GROWTH, QUALITY AND YIELD RESPONSES OF SOME NEW SUGARCANE VARIETIES TO RATES OF NITROGEN AND POTASSIUM FERTILIZERS IN KIBOS –WESTERN KENYA

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ANALYTICAL CHEMISTRY

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ABSTRACT

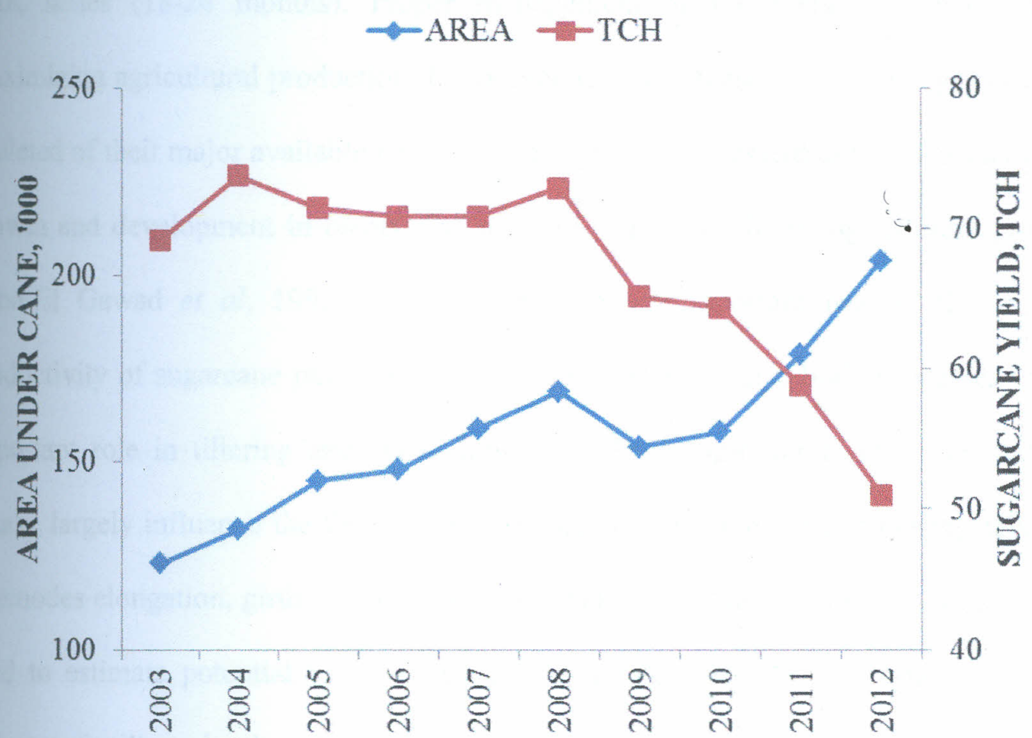
About 60% of the world's sucrose comes from sugarcane (*Saccharum officinarum L.*). In Kenya, sugar is produced exclusively from sugarcane grown in the Nyanza, part of the Rift Valley the Western Kenya sugar belts and Kwale County at the Coast. Production in Kenya has declined despite increased area under cane and introduction of high yielding varieties. The yields continue to decline possibly due to use of agronomic inputs recommended for old varieties which may be inappropriate for these elite varieties. Optimal nutrients, especially nitrogen and potassium fertilization have not been established for the new varieties. The Kenya Sugar Industry is changing the policy to pay farmers on sucrose content of cane. However influence of nitrogen and potassium fertilization on sucrose content of the new varieties is unknown. This research was conducted to establish the variations of growth parameters, yield and cane quality due to varieties, nitrogen and potassium fertilizer. The experimental design was split- split plot with four replications of three varieties CO 421 (control), KEN 83-737 and KEN 82-472 as main plots, four nitrogen rates (0, 50, 100,150 Kg N/ha) as sub plots and two potassium rates (0, 100 Kg K_20/ ha) as sub-sub plots. There was significant ($p \leq 0.05$) difference due to varieties in tillers from 4 months after planting (MAP) and girth from 14 MAP and height from12 MAP. CO 421 yielded significant higher ($p \leq 0.05$) than the other varieties followed by KEN 83-737. All varieties yielded higher than the yields recorded in commercial scale suggesting, improper application of other inputs may be responsible for the observed low commercial yields. Stalk height from 12 MAP and girth from14 MAP were significantly correlated with yield, (R-squared =0.59 and 0.66 respectively) suggesting that these parameters can be used as yield predictors. Nitrogen continued to increase growth parameters, yield and quality beyond 150Kg N /ha suggesting the need to establish whether the recommended fertilizer rates are optimal and include potassium for improved productivity in new varieties. There was significance response in yields to potash of the KEN varieties but not CO 421, confirming that these new varieties would benefit from its application. There was varietal difference in leaf nutrient content with age of the plant suggesting that for advisory purposes sampling time must clearly be defined. Commercial Cane Sugar (CCS %) of varieties was different, CO 421 had significantly ($p \leq 0.05$) higher CCS% than the new varieties, showing that it may still be a potential variety for payment on Sucrose. pol% levels reached maximum at 16 MAP for, KEN 8KEN 83-737 and KEN 82-472 demonstrating that new varieties should be harvested at 16 MAP for realization of high sugar output. These outcomes will establish nutrients diagnostic guide, N and K rates and optimal harvesting time that will guarantee better quality and yield for new sugarcane varieties.

CHAPTER 1

1 INTRODUCTION

1.1 Background information

Sugarcane (*Saccharum officinarum L.*) is an important and highly priced field crop in the tropics, contributing to the world economy as food, fodder, fibre, fuel and fertilizer (Lingle *et al.*, 2000). In Kenya sugar is produced exclusively from sugarcane grown in the Nyanza (Migori, Nyando and Kisumu Districts), parts of Rift Valley counties (Kericho and Nandi counties) Western Kenya (Mumias, Butere, Bungoma and Busia Counties) and Mombasa Kwale County. These zones contrast sharply with other sugarcane growing zones in the world due to high altitudes that range from 1100 to 1600m above mean sea level. The area under sugarcane in Kenya cultivation has been steadily increasing from approximately 148,000 ha in 2006 to 204,000 ha in 2012 (Figure 1 KSB, 2012). This expansion is attributed to the small-scale farmers opening up new land for sugarcane growing. However, area of sugarcane harvested annually has remained at about 50,000 ha per year, less than 50 per cent of the total cultivated area (Anon, 2012). This scenario that may be due to in efficiencies in sugar production technologies has led to production of less sugar than the projections.



