 and KEN83 - 737 with age.

Potash rates (Figures 28) significantly ($p \leq 0.05$) increased brix% in cultivars from 10th to the peaks at 14th MAR in test cultivars. The data agreed with the findings of Ahmed *et al.* (2009) and Hunsigi (2011). The zero rate registered a lower brix% than100kg K/ha rate throughout the study.

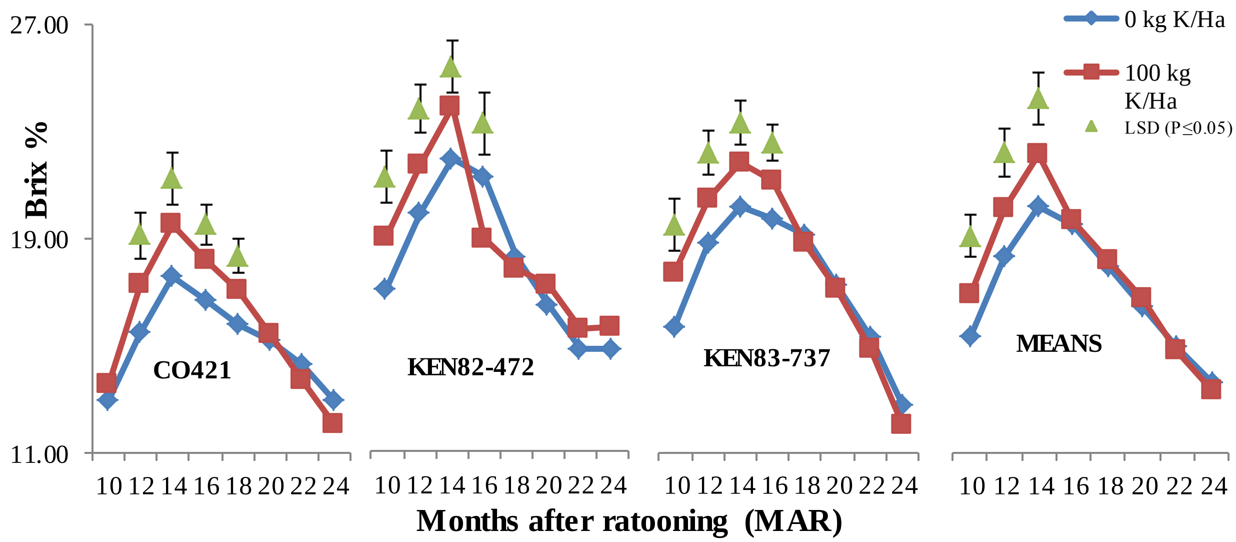

Figure 28: Brix % due to K fertilizer rates in CO421, KEN82-472 and KEN83-737 with age

In Kenya, the results concurred with the Kenya Sugar Industry support (KESREF, 2008) of 100 kg K/ha rate for all cultivars. The brix level increased from 10th to the peak at the 14th MAR (Figure 28) thereafter, it declined. The results therefore indicated that the soils were indeed in need of potassium for improved ratoon sugarcane productivity in western Kenya.

Table 53: Variations in brix % due to cultivars, N and K_2O rates from 10 - 12[th] MAR

Cultivar	N Rates kg/ha	10th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Brix%	12th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Brix%
CO421	0	12.0	12.3	12.2		14.2	15.6	14.9	
	50	13.7	14.5	14.1		16.5	17.8	17.1	
	100	13.4	14.4	13.9		16.2	19.0	17.6	
	150	12.7	13.2	12.9		15.2	16.7	16.0	
	Mean K	12.9	13.6		13.3	15.5	17.3		16.4
	C V (%)	4.9				12.2			
	LSD ($p \leq 0.05$)	NS		NS		1.7		NS	
KEN 82-472	0	15.5	17.4	16.5		19.6	21.0	20.3	
	50	17.3	19.7	18.5		20.5	21.7	21.1	
	100	18.0	20.5	19.3		20.5	23.3	21.9	
	150	17.1	18.0	17.6		18.8	20.2	19.5	
	Mean K	17.0	18.9		17.9	19.8	21.6		20.7
	C V (%)	13.3				8.8			
	LSD ($p \leq 0.05$)	1.9		0.8		1.8		0.8	
KEN 83-737	0	13.1	16.1	14.6		17.5	19.6	18.6	
	50	16.9	17.6	17.3		18.9	20.5	19.7	
	100	16.7	18.6	17.6		20.1	21.6	20.9	
	150	14.9	17.0	16.0		16.9	18.0	17.5	
	Mean K	15.4	17.3		16.4	18.4	19.9		19.2
	C V (%)	12.1				8.4			
	LSD ($p \leq 0.05$)	1.9		1.2		1.6		1.1	
Overall Means	0	13.6	15.2	14.4		18.7	17.9	18.3	
	50	16.0	17.3	16.6		20.0	19.3	19.7	
	100	16.0	17.8	16.9		21.3	20.1	20.7	
	150	14.9	16.1	15.5		18.3	17.6	18.0	
	Mean K	15.1	16.6			17.9	19.6		
	C V (%)	9.8				9.4			
	LSD ($p \leq 0.05$)	1.5		0.8	1.5	1.7		0.8	1.6

Legend: NS -Non significant; Old cultivar - CO421; New cultivars- KEN82-472; KEN83-737

Table 54: Variations in brix % due to cultivars, N and K_2O rates from 14 - 16th MAR

Cultivar	N Rates kg/ha	14th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Brix %	16th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Brix%
CO421	0	16.0	17.6	16.8		15.1	16.3	15.7	
	50	18.5	20.0	19.2		17.6	18.6	18.1	
	100	18.7	21.8	20.3		17.7	20.3	19.0	
	150	17.2	18.9	18.1		16.3	17.5	16.9	
	Mean K	17.6	19.6		18.6	16.7	18.2		17.4
	C V (%)	11.1				9.0			
	LSD ($p \leq 0.05$)	2.0		1.0		1.5		0.9	
KEN 82-472	0	20.9	22.3	21.6		19.8	17.7	18.8	
	50	22.5	23.6	23.0		20.7	18.5	19.6	
	100	22.7	24.8	23.7		22.4	19.5	21.0	
	150	21.0	24.3	22.7		21.7	19.6	20.7	
	Mean K	21.8	23.7		22.8	21.2	18.8		20.0
	C V (%)	9.0				10.9			
	LSD ($p \leq 0.05$)	2.0		0.7		2.3		NS	
KEN 83-737	0	18.7	20.7	19.7		18.3	20.0	19.6	
	50	20.5	22.0	21.3		20.3	21.5	20.7	
	100	21.8	23.3	22.5		19.5	20.7	22.0	
	150	17.5	18.8	18.2		18.8	19.9	20.4	
	Mean K	19.6	21.2		21.2	19.2	20.5		20.7
	C V (%)	7.9				6.7			
	LSD ($p \leq 0.05$)	1.6		1.3		1.3		NS	
Overall Means	0	18.5	20.2	19.4		17.7	18.0	17.9	
	50	20.5	21.8	21.2		19.5	19.5	19.5	
	100	21.1	23.3	22.2		19.9	20.2	20.0	
	150	18.6	20.7	19.6		19.0	19.0	19.0	
	Mean K	19.7	21.5			19.0	19.2		
	C V (%)	9.3				3.2			
	LSD ($p \leq 0.05$)	1.8		0.6	1.6	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 55: Variations in brix % due to cultivars, N and K_2O rates from 18 - 20[th] MAR