Source: KSB, 2012

Figure 1: Area under cane and yield trends (2003 to 2012)

Sugar cane yields in Kenya have been fluctuating and declining in the past 10 years in all factory zones (Anon 2012). The mean cane yield declined over all sugar zones from 90.8 TCH in 2006 to 51TCH in 2012 respectively (Figure 1). Factors contributing to low sugarcane yields have been speculated to include low yielding varieties, inadequate use of fertilizers, over reliance on rainfall for crop water requirement, low adoption of agronomic technologies among others (Amolo *et al.*, 2006). However there has been no reliable data to explain these observations. Efforts to overcome low production using new early maturing varieties such as KEN series (16-18 months) have not succeeded since production has continued to be low. It is not known if the continued low production even in the new varieties is due to use of agronomic inputs of earlier late maturing varieties such as CO and

EAK series (18-24 months). Proper management of fertilizers is a major factor in maximizing agricultural production. In continuous and intensive cropping systems, soils are depleted of their major available plant nutrients. Nitrogen is essential for vigorous vegetative growth and development in plants, and nitrogen deficiency limits agricultural productivity (Abd-El Gawad *et al*, 1992). The nutrient play an important role in the growth and productivity of sugarcane plants and is vital for most plant metabolic processes playing an important role in tillering and stalk elongation. These agronomic attributes and nutrient uptake largely influence the final yield of sugarcane. The number of tillering/stalk number, internodes elongation, girth diameter, and final plant height are agronomic traits that may be used to estimate potential yields of sugarcane during early growth. The management of nitrogen fertilizer is therefore important to sugar industry as it influences sugarcane production (Thornburn, 2004). Vegetative growth of cane is mainly a function of nitrogen fertilization rather than potassium and phosphorus which regulate the growth and development function (Miles, 2009). However, nitrogen is sensitive to a range of factors including soil type, fertiliser type and the available soil water status (Rehman, 1995).

Sugarcane varieties pose varying potentials of effectively utilizing fertilizer nutrients to increase yield and quality. Some varieties have the capacity to increase cane yield without seriously affecting juice quality under nitrogen fertilization, while in others juice quality declines due to nitrogen application (Cock, 2001). It is not known how varying nitrogen fertilizer rate influence yield and quality of the new cane varieties.

The Kenyan sugar industry at its inception used blanket rates of 100Kg N, 50 Kg P_2O_5 and 45Kg K_2O) till mid 1980s when the industry stopped potassium fertilization of cane quoting no response of trials on potassium (KESREF, 2002, 2007). But most of these trials were not conclusive. Research efforts have been intensified to breed early maturing (16 months) and high yielding varieties (KEN 82-247, KEN 82-401, KEN 82-808 and KEN 83-737). However agronomic inputs previously used on the old varieties continue to be used on the new varieties. It is not known if these recommended inputs are also optimal for the new varieties.

The current fertilizer regimes recommended for the sugar belts in Kenya, are devoid of use of potash. Potassium has been said to be adequate in East African soils (Willson, 1976) and it has been assumed to be adequate in the sugar cane growing soils despite long-term monoculture with cane. It is not known if the long term monoculture of sugarcane has depleted potash from the soils leading to low yields being realised in Kenya.

The Kenya sugar industry is proposing to pay farmers based on the sucrose level as opposed to the current payment based on weight (Kenya Sugar Act, 2001). This implies that although farmers may adopt the use of the new varieties, their incomes may not improve if their fertilizer use technology reduces sucrose levels. Although nitrogen is important for photosynthesis its deficiency suppresses in quality (Sreewarome *et al*., 2007) but its excessive application increase could lead to undesirable reduction of sucrose concentration (Larrahando and Villegas, 1995; Yang *et al.,* 2013). The importance of nitrogen and potassium on qualities of new varieties have not been quantified

Analysis of tissue samples from crop plants is considered an objective method of diagnosing nutrient deficiencies and imbalances, and evaluating the effectiveness of the current nutrient management program (Miles *et al*., 2010). Leaf analysis is widely used as a nutrient management tool in sugarcane production (Rice *et al*., 2002). If carried out timely, leaf analysis permits the application of supplementary fertilizers before yields and quality are adversely affected by deficiencies or imbalances. The numerous complications inherent in the interpretation of plant analytical data have long been recognized (Reuter and Robinson, 1997). Nutrient concentrations in plant tissues are not only a reflection of soil nutrient supply levels and plant genetic characteristics, but are influenced by other factors, including the plant growth stage (age), temperature and moisture supply, and factors which impact on plant growth and vigour, such as diseases and insect damage (Mengel and Kirkby, 2001). Furthermore, interactions between nutrients strongly influence their final concentrations in plant tissues (Robson and Pitman, 1983; Wilkinson *et al.*, 2000). Over the years, methods of interpreting plant nutrient data have received much attention. Currently, the Critical Nutrient Concentration (CNC) and Diagnosis and Recommendation Integrated System (DRIS) are widely used methods in the routine interpretation of leaf nutrient data (Meyer, 1981; Reuter and Robinson, 1997). The use of leaf analysis to relate yield to plant nutrient status has not been embraced by the Kenyan sugar industry.

1.2 Problem statement

Sugarcane production in Kenya has been low or declining despite increased area under cane. It was the estimation of the sugar industry that the national demand would be met if area under cane produced optimally. To mitigate the low or declining yields, the industry has introduced new highly yielding and early maturing varieties. However, the low or declining yields and shortages have persisted. Part of the problem has been speculated to the fact that the industry has continued to use the agronomic inputs recommended for the late maturing, low yielding varieties on these new varieties. It is not known if these agronomic inputs are appropriate for the new varieties. Nitrogen is the main nutrient in cane production. The optimal nitrogen rates for the realization of optimal cane and sugar yields of new varieties have not been determined. Although potassium is an important nutrient in cane production, its use was discontinued in Kenyan sugarcane production. It is not known if the cane yield decline is due to continuous cane production in the same fields without replenishment of potassium levels and whether it is required by the new varieties for realization of better cane and sugar yields. Early growth parameters have been used to predict yields in many crops including sugarcane. It is not known if early growth parameters can be used to predict sugarcane yields in Kenya especially for the new varieties. Plant tissue testing for measuring nutrient status has been used in many parts of the world to establish possible nutrient deficiencies that may lead to low crop production. Evaluation of the methods under Kenyan conditions has not been done. Sucrose content is influenced by varieties, agronomic practices including nitrogen and potassium fertilizers and age of plants. The optimal harvesting age of cane and influence of agronomic inputs on sucrose content have not been determined for the new cane varieties.

1.3 Research objectives

1.3.1 Broad objective

To assess the influence of varieties, some agronomic inputs on growth parameters, yield and quality and the use of growth parameters to predict cane yields of different sugarcane varieties.

1.3.2 Specific objectives

i. To compare the performance of KEN 83-737 and KEN 82-472 with the standard CO 421.

ii. To establish the response of KEN 83-737, KEN 82-472 and CO 421 to rates of nitrogen and use of tillers, stalk girth and height to predict yield.

iii. To establish the response of KEN 83-737, KEN 82-472 and CO 421 to rates of potassium and use of tillers, stalk girth and heights to predict yield.

iv. To evaluate leaf optimal sampling time and influence of nitrogen and potassium on leaf N, P and K content.

v. To evaluate the use of pol %and CCS% to predict optimal harvesting time of KEN 83-737 and KEN 82-472.

1.3.3. Null Hypothesis (Ho)

i. KEN 83-737, KEN 82-472 and CO 421 will not perform differently.

ii. KEN 83-737, KEN 82-472 and CO 421 will not respond to rates of nitrogen and early growth parameters will not predict yield.

iii. KEN 83-737, KEN 82-472 and CO 421will not respond to rates of potassium and early growth parameters will not predict yield

iv. Leaf optimal sampling time and influence of nitrogen and potassium on leaf macro nutrient content KEN 83-737, KEN 82-472 and CO 421 will not be useful for evaluation.

v. The use of quality parameters to predict optimal harvesting time of the new varieties will not be useful for evaluation.

1.4 Justification

Use of appropriate agronomic inputs will improve yields and quality of cane leading to improved livelihoods of players in the sugar sector and general improvement of the economy. Leaf nutrient diagnosis will determine nutrients limiting cane production and thus result in timely intervention leading to increased yields. The establishment of optimal harvesting period shall ensure maximum sugar production that shall ensure adequate national supply of the commodity. These interventions will ensure a vibrant sugar sector, creates wealth and employment.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Sugarcane varieties and influence on productivity

Varieties play a key role in both increasing and decreasing sugar yield per unit area, while use of unapproved, inferior quality cane varieties affect sugarcane production negatively (Mian, 2006). The solution of low cane yield and sugar recovery problem lies in the planting of improved cane varieties (Chattha *et al.*, 2006). Genetically improved varieties may bear ability to produce satisfactory results yield for per hectare and sugar percentage under given set of environmental conditions, (El-Geddaway, *et al.*, 2002). Unless the genetic potentialities of a variety are high, mere provisions of growing conditions such as manuring, irrigation etc (Keerio *et al,* 2003), will not lead to appreciable improvement in cane or sugar yield. Increase in cane yield might be due to maximum plant height, weight per stool and cane girth. (Khan *et al.,* 2002). Higher cane yield is the function of high potential variety (Nazir *et al.,* 1997). Indeed cane yields depend upon number of stalks per hectare and weight per stalk. (Javed *et al.,* 2002), Weight per stalk depends on stalk length and girth. Good germination and tillering with synchronized millable canes of average thickness are desired selection parameters to evaluate the agronomic performance of sugarcane varieties, (Habib *et al.*, 1991). The major sugarcane varieties grown in Kenya are CO 617, CO 421, CO 945, and N14 which occupy more than 65% of total sugarcane surface. Other varieties include CO 1148, EAK 70-79 and CB 38-22. Varieties CO 617 and CO 421 are dominant in the Nyando and Nzoia sugar zone while N14 and CO 945 dominated the Mumias and Awendo (Sony) sugar zones. However, varieties like CO 421 and CO 945 are late maturing have low sucrose content and have become susceptible to the major diseases such as smut, mosaic and ratoon stunting. In order to improve and sustain sugarcane productivity in Kenya the efforts to develop better varieties must be intensified

KESREF has made great strides in fulfilling its mandate of developing improved sugarcane varieties for the Kenya Sugar Industry. The varieties are: KEN 82-216, KEN 82-219, KEN 82-247, KEN 82-401, KEN 82-808 and KEN 83-737. Key positive attributes of these varieties include early maturity (harvest in 15-19 months), and high sugar and cane yields. The variations in their early growth parameters have not been determined. It is not known if the parameters can be used to predict cane yields in Kenya.

2.2 Nutritional requirements for sugarcane

For any crop to grow and remain healthy, adequate nutrients must be supplied from the soil and/or air. Elements of nutritional concern for sugarcane include N, P, K, Mg, B, Cu, Man, Si, and Zn. A deficiency or over abundance of one or more of the above elements may limit yields and affect quality (Rice *et.al.* 2002). Growers striving to produce high crop yields should pursue management strategies that deliver a balanced supply of nutrients to the plant. N, P and K are the major nutrient required in high amounts for high cane yield (Khan, *et al.*, 2002). Indeed, deficiency of these macronutrients leads to serious decline in yield (Karsten *et al.*, 1992) and quality (Khan *et al.*, 2003).

NPK requirements of sugarcane are higher than those of other commercial crops because of its high dry matter and energy production per unit area (Srivastava, 1979). A crop having yield of 100 t ha^{-1} removes 207 kg N, 30 kg P_2O_5 and 233 kg K_2O from the soil (Jagtap *et al.*, 2006). Therefore these elements must be added in adequate quantities in the root zone of the crop to obtain higher yield· Although new cane varieties are released due to their high yields the fertilizer imputes used on them are the same on all cane varieties (KESREF Growers Guide, 2002). It is not known if the nitrogen fertilizer rates are in appropriate for the new varieties there by limiting their productivity.