Cultivar	N Rates kg/ha	18th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Brix %	20th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar Brix %
CO421	0	14.2	15.2	14.7		13.3	13.9	13.6	
	50	16.7	17.5	17.1		15.6	16.4	16.0	
	100	16.8	19.1	18.0		17.3	16.4	16.8	
	150	15.5	16.4	16.0		14.5	15.1	14.8	
	Mean K	15.8	17.1		16.4	15.2	15.4		15.3
	C V (%)	7.9				4.5			
	LSD ($p \leq 0.05$)	1.3		0.8		NS		0.8	
KEN 82-472	0	16.9	17.0	17.0		15.9	16.1	16.0	
	50	17.7	18.1	17.9		17.3	17.2	17.2	
	100	19.4	18.9	19.1		17.3	18.1	17.7	
	150	18.9	17.1	18.0		15.2	17.3	16.3	
	Mean K	18.2	17.8		18.0	16.4	17.2		16.8
	C V (%)	5.0				4.4			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 83-737	0	17.7	17.8	17.8		15.8	16.0	15.9	
	50	19.5	19.0	19.3		18.0	17.9	18.0	
	100	19.3	18.9	19.1		17.2	16.7	16.9	
	150	18.3	17.8	18.0		16.5	16.5	16.5	
	Mean K	18.7	18.4		18.5	16.9	16.8		16.8
	C V (%)	4.4				2.5			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	16.3	16.7	16.5		15.0	15.3	15.2	
	50	18.0	18.2	18.1		17.0	17.1	17.1	
	100	18.5	19.0	18.7		17.2	17.1	17.2	
	150	17.6	17.1	17.3		15.4	16.3	15.9	
	Mean K	17.6	17.7			16.2	16.5		
	C V (%)	2.9				2.2			
	LSD ($p \leq 0.05$)	NS		NS	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 56: Variations in brix % due to cultivars, N and K_2O rates from 22nd - 24th MAR

Cultivar	N Rates kg/ha	22nd MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Brix%	24th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. Brix%
CO421	0	13.1	12.5	12.8		12.8	11.7	12.2	
	50	15.3	14.8	15.1		14.4	13.1	13.8	
	100	14.4	14.6	14.5		12.5	12.5	12.5	
	150	14.3	12.9	13.6		12.1	11.0	11.6	
	Mean K	14.3	13.7		14.0	13.0	12.1		12.5
	C V (%)	4.2				7.0			
	LSD ($p\leq0.05$)	NS		NS		NS		NS	
KEN 82-472	0	14.8	14.9	14.9		14.8	14.9	14.9	
	50	15.3	15.2	15.2		15.2	15.3	15.2	
	100	16.1	16.9	16.5		16.1	16.9	16.5	
	150	13.1	15.2	14.1		13.1	15.2	14.1	
	Mean K	14.8	15.5		15.2	14.8	15.6		15.2
	C V (%)	4.9				5.3			
	LSD ($p\leq0.05$)	NS		NS		NS		NS	
KEN 83-737	0	14.0	14.0	14.0		139	11.1	11.2	
	50	16.0	15.5	15.8		12.6	11.9	12.3	
	100	15.9	15.4	15.6		14.0	13.2	13.6	
	150	14.2	13.6	13.9		12.6	11.5	12.1	
	Mean K	15.0	14.6		14.8	12.6	11.9		12.3
	C V (%)	5.6				5.6			
	LSD ($p\leq0.05$)	NS		NS		NS		NS	
Overall Means	0	14.0	13.8	13.9		13.0	12.6	12.8	
	50	15.5	15.1	15.3		14.1	13.4	13.7	
	100	15.5	15.6	15.5		14.2	14.2	14.2	
	150	13.9	13.9	13.9		12.6	12.6	12.6	
	Mean K	14.7	14.6			13.5	13.2		
	C V (%)	2.8				3.2			
	LSD ($p\leq0.05$)	NS		NS	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

4.5.3 Commercial cane sugar percentage (CCS %)

Commercial cane sugar (CCS %) gives the estimate of the percentage of recoverable sucrose from cane juice. The influence of cultivars and effects of N and K_2O fertilizer applications on ratoon cane commercial cane sugar (CCS) are presented in Figures 29 - 31 and Tables 57 - 60.

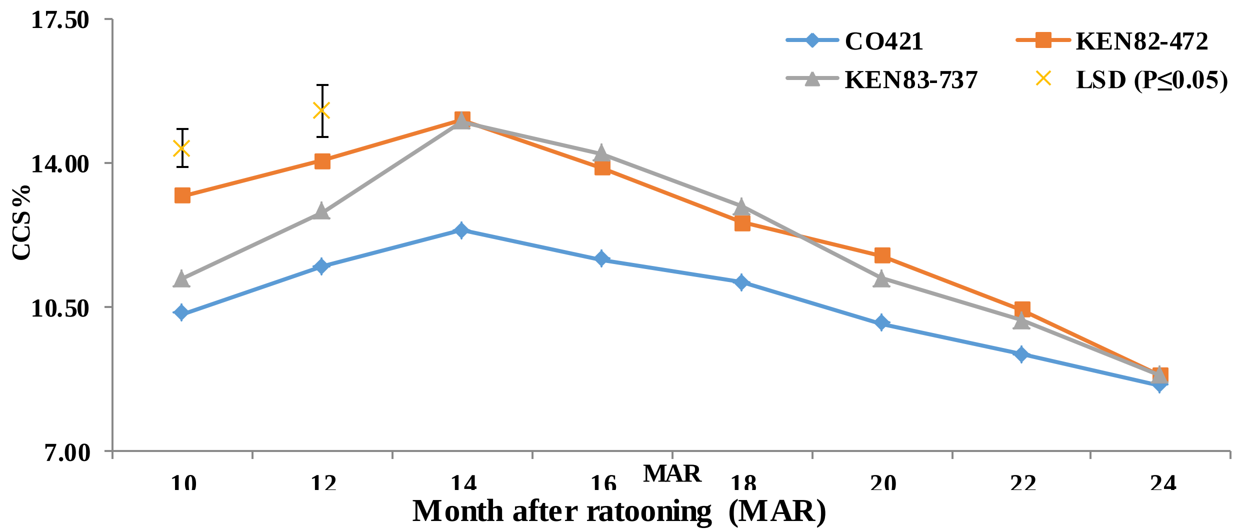

Figure 29: Influence of cultivars on ratoon cane commercial cane sugar, CCS%.

The CCS% significantly ($p \leq 0.05$) varied with cultivars from 10th - 12th MAR. The new cultivars had numerically similar values but significantly ($p \leq 0.05$) higher CCS% than the old CO421. The differences could have been due to genetic make ups of the cultivars; hence proper cultivar selection is critical in realization of high sucrose production. The CCS% increased from the 10th - 14th MAR when a uniform peak was attained. After the peaks, CCS% declined in all the cultivars (Figure 29) where cultivars recorded different CCS% levels. However, the data contradicted other finding (Ahmed *et al.*, 2010) where cultivar had non-significant influences on CCS%. These results demonstrate that for the realization of high sucrose from ratoon crops, both new and old cultivars should be harvested between 12th - 16th MAR in western Kenya.

The N rates (Figure 30) increased CCS% significantly ($p \leq 0.05$) in all the cultivars from 10th - 14th MAR. The data agrees with other results Habib *et al.* (1991), Rehman *et al.*, (1992) and Larrahando and Villagas, (1995) who observed increasing CCS% values with increasing N rates.