2.2.1 Nitrogen requirement of sugarcane

Nitrogen's important role in growth and productivity of sugarcane is well documented (Abd-El Gawad *et al.*, 1992). Among known elements N is the primary nutrient limiting sugarcane production (Wiedenfeld and Enciso, 2008) throughout the world. The management of N fertilizer is important to sugar industry for optimization of productivity as it is an important nutrient for sugarcane production (Thornburn, 2004). Sugarcane can absorb between 41 and 45% of the applied nitrogen fertilizer (Ando *et al.*, 2002). The response to applied N is particularly sensitive to a range of factors including soil type, fertiliser type and the available soil water status (Rehman, 1995; Wiedenfeld, 1995; Wood *et al.*, 1996; Legendre *et al.*, 2000). One factor that is consistently important across all growing regions is crop age. Typically, stubble cane crops are applied with higher N rates than plant cane crops (Wood, 1964; de Geus, 1973), this is because stubble cane crops show a higher response to applied N compared to plant cane crops. This higher response of stubble cane crops is because sugarcane is either planted after a fallow period or within a rotation with soybeans, thus allowing the soil to build soil N reserves while crop age is important, other factors can influence different N rates between growing regions. The worldwide application of N fertilizers for sugarcane production is highly variable, ranging from 45 to 300 kg N ha^{-1} (Srivastava and Suarez, 1992). Nitrogen fertilizer application has been demonstrated to improve cane yields in many studies. In Somalia maximum stripped cane yield was obtained by applying NPK at 170-110-100 kg ha^{-} (Malik *et al.*, 1993),while in Pakistan maximum number of millable cane and highest cane yields was recorded at N 100-150 kg/ ha (Nasir *et al.,* 1994) contrary to Ehsanulla and Iqbal, 2001 who found highest millable cane by application of 200 kg N ha^{-1}, other yield responses of N up to 300 kg ha^{-1} was also observed by Ahmed *et al.* 2005. High N rates (168 kg N ha^{-1}) increased fresh cane yield in stubble cane crops only under high irrigation levels, but under medium or low irrigation levels, the increased N rate either had no significant effect or a negative effect on fresh cane yield (Wiedenfeld, 1995). Significant increase in stripped cane yield in response to higher levels of N has already been reported (Bastidas *et al.,* 1989; Bangar *et al.,* 1994; Mishra *et al.,* 2004; Singh *et al.,* 2004).

The establishment of optimum N fertilization rates for Kenya has been limited to few in conclusive studies (Mutanda, 1983; Anon, 2001, 2002, 2004). Use of urea is recommended at 100 kg N/ ha (KESREF Growers Guide, 2002). It is not known if this rate is optimal for the recently released high yielding and first maturing varieties.

2.2.2 Nitrogen effect on growth parameters

Sugarcane N requirements are greatest in early stages of growth, germination and "boom stage" growth periods (Samuels, 1969b). During this stage there are major changes in some growth parameters such as girth, tillering and stalk height. The plant height and cane girth are the major contributing factors for high cane yield (Rehman *et al.,* 1992). The number of cane stalks/stools is regarded as the most important character contributing directly to higher yield (Singh *et al.*, 1985; Raman *et al.*, 1985). Both the stalk number and weight should be assessed to have an accurate yield potential of the variety (Quebedeadux and Martin, 1986; Khan *et al.*, 2000, 2002). Cane and sugar yields due to increasing N application are attributed to improved millable stalk population, stalk girth, height and leaf area index

(Franco *et al*., 2010). In India, Bangar *et al,* (1992) recorded positive significant correlation between N levels and cane diameter while Ehsanullah and Iqbal, (2001) did not record any difference in cane diameter with increasing N. There has been no study relating the early growth parameters to rates of nitrogen to sugarcane yields of the sugarcane varieties in Kenya.

2.2.3 Nitrogen fertilizer and sugarcane quality

Important sugarcane quality parameters for assessing cane maturity are the juice brix, pol or sucrose percentage and purity. However, most researchers focus their evaluation on pol % cane. Nitrogen is necessary for vigorous growth of sugar cane. However, if applied in excess; nitrogen can slow down the ripening process, especially under wet conditions and high temperatures since the cane crop resumes active vegetative growth including production of new tillers (Habib *et al.,* 1991; Atta *et al.,* 1992a, b; Rehman *et al.,* 1992; Larrahando and Villagas, 1995; Ali *et al*., 2002).

Nitrogen deficiency results in reduction of leaf area and thus, causes photosynthesis reduction which in turn leads to suppress in quality (Sreewarome *et al*., 2007). Increase of nitrogen application excessively caused undesirable reduction of sucrose concentration (Larrahando and Villegas, 1995; Yang *et al.,* 2013). When a large number of varieties were grown at high and low nitrogen levels some varieties maintained high sucrose contents at high nitrogen levels indicating it may be possible to select genotypes that tolerate high nitrogen level (Cock, 2001). Non-significant effect of nitrogen on CCS % were attributed to non-significant effects on brix, sucrose and fibre percentages (Saleem *et al.,* 2012; Jeyaraman and Alagudurai, 2003; Patel *et al.,* 2004). However Ali *et al.,* (2002) noted a significant decrease in CCS % at higher rates of N. Cane yield and sucrose contents are significantly interrelated with applied fertilizers (Gawander *et al.,* 2004). Over-supply of N can decrease sucrose concentration in the millable stalk (Wiedenfeld, 1995; Chapman *et al.,* 1994). However, Muchow *et al*., (1996) reported slightly different results, in which a high nitrogen rate (268 kg N/ ha) slightly decreased sucrose content, but it increased cane yield to a level that produced non-significantly different sugar yields when comparing the low nitrogen rate to the high nitrogen rate. Although Muchow *et al,* (1996) found no significant differences in sugar yield between a high and a low nitrogen rates, there was a significant decrease in stalk sucrose levels when high nitrogen rates were applied. Losses due to low or high nitrogen rates on quality of varieties have not been established in Kenya, yet the industry proposes to pay farmers on quality of new varieties (Kenya Sugar Act, 2001).

2.3 Potassium requirement of sugarcane

The functions of potassium (K) in sugarcane have been extensively reviewed (Filho, 1985), and the benefits include resistance to lodging, diseases, pests and drought. The demand for K by sugarcane is high (Garcia *et al*., 2001). Potassium deficiency can result in depressed growth, slender stalks, and "firing" (an orange or reddish-brown discoloration) on older leaves. K is readily mobile in plant, so deficiencies are first observed in older plant leaves (Gracia *et al*., 2001). Young leaves are generally all dark green. The most distinguishing characteristic of this deficiency is a red discoloration on the upper surface of the leaf blade midrib (Rice *et al*., 2009). Discoloration on both sides of the midrib may indicate a fungal disease infection (Garcia *et al*., 2001). Under severe deficiency, the leaf spindle will distort, producing a characteristic "bunched top" or "fan" appearance (Rice *et al*., 2009). Poor bud germination, decreased drought and disease resistance are associated with K deficiency (Kwong, 2002). The applied potash as a fertilizer is gradually released to the soil solution

(Aguado-Lara *et al.*, 2002; Garcia *et al.*, 2002). Potassium as muriate of potash is recommended to be applied at 80 kg K/ha to sugarcane either on its own or in combination with other fertilizers. In clay soils this should be split application of K and N to minimise K^+ fixation (Ando *et al.*, 2000). However, in Kenya application of potash was discontinued in the early 1980s (KESREF, 2002, 2007), despite signs of deficiency in South Nyanza and Mumias in early 1990's. Although old sugarcane lands have continued to produce cane, there has been no remedial K application to replenish what has been harvested with crop or lost via other sources. It is not known if the lack of application of K is contributing to the low yields being realised in Kenya.