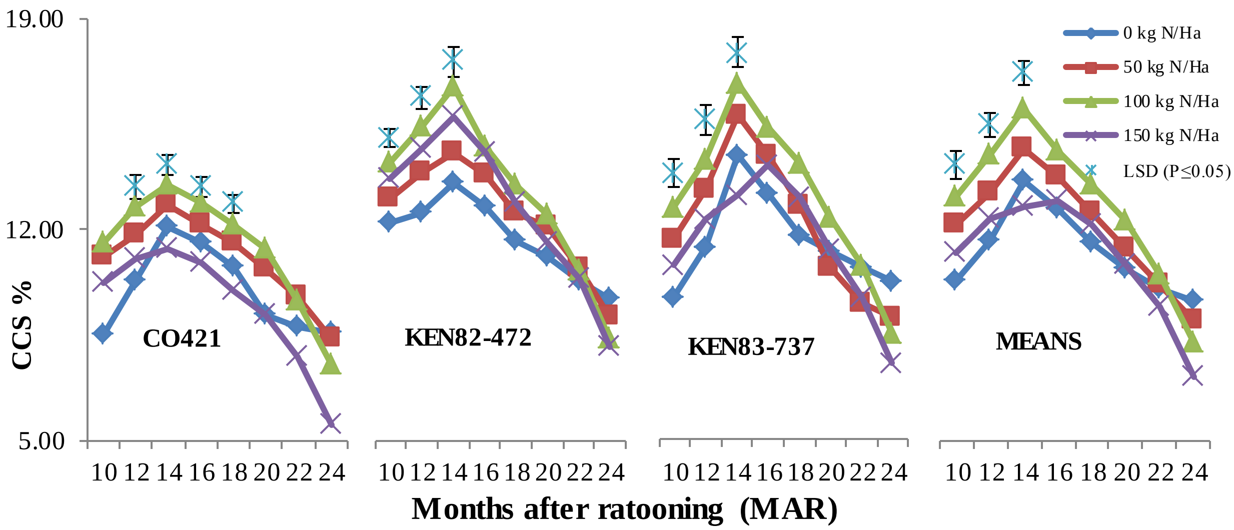

Figure 30: Variations in CCS% due to N fertilizer rates with age

The 150 kg N/ha rate achieved the peak later at the 16th MAR. These findings are in line with other reports (Muchow *et al.*, 1995; Meyer and Wood, 2001; Inman-Bamber, 2004; Rattey and Hogarth, 2001) who found that excessive N application led to decline in assimilates due to its extending vegetative growth while slowing down of ripening. However, non-significant differences in CCS % at with varied N rates had been reported (Patel *et al.*, 2004; Koochekzadeh *et al.*, 2009; Saleem, 2012). Furthermore, the current data supports the recommendation (KESREF, 2008) of 100 kg N/ha rate to ratoon crop. After the peak at 14th MAR, the CCS values declined. The data indicates that longer stay of the ratoon crops beyond these durations would cancel the benefits of N rates in sucrose production. Similar results had been observed (Ong'injo and Olweny, 2011) at the coastal region of Kenya with early peaks between 10 - 12th MAR. This could have been attributed to higher temperatures which enhance maturity. Therefore, 100 kg N/ha rate would be the most beneficial to ratoon cane production.

The K_2O rates significantly ($p \leq 0.05$) increased CCS% in all the cultivars (Figure 3) from 10th - 14th MAR and were similar with other reports (Malavolta, 1994; Satisha *et al.*, 1996). Similar data had been obtained in Kenya (KEREF, 2008) that led to the recommendation of 100 kg K_2O/ha. In other studies (Wood, 1990; Gulati *et al.*, 1998), the potash rates did not influence CCS production. The benefits of K_2O application in the ratoon crops were only realized between 12th - 18th, 10th - 14th and 10th - 16th MAR in CO421, KEN82-472 and KEN83-737 cultivars respectively.

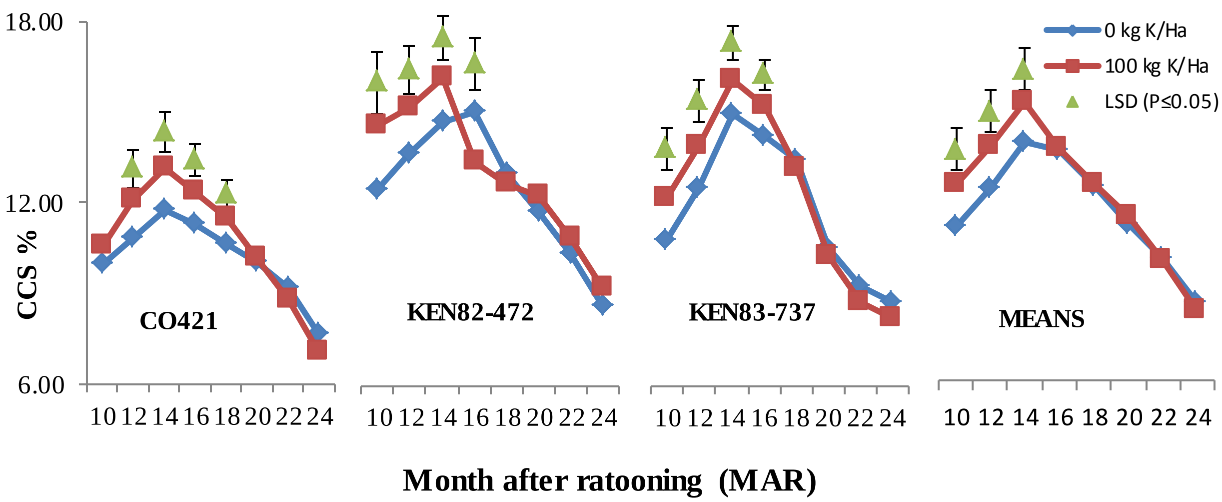

Figure 31**: Variations in** CCS% due to K_2O rates with age

The period of responses observed in this study create time limits within which ratoon crops of different cultivars can be harvested to improve sucrose output. Benefits in sucrose production can be realized through cultivars selection. Potash rates application is asure way of improving on the sugar recovery in western Kenya.

Table 57: Variations in CCS % due to cultivars, N and K_2O rates (10 - 12^{th} MAR)

Cultivar	N Rates kg/ha	10^{Th} MAR K_2O Rates kg/ha 0	10^{Th} MAR K_2O Rates kg/ha 100	10^{Th} MAR Mean N Rate	10^{Th} MAR Mean Cultivar CCS %	12^{th} MAR K_2O Rates kg/ha 0	12^{th} MAR K_2O Rates kg/ha 100	12^{th} MAR Mean N Rate	12^{th} MAR Mean Cult. CCS%
CO421	0	8.4	8.6	8.5		9.8	10.8	10.3	
	50	10.8	11.4	11.1		11.4	12.3	11.8	
	100	10.7	12.4	11.5		11.8	13.7	12.8	
	150	10.1	10.4	10.3		10.6	11.6	11.1	
	Mean K	10.0	10.7		10.3	10.9	12.1		11.5
	C V (%)	7.1				11.3			
	LSD ($p \leq 0.05$)	NS		NS		1.2		0.8	
KEN 82-472	0	11.1	13.2	12.1		12.0	13.0	12.5	
	50	11.7	14.2	13.0		13.5	14.2	13.8	
	100	12.9	15.4	14.2		14.8	15.9	15.3	
	150	13.2	14.0	13.6		13.0	16.2	14.6	
	Mean K	12.2	14.2		13.2	13.3	14.8		14.1
	C V (%)	16.2				11.2			
	LSD ($p \leq 0.05$)	2.0		0.6		1.5		0.7	
KEN 83-737	0	8.7	10.8	10.1		10.3	12.4	11.4	
	50	10.2	11.9	11.0		13.0	13.5	13.3	
	100	12.0	13.3	12.8		13.7	14.9	14.3	
	150	10.0	11.5	10.1		11.6	13.0	12.3	
	Mean K	10.5	11.8		11.2	12.2	13.5		12.8
	C V (%)	12.4				10.7			
	LSD ($p \leq 0.05$)	1.3		0.9		1.3		1.0	
Overall Means	0	9.4	10.9	10.1		10.7	12.1	11.4	
	50	11.3	12.5	11.9		12.6	13.3	13.0	
	100	11.9	13.7	12.8		13.4	14.9	14.1	
	150	11.1	12.0	11.5		11.7	13.6	12.7	
	Mean K	10.9	12.3			12.1	13.5		
	C V (%)	12.2				11.0			
	LSD ($p \leq 0.05$)	1.3		NS	0.9	1.3		0.7	1.3

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 58: Variations in CCS % due to cultivars, N and K_2O rates (14 - 16^{th} MAR)

Cultivar	N Rates kg/ha	14^{1h} MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar CCS %	16^{th} MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. CCS%
CO421	0	11.5	12.7	12.1		11.1	11.9	11.5	
	50	12.3	13.3	12.8		11.8	12.5	12.2	
	100	12.4	14.6	13.5		11.9	13.8	12.9	
	150	10.8	12.0	11.4		10.5	11.3	10.9	
	Mean K	11.8	13.1		12.5	11.3	12.4		11.9
	C V (%)	11.7				9.3			
	LSD (p≤0.05)	1.2		0.7		1.0		0.7	
KEN 82-472	0	13.0	14.0	13.5		13.4	11.9	12.7	
	50	14.1	14.9	14.5		14.5	13.0	13.7	
	100	15.9	17.4	16.6		15.7	13.7	14.7	
	150	14.5	16.8	15.6		15.2	13.7	14.5	
	Mean K	14.4	15.7		15.1	14.7	13.1		13.9
	C V (%)	9.6				11.1			
	LSD (p≤0.05)	1.2		1.0		1.5		NS	
KEN 83-737	0	13.7	15.1	14.4		12.5	13.8	13.2	
	50	15.2	16.2	15.7		14.0	14.8	14.4	
	100	16.2	17.3	16.8		14.9	15.8	15.3	
	150	12.6	13.5	13.1		13.7	14.4	14.1	
	Mean K	14.5	15.5		15.0	13.8	14.7		14.2
	C V (%)	7.5				6.6			
	LSD (p≤0.05)	1.0		1.0		0.8		NS	
Overall Means	0	12.7	13.9	13.3		12.4	12.5	12.5	
	50	13.9	14.8	14.3		13.4	13.4	13.4	
	100	14.9	16.4	15.6		14.2	14.4	14.3	
	150	12.6	14.1	13.4		13.1	13.1	13.1	
	Mean K	13.5	14.8			13.3	13.4		
	C V (%)	9.5				0.9			
	LSD (p≤0.05)	1.2		0.82	NS	0.1		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 59: Variations in CCS % due to cultivars, N and K_2O rates (18 - 20th MAR)

Cultivar	N Rates kg/ha	18th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar CCS %	20th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. CCS%
CO421	0	10.4	11.1	10.7		9.0	9.4	9.2	
	50	11.3	11.8	11.5		10.5	11.0	10.7	
	100	11.3	13.0	12.1		11.6	11.0	11.3	
	150	9.6	10.3	10.0		9.0	9.4	9.2	
	Mean K	10.7	11.5		11.1	10.0	10.2		10.1
	C V (%)	8.2				1.9			
	LSD ($p \leq 0.05$)	0.8		0.6		NS		NS	
KEN 82-472	0	11.5	11.6	11.6		11.0	11.1	11.0	
	50	12.4	12.6	12.5		12.1	12.0	12.1	
	100	13.6	13.2	13.4		12.1	12.7	12.4	
	150	13.4	12.2	12.8		10.8	12.2	11.5	
	Mean K	12.7	12.4		12.6	11.5	12.0		11.7
	C V (%)	2.5				4.4			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 83-737	0	11.7	11.8	11.8		11.3	11.2	11.3	
	50	12.9	12.6	12.8		10.7	10.8	10.7	
	100	14.3	14.0	14.2		12.2	12.5	12.4	
	150	13.2	12.8	13.0		11.3	11.3	11.3	
	Mean K	13.0	12.8		12.9	11.4	11.4		11.4
	C V (%)	1.7				0.6			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	11.2	11.5	11.4		10.4	10.6	10.5	
	50	12.2	12.4	12.3		11.1	11.3	11.2	
	100	13.1	13.4	13.2		12.0	12.1	12.0	
	150	12.1	11.8	11.9		10.3	10.9	10.6	
	Mean K	12.1	12.3			11.0	11.2		
	C V (%)	0.9				2.3			
	LSD ($p \leq 0.05$)	0.1		NS	NS	0.3		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

Table 60: Variations in CCS % due to cultivars, N and K_2O rates (22 - 24th MAR)

Cultivar	N Rates kg/ha	22nd MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cultivar CCS %	24th MAR K_2O Rates kg/ha 0	100	Mean N Rate	Mean Cult. CCS%
CO421	0	8.9	8.6	8.7		9.1	8.0	8.5	
	50	9.9	9.6	9.8		9.0	7.8	8.4	
	100	9.6	9.7	9.7		7.5	7.5	7.5	
	150	8.2	7.3	7.8		6.1	5.0	5.5	
	Mean K	9.2	8.8		9.0	7.9	7.0		7.5
	C V (%)	4.4				11.4			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 82-472	0	10.2	10.3	10.2		9.6	9.7	9.7	
	50	10.7	10.6	10.7		9.0	9.1	9.1	
	100	10.3	10.8	10.5		8.1	8.6	8.4	
	150	9.6	11.1	10.3		7.4	8.8	8.1	
	Mean K	10.2	10.7		10.4	8.5	9.1		8.8
	C V (%)	4.9				6.5			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
KEN 83-737	0	10.7	10.7	10.7		10.3	10.2	10.3	
	50	9.7	9.3	9.5		9.3	8.8	9.0	
	100	10.9	10.6	10.7		8.8	8.2	8.5	
	150	10.0	9.5	9.7		7.9	7.1	7.5	
	Mean K	10.3	10.0		10.2	9.1	8.6		8.8
	C V (%)	2.9				5.5			
	LSD ($p \leq 0.05$)	NS		NS		NS		NS	
Overall Means	0	9.9	9.8	9.9		9.7	9.3	9.5	
	50	10.1	9.8	10.0		9.1	8.5	8.8	
	100	10.3	10.4	10.3		8.1	8.1	8.1	
	150	9.3	9.3	9.3		7.1	7.0	7.0	
	Mean K	9.9	9.8			8.5	8.2		
	C V (%)	1.7				3.4			
	LSD ($p \leq 0.05$)	NS		NS	NS	NS		NS	NS

Legend: NS -Non significant; Old cultivar -CO421; New cultivars- KEN82-472 and KEN83-737

4.6 Prediction of the optimal maturity time of cultivars using CCS %

The responses of CCS% of the three cultivars to age (MAR) were subjected to quadratic regression analysis (Table 61). Cultivars, N and K_2O rates, data fitted quadratic equations with $R^2 \geq 0.85$, indicating that most of the variabilities were accounted for with over 85 % accuracy.

Table 61: Regression analysis on CCS% of CO421, KEN82-472 and KEN83-737

Cultivar	N Rates kg/ha	R^2	x and y values @ $\frac{dy}{dx} = 0$	
			y (CCS%)	x (MAR)
CO421	0	0.811	11.15	14.3
	50	0.892	12.06	13.2
	100	0.904	13.03	12.9
	150	0.804	11.15	13.3
	K_2O Rates, kg/ha			
	0	0.813	11.35	13.1
	100	0.891	12.47	11.9
Cultivar Mean		0.85	11.88	13.0
	N Rate, kg/ha			
KEN 82-472	0	0.703	12.69	12.8
	50	0.965	13.90	12.4
	100	0.986	15.39	11.5
	150	0.963	14.39	12.8
	K_2O Rates, kg/ha			
	0	0.909	12.891	12.4
	100	0.975	16.29	11.5
Cultivar Mean		0.92	14.34	12.2
KEN 83-737	0	0.80	12.79	13.1
	50	0.97	13.99	12.4
	100	0.99	15.49	11.1
	150	0.93	14.39	12.6
	K_2O Rates, kg/ha			
	0	0.909	12.99	12.7
	100	0.975	16.18	10.8
Cultivar Mean		0.93	14.38	12.0

Legend: x = MAR and y = CCS% at maximum, @ $\frac{dy}{dx} = 0$

The calculated point of maximum at $\frac{dy}{dx} = 0$ represented the maximum quality time (MAR) and most ideal age for harvesting ratoon canes when yields are not taken into account. The new and early maturing KEN82-472 and KEN83-737) cultivars attained numerically-similar quality time at 12.2 and 12th MAR, respectively. The old and late maturing CO421 recorded a lower CCS% later at approximately 13th MAR. The data agreed with the record (KESREF, 2002) that the newly introduced cultivars possess more superior quality attributes than the old cultivars. However, the results contradicted the recommendations (KESREF, 2007) of harvesting age of 15th and 20th MAR for new and old cultivars respectively. Further variance is observed in a report by Ong'injo and Olweny (2011) on trials conducted in the Kenyan coast that established that ratoon-cane crops be harvested at the 9th MAR. Indeed, this is because of warmer and more humid climatic conditions which promote faster growth of sugarcane compared to that in western Kenya.

CHAPTER 5

4.0 SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER STUDY

5.1 Summary

Only soil K significantly ($p \leq 0.05$) declined due to cultivars at 0 - 15 cm soil depth at post-harvest. The ratoon sugarcane crops had greater K extracting potentialities than the plant crops. Nitrogen and potash fertilizer rate applications altered all soil pH and nutrient elements. However, only K_2O rate application caused significant ($p \leq 0.05$) variations on all of the properties.

Cultivars had significant ($p \leq 0.05$) changes in foliar nutrients from the 3^{rd} to 6^{th} MAR in N, P, K, Ca, Fe, Mn and Zn. The increments were higher in new than old cultivars. Peaks were generally attained at the 5^{th} MAR. After the attainment of the peaks, foliar nutrients levels declined more rapidly in the new cultivars than in the old cultivar. This implied that sampling conducted later than 5^{th} MAR would give lower nutrients contents for the new cultivars. The N and potash fertilizer applications significantly ($p \leq 0.05$) increased foliar N, P, K, Ca, Fe, Mn and Zn levels. The 100 kg N/ha and 100 kg K_2O/ha rates recorded significantly higher ($p \leq 0.05$) foliar nutrients contents.