2.3.1 Effect of potassium on yield of sugarcane

Potassium is an important nutrient in sugarcane production. The effects of potassium on sugarcane yields and use in sugar-producing countries have been reviewed (Filho, 1985; Malavolta, 1994). Variable sugarcane yield responses were reported. In Fiji only 33% of the sites studied showed a response to potassium fertilization (Yang and Chen, 1991). Under Vidarbha conditions in India there was no response to potassium applied at 50-100 kg K_2O/ha (Lakholine *et al.,* 1979; Olalla *et al.,* 1986). There was no significant yield response to applied potassium (Perez and Melga, 1998) in andisol soils. In a sandy loam calcareous soil of North Bihar, cane yield significantly increased from potassium fertilization (Prasad *et al.,*1996). Similarly, in Sao Paulo State of Brazil raising application of potassium progressively increased cane yield. (Korndorfer, 1990). In Pakistan number of millable canes per unit area, cane diameter and length of internodes and sucrose in the cane increased with increasing rates of potassium fertilizer (Khosa, 2002; Ghaffar *et al.*, 2010). In Kenya, it is not known if the lack of applying K has compromised yield.

2.3.2 Effect of potassium on sugarcane quality

The most important function of potassium in sugarcane is improvement in cane quality by converting reducing sugars to recoverable sugars (Hunsigi, 2011). The nutrient flushes out nitrogen and tissue moisture to assist sugarcane to reach a stage of maturity. In general, improvement in commercial cane sugar (CCS) is due to increase in cane yield and pol % cane (sucrose). Improving cane quality is one of the most important means for maximizing profitability in the sugarcane industry. Grinding cane with a high percentage of recoverable sucrose is profiAnnex as it reduces the cost per unit ton of sugar produced. Juice quality is therefore an important determinant of maximum sucrose yield. However, a potassium fertilizer trial in Mauritius showed no response to potassium in cane yield and was not accompanied by an increase of sucrose in the cane (Ng Kee Kwong, 2002). In India although potassium application in two equal splits gave maximum cane yield, juice quality was unaffected (Gulati *et al.*, 1998).

A more vivid example of potassium lowering sucrose recovery is provided by (Korndorfer, 1990) who observed that vinasse (distillery slops) when applied at 120 m^3/ ha to a dark red dystrophic latosol in Brazil increased cane yield from 98 to 127 Tc/ha but decreased recoverable sucrose concentration in cane from 15.0 to 13.1%. Excessive uptake of potassium from soil depressed the recovery of sucrose during milling (Filho, 1985). In another study a significant depression in sucrose concentration of cane resulted by an application of 183 kg K_2O/ ha in South Africa (Wood, 1990). In Kenya the role of potassium for juice quality has not been investigated. There is need of a re-look at potassium application in the Kenyan sugar industry since non-use could be contributing to the current low sugar content in cane.

2.4 Determination of plant nutritional status

Fertilizer management is an important agronomic practice in sugarcane production. Sugarcane producers rely on field fertilizer trials, soil testing and foliar analysis to plan fertilizer programs (Elwali and Gascho, 1984). The use of leaf nutrient analysis in combination with visual evaluation of malnutrition symptoms can complement the fertilization program and give useful information that will improve decision. Leaf analysis provides a picture of crop nutritional status at the time of sampling. For sugarcane leaf analysis, the top visible dewlap (TVD) leaf has been sampled during the grand growth period to evaluate the plant nutritional status (Gascho and Elwali, 1978; McCray *et al.*, 2006; Rice *et al.*, 2002). The leaf is metabolically very active, functioning as the site of photosynthesis, which determines the primary processes occurring within the plant. Leaves are also a major site of carbohydrate and mineral storage. Leaf analysis gives both the levels of the nutrients as well as the ratios of one element with another; therefore interactions between elements are more discernible, and hence more easily rectified. Yields of sugar cane is highly correlated with leaf nutrient status during the maximum growth period indicating that leaf analysis may allow early detection of nutritional problems (Holford, 1968). Plant analysis could also be a useful tool for correcting plant nutrient deficiencies and imbalances (Baldock and Schulte, 1996; Miles, 2010) and optimize crop production (Walworth *et al.*, 1986), through evaluation of nutrient requirements. Results of foliar analyses are interpreted on the basis of the critical nutrient level (CNL) which defines a nutrient concentration below which the nutrient is considered to limit production Annex 1). The CNL refers to the concentration of a particular nutrient in a particular plant part at a specific stage of growth, at which production losses reach 10% (McCray *et al.*, 2006). The

CNL approach may also include the use of "nutrient's optimum range", defined as the range of concentration of a nutrient considered optimum for production. However, the interpretation of CNL depends on age of the plant at sampling, the sugarcane variety, plant part sampled, soil condition and inorganic fertilizer application (Gascho, 2000). When using CNL approach it is particularly important to collect leaf samples at the specified growth stage because nutrient contents change during the crop growth cycle.

Table 1: Foliar critical nutrient levels and optimum ranges

Nutrients	Critical Level	Optimum Range
N	1.80 %	2.00-2.60 %
P	0.19 %	0.22-0.30 %
K	0.90 %	1.00-1.60 %

Source: McCray *et al.*, 2006.

In Kenya no attempt has been made to guide fertilizer application programs based on foliar diagnostic techniques. The general practice is applying a fixed rate of fertilizer regardless of variety and soil type.

The critical green leaf nitrogen concentration for photosynthesis in sugarcane (Keating *et al.*, 1999) ranges from 1.2% N at emergence or ratooning to 0.5% at flowering. Despite sufficient levels of nitrogen fertilizer, sugarcane leaf nitrogen is known to decrease during approximately the second half of sugarcane growth (Haslam and Allison, 1985). This is likely to change depending on when nitrogen fertilizer is applied. Usually, nitrogen is required in greater amounts in the early stages of sugarcane growth (Samuels, 1969a, 1969b). It therefore necessary that leaf nitrogen in the early stages is determined and correlated with ultimate yields. Application of high rates of nitrogen affects the levels of other nutrients in tea plants (Owuor, 1997; Kamau *et al.,* 2003). This is not well documented for sugarcane in Kenya. It is also not known if other nutrients in sugarcane, apart from nitrogen, have significant effects on the sugarcane yields, and if the application of nitrogen influences their level.