The cultivars significantly ($p \leq 0.05$) influenced yields. Increasing N fertilizer application rates significantly ($p \leq 0.05$) increased cane yields. The 100 kg N/ha had the highest yield for old CO421 and new (KEN82-472 and KEN83-737) cultivars. The K_2O rates exhibited significant ($p \leq 0.05$) increases in yields in all cultivars.

Cultivars significantly influenced pol% from 10th to 14th MAR. KEN82-472 and KEN83-737 recorded higher pol% than CO421. Thereafter, pol% declined, but more drastically in KEN82-472 and KEN83-737 than CO421. The N rates, significantly ($p \leq 0.05$) increased pol% in all the cultivars. The responses were realized before and after the peaks in all the cultivars. The 150 kg N/ha rates recorded lower pol % values than the control rates throughout the study period. The K_2O rates significantly ($p \leq 0.05$) increased pol%. At the 10th MAR, zero K_2O rate registered lower pol% than the test rate. The responses were similar to the other quality parameters i.e. brix% and CCS%. The regression analysis R^2 values were significantly ($p \leq 0.05$) high at above 0.85 thus indicating that most of the variabilities were accounted for with over 85% accuracy. The new KEN82-472 and KEN83-737 achieved maximum CC% at 12.2 and 12th MAR with 14.34% and 13.92 % CCS respectively. The CO421 had a lower CCS of 11.92% later at 13th MAR.

5.2 Conclusion

Cultivars influenced only soil pH and K_2O nutrient level within the top soil. The effects of N rates could manifest later on. The soils were deficient of K and 100 kg N/ha and 100 kg K_2O/ha rates may give the highest foliar uptake of nutrients. Foliar sampling and analysis before the 5th MAR would be most ideal for nutrient determination of ratoon cane crops in western Kenya. Yields are cultivar dependent and therefore cultivar selection is vital for improved ratoon-cane crop yield. The 100 kg N/ha is optimal to ratoon sugarcane production in western Kenya. Potash (100 kg K_2O/ha) application benefited ratoon cane production in western Kenya. The new KEN82-472 and KEN83-737 cultivars recorded numerically similar CCS% at the 12th MAR earlier than the old CO421cultivar with lower CCS % later at the 13th MAR. This implies that the new KEN82-472 and KEN83-737 are better ratooners than CO421.

5.3 Recommendations

Soil sampling and testing should not be frequently done since the treatment effects on soil physicochemical parameters could manifest after some time. The 100 kg N/ha is still appropriate for ratoon crops of sugarcane. The application of potash 100 kg K_2O/ha should be re-introduced into the fertilization schedule in western Kenya. Foliar diagnostic tool should be used to guide fertilizer plant requirement before the 5th to MAR. Appropriate harvesting time for new early maturing and old late maturing cultivars should be at the 12th and 13th MAR respectively. The harvesting ages should be judiciously observed particularly the new cultivars if the canes will be sold to millers based on sucrose content.

5.4 Future Studies

It is necessary to evaluate changes in yields with age of the cultivars to enable determination of optimal harvesting time based on yields and quality. Only one rate above the potash (K_2O) control rate was evaluated for K_2O fertilization, therefore rates below and above the 100 kg K_2O/ha be evaluated. Economic optimal N and K_2O rates for adoption in both early and late maturing cultivars should also be determined.

REFERENCES

Abayomi, A. Y. (1987): Growth, yield and crop quality performance of sugarcane cultivar CO957 under different rates of application of nitrogen and potassium fertilizers. *Journal of Agricultural Sciences Cambridge,* **109**:285 - 292.

Abou-Khalifa, A. A. B. (2012): Evaluation of some rice varieties under different N-levels. *Advanced Applied Science and Research, **3**(2), 1144 - 1149.*

Aguado-Lara, G.; Ecthevers - Bara, J. D.; Hiadalgo-Moreno, C.; Galvis-Espindola, A.; Aguirre-Gomez, A. (2002): Dinámica depotasioen suelos agrícolas. *Agrociencia*, **36** (1):11 - 21.

Ahmed A. M. and Ferweez, H, (2004): Effect of forms and levels potassium fertilizer on productivity and quality of sugarcane. *Minia Journal of Agricultural Research and Development*, ***24**(4):701 - 716.*

Ahmed, M. A.; Ferweez, H.; Saher, M. A. (2009): The optimum yield and quality properties of sugarcane under different organic, N and K fertilizer levels. *Journal of Agricultural Research, Kafer El - Sheikh University,* **35** (3) 879 - 896.

Ahmed, A. O.; Obeid, A.; Dafalla, B. (2010): The influence of character association on behavior of sugarcane genotype (Saccharum Spp.) for cane yield and juice quality. *World Journal of Agicultural Sciences, **6**(2): 207 - 211.*

Akhtar, M.; Ali, F. G.; Saeed, M.; Afghan, S. (2000): Effect of moisture regimes and fertilizer levels on yield and parameters of spring planted cane. *Pakistan Sugar Journal, **15**(5):2-6.*

Akhatar, M.; Akhatar, M. E. (2002): Effect of different rates of potassium on agronomic traits, productivity and quality of sugarcane. *Asian Journal of Plant Sciences,* **1**(4):349 - 351.

Ambachew, D.; Abiy, F.; Zeleke, T. (2012): Correlation of foliar nutrient status with yield of Sugarcane Varieties at Different Crop Stages and Nitrogen Levels at Wonji - Shoa and Finchaa sugarcane plantations of Ethiopia. *Ethiopian Journal of Applied Science and Technology,* **3**(1):9 - 22.

Amolo, R. A.; Abayo, G. O.; Muturi, S. M.; Rono, J. K.; Nzioki, H. S.; Ochola, P. N. (2006): The influence of planting and harvesting time on sugarcane productivity in Kenya. KESREF Technical Bulletin 1, 21 - 26.

Anderson, D. L.; Bowen, J. E. (1990): Sugarcane nutrition. Potash and Phosphate Institute of Canada and Foundation of Agronomic Research, Atlanta. Georgia.

Baldock, J. O.; Schulte, E. E. (1996): Plant analysis with standardized scores combines DRIS and sufficiency range approaches for corn. *Agronomy Journal,* **88**:448 - 456.

Bell, M. J.; Garside, A. L.; Halpin, N. V.; Berthelsen, J. E. (2001): Yield response to breaking the sugarcane monoculture. *Australian Society of Agronomy.*

Bischoff, K. P.; Gravois, K. A. (2004): The development of new sugarcane varieties at the LSU AG Center. Journal of American Society for Sugarcane Technology, **24**: 142 - 164.

Blackburn, F. H. B. (1984): Sugarcane. *Longman Inc.;* New York. pp 30 - 42.

Bond, R. S. (1982): Maturity differences between varieties in the selection program. *Proceedings of Annual Congress of South African Sugar Technology Association,* **56**:136 - 139.

Bureau of Sugar Experiment Station (BSES), (1991): The standard laboratory manual for Australian sugar mills, *Analytical Methods and Tables,* Volume 2, Brisbane, Australia.

Cavalot, P. C.; Deville, J.; Kee N. K., (1990): Potassium fertilization of sugarcane in relation to its availability in soils of Mauritius. *Revue Agricole et Sucrière, Ile Maurice* **69**,30 - 39.

Central Bureau of Statistics, (2004b): Economic Survey2004. Ministry of Planning and National Development. Republic of Kenya. Government Printer, Nairobi. pp 243.

Chang, Y. S. (1995): The trend of sucrose accumulation during maturation of sugarcane with special reference to the maturity of sugarcane cultivars. *Report of the Taiwan Sugar Research Institute* **148** (1995): 1 - 9.

Chattha, A. A.; Rafique, M.; Afzal, M.; Ahmed, F; Bilal, M. (2006): Prospects of sugar industry and sugarcane cultivation in Punjab.

Cock, J. H. (2001): Sugarcane growth and development conditions. *Pakistan Journal of Botany*, **40:**2107 - 2113.

Cox, M.; Hogarth, M. and Smith, G. (2000): Disease Management. In "*Manual of cane growing*", M. Hogarth, P. Allsops, Eds, Bureau of Sugar Experimental Stations, Indooroopilly, Australia. pp 91 - 108.

Dawson, D. (2002): Cane trash - use and management. Available from: http: www. canegrowers.com.au / share / Fact Sheets / Cane % trash.pdf.

Das, D. K. (2000): Micronutrients - Their Behavior in Soils and Plants. Kalyani Publishers, New Delhi - 110002. 14 - 07 - 2013.

Das, P. K.; Nayak, N.; Mahapatra, S. S. (1997): *Indian Sugar*, XLVI: pp 111 - 113.

Debiprasad, D.; Hrusikesh, P.; Ramesh, C. T.; Mohammad, S. (2010): Effect of organic and inorganic sources of N on Fe, Mn, Cu and Zn uptake and content of rice grain at harvest and straw at different stages of rice (*Oryza sativa*) crop growth. *Advanced Applied Science and Research,* ***1****(3), 36 - 49.*

Domaingue, R., Ramdoyal, K., Mamet, L. D., Bissessur, D., Rivet, L. (1998): Breeding and selection program at the Mauritius Sugar Industry Research Institute, MSIRI.

Duhan, B. S.; Singh, M. (2002): Effect of green manuring and N on yield and uptake of micro - nutrients by rice. *Journal of the Indian Society of Soil Science, **50**(1):178 - 180.*

Ehsanulla, A. I.; Iqbal, K. (2001): Effect of different nitrogen and phosphorus levels on quantitative and qualitative traits of cane. *Journal of Biological Sciences **1**(4), 240 - 241.*

El-Sogheir, K.S.; Ferweez, H. (2009): Optimum harvesting age of some promising sugarcane genotypes grown under different nitrogen fertilizer levels. *Egyptian Journal of Applied Science,* **24**(3):195 - 214.

Eman, I.; El - Sarag; Moselhy, S. H. (2013): Response of sugar beet quantity and quality to N and K fertilization under sandy soils conditions. *Asian Journal of Crop Science,* **5**:295 - 303.

Ezenwa, I. V.; McCray, J. M.; Newman, P. R.; Rice, R. W. (2005): Sugarcane leaf tissue sample preparation for diagnostic analysis. *Macmillian/CTA, United Kingdom.*

Ezenwa, I. V.; McCray, J. M.; Newman, P. R.; Rice, R. W. (2008): Cane leaf tissue sample preparation and analysis. Florida Cooperative Extension Service Pub. SS - AGR - 259.

Fauconnier, R. (1993): Sugarcane, *Macmillan Press Ltd, London, UK.*

Filho, J. O. (1985): Potassium nutrition of sugarcane. *In*: Potassium in Agriculture (Ed. Munson, R.D.). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison. pp 1045 - 1062.

Franco, H. C. J.; Trivelin, P. C. O.; Faroni, C. E.; Vitti, C. A; Otto, R. (2010): Stalk yield and technological attributes of planted cane as related to N fertilization. *Science. Agriculture. Piracicaba, Brazil,* **67**:579 - 590.

Gana, A. K. (2008). Determination of optimal rate of nitrogen for chewing sugarcane production in the Southern Guinea Savanna of Nigeria. *Sugarcane Technology,* **10**:278 - 279.

Garcia, S. S,; Lopez, B. I. G.; Lopez, P. J. D.; Espinoza, L. C.; Estrada. C. M. (2001): Potassium dynamics in Mexican Sugarcane Soils Proc. ISSCT.

Garside, A. L.; Bell, M. J. (2003): Management of legume residues to maximize the N-benefit to the sugarcane crop. *Proceeding of the International Society of Sugarcane Technolologists, 26: Sugarcane Agronomy.*

Gascho, G. J. (1983): The effect of N rate on four sugarcane varieties grown on sandy soil. *Journal of American Society of Sugar Cane Technology,* **2**:84.

Gascho, G. J. (2000): Sugarcane. In: C. R Campbell (ed.) Reference sufficiency ranges for plant analysis in the southern region of the United States. Southern Cooperative Series Bulletin No. 394. North Carolina.

Glaz, B.; Powell, G.; Perdomo, R.; Ulloa, M. F. (2000): Sugarcane response to P in relation to soil testing recommendations on Everglades histosols. *Agronomy Journal,* **92**:375 - 380.

Gonzales, A. R.; Galvez, R. G. (1998): Early maturing varieties of high sugar content. *Sugar Cane Abstracts, Cane breeding and varieties,* **5**: 23.

Graham, M. H.; Haynes, R. J.; Meyer, J. H. (2000): Changes in soil fertility induced by trash retention and fertilizer rates on long-term trash management trial at Mount Edgecombe. *Proceedings of South African Sugarcane Technology Association,* **74**:109 - 113.

Gulati, J. M. L.; Behera, A. K.; Nanda, S.; Saheb, S. K. (1998): Response of sugarcane to potash. *Indian Journal of Agronomy,* **43:** 170 - 174.

Habib, G.; Malik, K. B.; Chatta, M. Q. (1991): Preliminary evaluation of exotic cane varieties for some quantitative characters. *Pakistan Journal of Agriculture Research,* ***12****(2):95 - 100.*

Hadi, A.; Taran, S. A; Azeem, A.; Saeed, Z.; Aslam. A. (1997): Wheat response to zinc application in rice, Balochistan. *Pakistan Journal of Soil Sciences,* ***13****:25-27.*

Hartemink, A. E. (1998): Acidification and pH buffering capacity of alluvial soils under sugarcane. *Experimental Agriculture*, ***34****:231 - 243.*

Haynes, R. J.; Hamilton, C. S. (1999): Effects of sugarcane production on soil quality: A synthesis of world literature. *Proc. S. Afr. Sugar Technol. Assoc.* **73**, 45 - 51.

Hunsigi, G. (2011): Potassium management strategies to realize high yield and quality of sugarcane *Karnataka J. of Agricultural Research,* **24** (1): 45 - 47.

Hurney, A. P.; Berding, N. (2000): Impact of suckering and lodging on productivity of cultivars in the wet tropics. *Proc. Aust. Soc. Sugar Cane Technol.* **22**:328 - 333.

ICUMSA.(1994): International commission for uniform methods of sugar analysis. Method GS5/7-1, Methods Book, with 1st Supplement 1998, UK, pp 1-8.

Ige, D. V.; Adepetu, J. A.; Obi, O. A. (2005): Effect of organic amendments on phosphorus release in soils of south western Nigeria. *Ife Journal of Agriculture, 21:216 - 228.*

Inman-Bamber (2004): A growth model for sugarcane based on a simple carbon balance and the CERES. Maize water balance. *South African Journal of Plant and Soil Sciences,* **8:**83 - 99.

Jaetzold, R.; Schmidt, H.; Hornetz, B.; Shisanya, C. (2005): Natural conditions and farm management information (2nd Edition), Part A. West Kenya, Subpart A1: Western province In: Farm Management Handbook of Kenya Volume II. Ministry of Agriculture. Nairobi.

Jaetzold, R.; Schmidt, H.; Hornetz, B.; Shisanya, C. (2007): Ministry of Agriculture, Farm Management Handbook of Kenya. Vol II-Natural Conditions and Farm Management Information 2nd Edition, Part A West Kenya (Nyanza and Western Provinces) pp 1;81.

Jagtap, S. M.; Jadhavi, M. B; Kulkarm, R. V. (2006): Effect of levels of NPK on yield and quality of sugarcane (cv. Co. 7527*). India. Sugar J.* **56:** 35 - 40.

Jamoza, J. E. (2005): Sugarcane variety improvement in Kenya. *Proceedings of South Africa Sugarcane Technology Association,* **79**:230 - 234.

Jarrell, W. M.; Beverly, R.B. (1981): The dilution effect in plant nutrition studies. *Advanced Agron*onomy **34**: 197-224.

Keating, B. A.; Robertson, M. J.; Muchow, R. C.; Huth, N.I. (1999): Modelling sugarcane production systems I. Development and performance of the sugarcane module.*Field Crops Research.***61**:253-271.

Keerio, H. K.; Panhwar, R. N; Memon, Y. M; Araen M. Y.; Chohan, M; Qazi B. R. (2003): Qualitative and quantitative performance of some promising and commercial sugarcane varieties under agro-climatic conditions of Thatta. *Pakistan Journal of Applied Science,* **3** (10 - 12): 670 - 673.

Kenya Sugar Research Foundation (KESREF), (2002): Annual Report.

Kenya Sugar Research Foundation, (KESREF), (2003): Technical Information on Sugarcane.

Kenya Sugar Research Foundation, (KESREF), (2005): Annual Report 2005 - 2010, pp 61.