2.4.1 Factors affecting leaf nutrient concentrations

Nutrient concentrations vary with the age of the tissue or organ, with this being essentially a reflection of variations in water content (Mengel and Kirkby, 2001). Young tissues have relatively high water contents and are rich in nutrients, particularly N, P and K, which are dissolved in the water. Concentrations of these nutrients decrease with increasing age of the tissue. Decreases in nutrient concentrations as the plant ages relate mostly to N, P and K (Mengel and Kirkby, 2001).

Concentrations of less mobile nutrients, such as Ca, Mg, Mn and B, are less affected by plant age, and may even increase in concentration with ageing (Mengel and Kirkby, 2001). It is not known how leaf nutrient vary with time from planting and if the critical nutrient levels are influenced by sampling time.

2.5 Determination of optimum harvesting age for sugarcane

Sucrose content and predicting maturity of sugarcane play important role both in cane payments systems and harvesting schemes as well as in experiments of comparing maturity conditions among different varieties (Stmopen.Net, 2013). Several standard analytical methods are available to determine the peak maturity or quality so that the cane is harvested at right time (Ong'injo and Olweny, 2011). Without such analysis several farmers take-up cane harvesting based on crop age and appearance. Maturity is determined by monitoring sugar yield parameters such as, pol % cane, brix % cane, commercial cane sugar (CCS), and ton cane per hectare (Blackburn, 1984; BSES, 1991). Most sugar factories give cutting orders to farmers based on crop age. This is not a scientific method since planting time, varieties, crop management practices and weather conditions influences maturity. Yellowing and drying of leaves, metallic sound of mature canes when topped appearance of sugar crystal, glistening when a mature cane is cut in a slanting way and held against the sun are some of the visual indices of assessing maturity of cane. Important sugarcane quality parameters for assessing cane maturity are the juice brix, pol or sucrose percentage and purity. However, most researchers focus their evaluation on pol % cane (Blackburn, 1984; BSES, 1991) and reported values ranged from 10.49 -17.86. In milling operations, the preferred varieties are those with pol % cane and brix % cane values nearly equal at maturity, (Clements, 1980). Maturity age is relatively specific to industrial needs. For example, early maturing varieties are those ripening at 8-10 months in India (Blackburn, 1984; BSES, 1991), 10-11 months in Indonesia (Gonzales *et al.*, 1998), and, 9-10 months in Mauritius (Hunsigi, 1993). During the initial stages, the portion of sugar, that is stored as sucrose, is small and increases as growth continues (BSES, 1991). Towards maturity, vegetative growth is reduced and internode elongation rate is decreased while the sugar and fibre contents increase (Das *et al.,* 1997; BSES, 1991). Early maturing varieties have numerous benefits to both the growers and sugar industries by providing an efficient and reliable means of achieving increased sugar yields, save the raw material required for a given crop cycle and allow earlier commencement of the harvesting and the processing season, and ensure profitability (Ong'injo and Olweny, 2011). Good relationship between juice quality and yield parameters have been reported respectively (Das *et al.,* 1997). The exact time of harvesting based on quality has not been assessed especially on new varieties. It is also not known how rates of nitrogen and potassium influence optimal harvesting time.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Site description and land preparation

The study was conducted from November 2007 to July 2009 at Kenya Sugar Research Foundation (KESREF) - Kibos, located on longitude 34° 48'E and latitude 0° 04'S at 1184 m above mean sea level, situated 16 km North East of Kisumu City on Kisumu - Miwani Road. The area has a warm sub humid type of climate with a long term mean annual rainfall of 1464 mm and mean daily temperatures ranging from 21.5°C to 23.5°C (Jaetzold *et al.*, 2007).

The land was first ploughed using a mould board plough and then harrowed by the use of a disc plough. The plots were then designed into blocks with furrows 1.2 m a part within a plot.

3.2 Experimental layout

A split-split plot treatments arranged in a Randomized Complete Block Design was used in this trial. The trial was planted using seed cane of ages between 12 and 16 months, chopped into three budded setts. The experiment consisted of three varieties (CO 421, KEN 82-472 and KEN 83-737 as main plots, four nitrogen rates (0, 50, 100, and 150 Kg N /ha), as sub-plots and two potassium rates (0 and 100 Kg K_2O/ha) as sub-sub plots measuring six rows of 10 m length and 1.2m apart replicated four times. CO 421 a late maturing cane variety whose quality has been stable was used as control. KEN 82-472 and KEN 83-737 are high yielding and early maturing cane varieties recently released to the Kenya sugar industry (KESREF Technical Bulletin, 2007). Soil samples from the top 15cm and sub-soil of 15-30 cm were taken before planting and analysis of pH and N, P & K was analysed. A uniform rate of 50 kg P_2O_5/ha as single super phosphate was applied at planting in all plots. Nitrogen as urea and potassium as muriate of potash fertilizers were applied at 4 months after planting (MAP). The outer two rows were treated as guard rows while the inner four were for sampling for analysis. Weeds were controlled manually four times and smut removed by hand pulling and burying throughout the growth period.

Table 2: The Split – Split Plot Experimental Design Layout

	R_1			R_2			R_3			R_4	
	N_3K_1 20	N_4K_1 21		N_1K_1 20	N_3K_1 21		N_2K_1 20	N_1K_2 21		N_4K_2 20	N_3K_1 21
V_3	N_2K_2 19	N_2K_1 22		N_2K_2 19	N_4K_2 22		N_2K_2 19	N_4K_1 22		N_4K_1 19	N_2K_1 22
	N_1K_1 18	N_3K_2 23	V_1	N_4K_1 18	N_2K_1 23	V_3	N_3K_1 18	N_4K_2 23	V_2	N_2K_2 18	N_1K_1 23
	N_4K_2 17	N_1K_2 24		N_3K_2 17	N_1K_2 24		N_1K_1 17	N_3K_2 24		N_1K_1 17	N_3K_2 24
	N_1K_2 12	N_2K_1 13		N_3K_2 12	N_1K_1 13		N_4K_1 12	N_3K_2 13		N_1K_2 12	N_3K_1 13
V_2	N_3K_2 11	N_4K_1 14	V_2	N_4K_1 11	N_2K_1 14	V_1	N_3K_1 11	N_1K_2 14		N_3K_2 11	N_2K_2 14
	N_1K_1 10	N_4K_2 15		N_1K_2 10	N_3K_1 15		N_2K_2 10	N_2K_1 15	V_3	N_4K_2 10	N_2K_1 15
	N_3K_1 9	N_2K_2 16		N_4K_2 9	N_2K_2 16		N_1K_1 9	N_4K_2 16		N_1K_1 9	N_4K_1 16
	N_4K_1 4	N_3K_1 5		N_4K_1 4	N_1K_1 5		N_3K_2 4	N_2K_1 5		N_1K_1 4	N_3K_2 5
V_1	N_1K_2 3	N_4K_2 6	V_3	N_1K_2 3	N_2K_2 6	V_2	N_4K_2 3	N_1K_1 6	V_1	N_2K_1 3	N_4K_1 6
	N_2K_1 2	N_3K_2 7		N_4K_2 2	N_3K_1 7		N_1K_2 2	N_2K_2 7		N_1K_2 2	N_2K_2 7
	N_1K_1 1	N_2K_2 8		N_3K_2 1	N_2K_1 8		N_3K_1 1	N_4K_1 8		N_3K_1 1	N_4K_2 8

3.3 Data Collection

3.3.1 Soil sampling and analysis

At each plot, ten cores were taken randomly at 0-15 cm and 15-30 cm depths using a stainless-steel soil auger. The samples were then thoroughly mixed and a 1kg representative composite sub-sample drawn. The samples were air dried in the shade and ground with wooden pestle and mortar and passed through a 2 mm sieve to separate the coarse fragments (>2 mm). The sieved soil samples were stored in separate clean and dry containers and used for various physicochemical analyses for the levels of pH, N, P & K.

Soil pH was determined in a 1:2 soil:water suspension as described by using systronic digital 331 pH meter (Okalebo *et al.*, 2002)

3.3.2 Growth and yield data

The first tiller count was taken in March 2008 (four months after planting) till 8 months after planting this being the maximum tillering period, while the millable stalk count was taken at harvest. The tiller development was monitored by counting the number of tillers, Stalk height (cm) and diameter (mm) was determined at monthly intervals. Stalk height was measured by a meter rule while plant girth was measured by venire callipers. Sugarcane yield was determined by visually counting the total number of millable stalks, from the four centre rows, per treatment at harvest which were then converted into millable stalks per hectare (MSH). All stalks per treatment were weighed to get the net stalk weight in kilograms. The average mature stalk weight for each plot was estimated by dividing the total sugarcane sample weight by the number of stalks in the sample. The resulting figure was then converted into tons cane per hectare (TCH).

3.3.2 Leaf sampling and analysis

Sample collection was from March (4 MAP) to October (9 MAP) the grand growth period when most rapid nutrient uptake occurs. This also coincided with the long rainy season which is the recommended time for sampling. Twenty third visible dewlap (TVD) leaves from each plot were randomly sampled from the inner four rows four to nine months after planting. Samples preparation was by removal of midribs from leaf blades, rinsing in distilled water to remove soil and dust particles, followed by drying in the oven at 70°C for 72 hours and grinding (Okalebo *et al.,* 2002).

Ground samples were subjected to N, P and K analyses (Okalebo *et al*., 2002).

The samples were analysed for nitrogen by heating samples in the presence of sulphuric acid, H_2SO_4 for two and one half hours. The residue was cooled, diluted to 25 ml and analyzed for ammonia using KB 49 Gerhardt Kjeldalh equipment. Available phosphorus was extracted with sodium bicarbonate (0.5 *M*) at pH 8.5 (Olsen's reagent) and the amount of P in the extract was estimated by chloro-stannous reduced phospho-molybdate blue colour method using a 1650 PC Shimadzu UV-VIS Spectrophotometer, while samples were extracted with neutral ammonium acetate and determined for potassium by the use of 410 Sherwood flame Photometer.

The concentrations of the nutrients were compared with the nutrients critical value and optimum range.

3.3.4 Sampling for sugar quality and analysis

Twelve stalk samples were taken from each plot at the twelfth month after planting until harvest to determine their sugar and fibre contents (Anon, 1970), however, due to the breakdown of the mill, samples of 17, 18, 19, 20 MAP were not analysed. The sugarcane sample harvested comprised of randomly selected stalks within the four centre rows of the plot, which excluded the tops, green leaves, and senesced brown leaves. Each stalk was toped at the apical meristem and cut at the base just above the soil surface. The stalks were then crushed in a three roller mill and juice used for quality analysis according to sugarcane Laboratory Manual for Queensland Sugar Mills (Anon, 1970). Pol was measured by use of an Anton paar-mcp 250 Sucromat while brix by an index instrument GPR 53 X refractometer.

The two factors were then used to calculate CCS as follows:

Brix % in cane = Brix% in juice x (100 – ((fibre% + 3)/100)

Pol % in cane = pol% in juice x (100 – ((fibre% + 5)/100)

Impurities in cane = Brix % in cane – pol% in cane

CCS %= pol %in cane – 0.5 x (impurities)

3.4 Statistical analysis

The data were subjected to General Linear Models (GLM) procedure using Statistical Analysis Software (SAS) system for Windows, version 8.2 (SAS, 1999) as split-split plot treatment arrangement within randomized complete block design (RCBD).

Analysis of variance (ANOVA) and Least Significant Differences (LSD) tests techniques were employed for separation of means of treatments-effects at the $p \leq 0.05$ and regression analyses done.

CHAPTER 4

4 RESULTS AND DISCUSSION

4.1 Soil nutrient status

The soil's pH ranged from strongly to slightly acidic, was deficient in carbon, nitrogen and potassium but moderate in calcium before application of treatments.(Annex 3)

Table 3: Soil nutrient levels at planting

Parameter	Test Level	Interpretation
pH	4.7-6.7	strongly to slightly acidic
% Carbon	0.4-1.6	deficient
% Nitrogen	0.3-1.9	deficient
Calcium meq./100g soil	2 - 5	moderate
Potassium meq./100g soil	0.05 - 0.17	deficient in potassium

4.1 Performance of varieties and use of growth parameters to predict yield.

Changes in the tiller numbers from 4 to 8 months after planting (MAP) is presented in (Annexes 1-5, Figure 2). The tiller numbers for varieties CO 421 and KEN 82-472 were higher ($p \leq 0.05$) than that of KEN 83-737, from 4 to 5 MAP, respectively, to the end of the recording period. High tillers result in high yields. This shows that CO 421 will out yield the KEN varieties. Similar tiller variations with other varieties have been reported in other sugarcane growing countries (Habib *etal.,* 1991; Nasir *et al*., 1994; Lingle *et al*., 2000; Vasantha *et al.,* 2012). Varieties with high tillering abilities usually record high cane and sugar yields (Kadervel and Devaraj, 1977; Vasantha *et al.,* 2012). These results demonstrate that the varieties grown in Kenya have different tillering capacities suggesting that the yield potentials could be different. Although CO 421 is an old and late maturing variety, its tillering capacity was higher than or similar to one of the new early maturing KEN varieties.