Kenya Sugar Research Foundation, (KESREF), (2007): Technical Information on Sugarcane.

Kenya Sugar Research Foundation, (KESREF), (2008): Technical Information on Sugarcane.

Kenya Sugar Research Foundation, (KESREF), (2010): Technical Information on Sugarcane.

Khan, M. A.; Keerio H. K.; Junejo S.; Panhwar, R. N.; Rajput, M.A.; Memo, Y. M.; Qaz, B. R (2003): Evaluation of new sugarcane genotypes developed through fuzz. Correlation of cane yield and yield components. *Pak. J. of Applied Science.* ***3****(4): 270 - 273.*

Korndorfer, G. H. (1990): Potassium and sugarcane quality. *Informacoes Agronomicas,* **49**: 1 - 3.

Koochekzadeh, A.; Fathi, G.; Gharineh, M. H.; Siadat, S. A.; Jafari, S.; Alami - Saeid, K. H. (2009): Impacts of Rate and Split Application of N Fertilizer on Sugarcane Quality.

Kumar, V.; Verma, K.S. (1997): Relationship between nutrient element content of the index leaf and cane yield and juice quality of sugarcane genotypes. *Communication Soil Science and Plant Analysis*, **28** (11 - 12):1021 - 1032.

Kwong, K. F. (2002): The effects of K on growth, yield and quality of sugarcane. Sugar Research Institute, Reduit, Mauritius.

Lal, R.; Pierce, F. J. (1991): *Soil Management for Sustainability*. Published by Soil and Water Conservation Society, Ankey, USA.

Larrahando, J. E. ; Villegas, F. (1995): Control y Maduracion de la cana. In: *El Cultivo de la Cana et la Zona Azucarera de Colombia*. Cenicana, Cali, Colombia. pp 293 - 314.

Lee, K. H.; Jose, S. (2005): Nitrate leaching cottonwood and loblolly pine biomass plantations along a nitrogen fertilization gradient. *Journal Agriculture, Ecosystem and Environ*ment, **105**:615 - 623.

Legendre, B. L. (1985): Changes in juice quality of nine commercial cane varieties grown in Louisiana. *Journal of American Society of Sugarcane Technology*, **4**:54 - 57.

Lingle, S. E., Wiedenfeld, R. P.; Irvine, J. E. (2000): Sugarcane Response to saline Irrigation Water. *Journal Plant Nutrition*, **23**:469 - 486.

Malavolta, E., (1994): Nutrient and Fertilizer Management in Sugarcane. International Potash Institute Bulletin No. 14. pp 104. International Potash Institute, Basel, Switzerland.

Malik, N. A.; Afghan, S.; Ahmad, I.; Mahmood, R. A. (1993): Response of sugarcane cultivars to different doses of NPK fertilizer in Somalia. *Pakistan Sugar Journal*, **3**:10 - 15.

Mamet, L. D.; Galwey, N. W. (1999): A relationship between stalk elongation and earliness of ripening in sugarcane. *Experimental Agric*ulture, **35**:283 - 291.

Mandal, K. G.; Baral, U.; Padhi, J.; Majhi, P.; Chakraborty, H.; Kumar, A. (2012): Effects of cropping on soil properties and organic carbon stock in Deras region, India. *Regional Environmental Change,* **12**:899 - 912.

Marinho, M. L; Albuquerque, G. A. C. (1981): Effect of copper and zinc on yield of sugarcane in soils of the coastal plains of Alagoas. Brasil Acucareiro, **98**:41 - 50.

Marschner, H. (1986): Mineral Nutrition in Higher Plants.Acad. Press Inc. London, pp 279.

Martin, F. A. (1994): Standard Operating Procedures Manual for the Louisiana Sugarcane Variety Dev. Program, version 1994. Louisiana State University Agricultural Experimental Station. Baton Rouge.

McCray, J. M.; Ezenwa, I. V.; Rice, R. W.; Lang, T. A. (2006): Sugarcane Plant Nutrient Diagnosis. Florida Cooperative Extension Service Pub. SSAGR 128.

McCray, J. M.; Mylavarapu, R. (2010): Sugarcane nutrient management using leaf analysis. Florida Cooperative Extension Service Publication SS - AGR - 335. 16 - 08 – 2014.

Mengel, K; Kirkby, E. A. (2001): *Principles of Plant Nutrition*. Kluwer Academic Publishers, London, United Kingdom. Pp 849.

Mengistu, S. (2013): Effect of different N rates and time of application in improving yield and quality of seed cane of sugarcane (*Saccharum* spp. L.) variety B41/227. *International Journal of Scientific and Research Publications,* **3**(1):1 - 7.

Meyer, J. H.; Wood, R. A. (2001): The effects of soil fertility and nutrition on cane quality. A review. South Africa Sugar Association Experiment Station, Mount Edgecombe. South Africa.

Mian, A. M. (2006): Sugarcane variety composition in Pakistan. *Proceedings of Seminars on Agriculture*. Organized by *Pakistan Society of Sugar Technologists* held at Faisalabad on 19th June 2006. pp. 107 - 121.

Miles, N. (2010): Challenges and opportunities in leaf nutrient data interpretation *Proceeding of South African sugarcane technologists Association*, **83**:205 - 215.

Morris, D. R.; Glaz, B.; Powell, G.; Deren, C. W.; Snyder, G. H.; Perdomo, R.; Ulloa, M. F. (2005): Leaf P diagnosis of sugarcane in organic soils. *Journal of Plant Nutrition*, **28**: 1511-1523.

Muchovej, R. M.; Newman, P. R. (2004a): Nitrogen fertilization of sugarcane on a sandy soil II soil and groundwater analyses. *Journal American Society of Sugarcane Technologists*, **24**:225 - 240.

Muchovej, R. M.; Newman, P. R. (2004b): Nitrogen fertilization of sugarcane on a sandy soil: Yield and leaf nutrient composition. *Journal American Society of Sugarcane Technologists,* **24**:210 - 224.

Muchow, R. C.; Robertson, M. J.; Wood, A.W.; Keating, B.A. (1995): Effect of nitrogen on the time-course of sucrose accumulation in sugarcane. *Field Crop Research*. **47**:143 – 153.

Muhammad, A. S.; Muhammad, I.; Muhammad, T.; Kafeel, A.; Zafar, I. K.; Ehsan, E. V. (2010): Appraisal of press - mud and in-orgarnic fertilizers on soil properties, yield and sugarcane quality. *Pak. J. Bot.*,**42**(2):1361 - 1367.

Muhammad, C.; Ubedullah, A.; Riaz, N.; Saifullah, T. (2013): Effect of inorganic NPK different levels on yield and quality of sugarcane plant and ratoon crops. *International Journal of Agronomy and Plant Production. Vol.,* ***4*** *(S), 3668 - 3674.*

Mui, N. T.; Preston, T. R.; van Binh, D.; Ly, L. V.; Ohlsson, I. (1996): Effect of management on yield and quality of sugarcane and on soil fertility. *Livestock Research for Rural Development*, **8**(3):51 - 60.

Mumias Sugar, (2009): Agronomic Report.

Naga, M. K.; Kumar, M.; Subba Rao, M.; Sarala, N.V.; Giridhar, V. (2011): Response of Promising mid - late maturing sugarcane varieties to different N doses.

Najran *et al* (2012): Journal on food Agriculture, environment nitrogen rate effect on sugarcane juice and sucrose.

Nzioki, H. S.; Jamoza, J. E.; Olweny, C. O.; Rono, J. K. (2010): Characterization of physiologic races of sugarcane smut (*Ustilago scitaminea*) in Kenya. *African Journal of Microbiology Research*, **4**(16):1694 - 1697.

Ochola, P. (2013): Growth, quality and yield responses of some new sugarcane varieties to rates of N - K fertilizers in Kibos, Western Kenya. MSc. Thesis, Maseno University, pp 139.

Ochola Peris N.; Okinda Owuor P.; Manguro Arot L.; Abayo Onyango G. (2014). Yields and growth parameters responses of different sugarcane varieties to nitrogen and potash fertilizers in Nyando Belt, Kenya. East *African Agriculture and Forestry Journal*, **80**(4): 263 - 273.

Oindo, (2015): Thesis (Maseno University): Effects of rate and split application of nitrogen fertilizer on nutrients and harvesting time of ratoon crop of an early and late maturing sugarcane varieties in Western Kenya.

Okalebo, J. R.; Gathua, K. W.; Woomer, P. L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual. 2nd Edition. TSBF-CIAT and SACRED Africa, Nairobi, Kenya, 2002. pp128.

Olaoye, G. (2006): Yield potential of non-irrigated sugarcane germplasm accessions in a savannah ecology of Nigeria. *Journal of Agricultural Research, 7:69 - 75.*

Ongin'jo, E.; Olweny, C.O. (2011): Determination of optimum harvesting age for sugarcane ratoon at the Kenyan coast. *Journal of Microbiology and Biotechnology Research Scholars Library Journal Research*, **1** (2): 113 - 118. ISSN: 2231 - 3168 CODEN (USA): JMBRB4.

Owuor, P. O. (1997): Fertilizer use in tea: The case of nitrogen. Tea, 18: 132 - 143.

Panwar, B. S.; Katyal, S. K. (1986): NPK contents in summer planted sugarcane as affected by varieties, fertility levels and time of N application. *Indian Sugar Journal, **36**:283 - 290.*

Perez, O.; Melga, M. (1998): Sugarcane response to nitrogen, phosphors and potassium application in Andisol soils, Better Crops International. **12** (2):20 - 24.

Plaut, Z., Meinzer, F.; Federman, E. (2000): Leaf development, transpiration, ion uptake and distribution in sugarcane cultivars grown under salinity. *Plant Soil, **218**:59 - 69.*

Prasad, R.; Prasad, S.; Sakal, R. (1996): Effect of potassium and sulfur on yield and quality of sugar cane grown in calcareous soils. *Journal of Potassium Research, **12**: 29 - 38.*

Raju, S. S., Shinoj, P. K. Joshi, K., (2009): "Sustainable Development of Biofuels: Prospects and Challenges". *Economic and Political Weekly. 44(**52**): 65 - 72.*

Rattey, A. R.; Hogarth, D. M. (2001): The effect of different N rates on CCS accumulation over time. *Proceedings of International Society of Sugarcane Technolologists*, **24**:168 - 170.

Rehman, S.; Khan, G. S.; Khan. I. (1992): Coordinated uniform national varietal trial on sugarcane. *Pakistan Journal of Agricultural Research, **13**: 136 - 140.*

Rice, R. W.; Gilbert, R. A.; Lentini, R. S. (2002): Nutritional requirements for Florida sugarcane (online), *Florida Cooperative Extension Services*. UF/FAS, Doc SS - ARG - 228, University of Florida. Institute of Food Agricultural Science. Gainesville.

Richard, J. E. (2007): The effects of Nitrogen on sugarcane sucker production and sugar yield. A Thesis in The Department of Agronomy and Environmental Management. B. S. Southern University, pp 41.

Rizk, N. S.; El - Bashbishy A. Y.; Rasian, M. E. (2002): Effect of macro and micro-nutrients and farmyard manure on sugar cane. *Annals of Agric. Sci. Moshtohor,* 40(**4**):2311 - 2316.

Sadej, W.; Przekwas, K. (2008): Fluctuations of nitrogen levels in soil profile under conditions of a long-term fertilization experiment. *Plant and Soil Environment,* **54**(5):197 - 203.

Salassi, M. E.; Champagne, L. P.; Legendre, B. L. (2000): Incorporation of within - season yield growth into a mathematical programming sugarcane harvest scheduling model.

Saleem, M.F.; Ghaffar, A.; Anjum, S.A.; Cheema, M.A.; Bilal, M.F. (2012). Effect of N on growth and ield of cane. *Journal American Society of Sugar Technologists,* **32**:75 - 93.

SAS Institute, 2002: SAS for Windows. Version 8.02. SAS Institute, Cary, NC.

Satisha, G. C.; Krishnappa, M.; Srikanth, K. (1996): Input of sulphur on yield and quality of sugarcane. *Indian Sugar **45**(9): 397 - 401.*

Schroeder, B. L.; Wood, R. A.; Meyer, J. H. (1993): Foliar analysis in the South African sugar industry for diagnostic and nutrient trend purposes. In N. J. Barrow (ed.). Plant nutrition from genetic engineering to field practice: 299 - 302. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Schroeder, B. L.; Wood, A. W.; Kingston, G.; Meyer, J. H.; Barnard, R. O. (1999): Leaf analysis-What does it offer the Australian sugar industry? *Poceedings of Australian Society of Sugar Cane Technology*, **21**:122 - 130.

Schroeder, B. L.; Wood, A. W.; Moody, P .W.; Stewart, R .L.; Panitz, J. H.; Benn, J. (2007): Soil-Specific Nutrient Management Guidelines for Sugarcane Production in the Johnstone Catchment. Technical Publication TE007001, BSES Limited, Indooroopilly.

Shukla S. S.; RayChaudhuri S. P.; Anjaneya B. R. (1995): Studies on foot hills soil of the *J. Ind. Soc. Soil Sci.*, ***13**: 115 - 122 MQ.*

Shukla, S.K. (2003): Tillering pattern, growth and productivity of promising sugarcane genotypes under various planting seasons and nitrogen levels in subtropical India. *Indian Journal of Agronomy*, **48** (4):312 - 315.

Singh, K. D. and B.K. Jha (1994): Transformation and availability of applied potassium to sugar cane in Calciorthent. *Indian Journal Society of Soil Science **42** (1):72 - 76.*

Snyder, C. S.; Bruulsema, T. W. (2007): Nutrient use efficiency and effectiveness in North America: Indices of agronomic and environmental benefits. *International Plant Nutrition Institute. Ref. No.07076.*

South Nyanza Sugar Company (Sony): (2008): Agronomic Report.

Sreewarome, A.; Seansupo, S.; Prammanee, P. and Weerathworn, P. (2007): Effect of rate and split application of nitrogen on agronomic characteristics, cane yield and juice quality. *Proceedings of International Society of Sugar Cane Technologists,* **26**: 465 - 469.

Srivastava, S. C.; Suarez, N. R. (1992): Sugarcane pg 257 - 266. In: *"World Fertilizer use Manual*. W. Wichmann, ed. BASFAG. Germany.

Stranack, R. A.; Miles, N. (2011): Nitrogen nutrition of sugarcane on an alluvial soil on the Kwazulu - Natal North Coast: effects on yield and leaf nutrient concentrations. *Proceedings of the South African Sugar Technologists Association,* **84**:198 - 209.

Sugar Act, (2001): The *Kenya Gazette Supplement No. 96 (Acts, No. 9).* Printed and Published by the Government Printers, Nairobi, Kenya, pp 719 - 762.

Taiz, L.; Zeiger, E. (2002): Plant Physiology. Sinauer Associates, Sunderland, MA. Pp. 566 - 7.

Thorburn, P. J., Meiera, E. A.; Probert, M. E. (2001): Modelling nitrogen dynamics in sugarcane systems: Recent advantages and applications. Field Crop Res., **92**: 317 - 351.

Walker, T. W.; Kingery, W. L.; Street, J. E.; Cox, M. S.; Gerard, P. D.; Oldham, J. L. (2007): Soil chemical properties and rice yield response to N rate and timing after precision leveling. Online Crop Management doi:10. 1094/CM - 2007 - 0119-02-RS. 12-03-2014.

Wawire, N. W.; Kahora, F. W.; Wachira, P. M.; Kipruto K. B. (2006): Technology adoption study in Kenya Sugar Industry. KESREF Technical bulletin (1): pp 51 - 71.

Woods, R. A. (1990): The roles of nitrogen, phosphorus and potassium in the production of sugarcane in South Africa. *Fertilizer Research **26:** 87 - 98.*

Yadav, R. L.; Prasad, S. R. (1992): Co nserving the organic matter contents of the soil to sustain sugarcane yield. *Exp. Agriculture. **28**:57-62.*

Yadava, R. S. (1993): Agronomy of sugarcane principle and practices. 1st Ed. NTEK computer System, 87. Rath Khana Moulviganj, Lucknow. p.200 - 201.

Yahaya, M. S.; Falaki, A. M.; Amans, E. B.; Busari, L. D. (2009): Correlation and path analysis of yield in sugarcane. *Nigerian Journal of Research and Production,* **15**(2):1 - 7.

Yang, S. J.; Chen, J. M. (1991): A review of fertilizer trials carried out by the Fiji Sugar Corporation between 1977 and 1987. Taiwan Sugar, 38:19-24.