The response in girth diameter of different sugarcane varieties from 12 to 21 MAP are presented in (Annexes 6-14) and Figures 3 and 4. Significant ($P \leq 0.05$) responses were observed from 14 MAP onwards. Variety KEN 82-472 had higher ($p \leq 0.05$) girth diameter than CO 421 and KEN 83-737. Although variety CO 421 had slightly higher girth diameter than KEN 83-737, the difference was not significant throughout. Such responses have been attributed to genetic differences (Habib *et al.,* 1991). The results were opposite those observed in the tillering abilities (Figure 2).

The changes in stalk height in the different varieties from 12 to 21 MAP are presented in (Annexes 15- 23 , Figures 5 & 6). The heights were in the order KEN 83-737 >CO 421> 82-472. Variety KEN 82-472 was significantly ($p \leq 0.05$) shorter than the other varieties throughout the recording period. Although the heights of KEN 83-737 and CO 421 did not significantly vary from 12 to 14 MAP, and 18 to 21 MAP, KEN 83-737 was taller ($p \leq 0.05$) than CO 421 between 15 and 17 MAP. These variations in height of varieties are similar to those observed in Pakistan (Habib *et al.*, 1991; Nonsheen and Ashraf, 2003) in other varieties. The numerical advantage in the tillers, stalk girth and stalk height were in variety CO 421, KEN 82-473 and KEN 83-737, respectively. Thus there was no single variety dominating in all the growth parameters monitored. Similar variations in growth parameters have been observed in other studies (Wiedenfield, 1995). The results demonstrate the inherent genetic differences in the varieties used and suggest one parameter may be unsuitable to use to predict possible yield potentials.

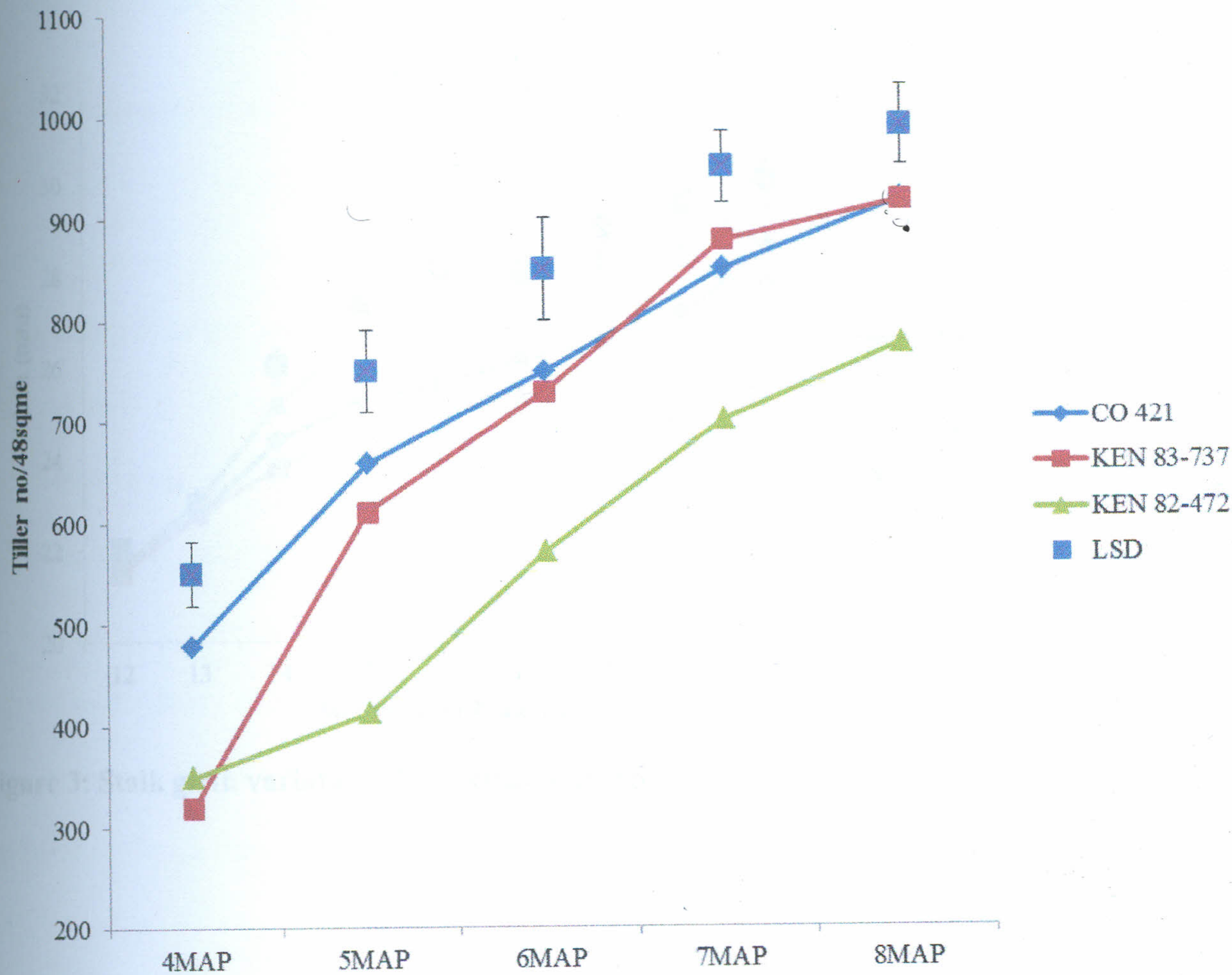


Figure 2: Tiller variations with varieties and age

4.1.1 Yield response of variety to nitrogen and potassium rates

The yield responses of the three variations are presented in Annex 4. Variety CO 421 out yielded KEN 83-737 ($p \leq 0.05$). Although the CO 421 numerically out-yielded KEN 82-472, the difference was insignificant. Such variations are attributed to genetic difference and varying abilities of the varieties to adapt to particular environment (Olaoye, 2006). The yields recorded in this study were much higher than those currently observed under field conditions in most parts of the Kenya sugar industry (Amolo *et al.,* 2006). Experimental conditions, can sometimes lead to slightly higher yields due to translation from the small plot sizes to TCH. However, such yields hardly exceed 5 to 10%. Thus the high yields observed in this study suggest other factors may be responsible for the low yields currently observed in the Kenya sugar industry. Possibly, management practices are not optimally intensified in Kenya sugarcane industry, causing the low yields. In India (Manimaran *et al.,* 2009), Australia (Bramley and Quabba, 2002) and Vietnam (Mui *et al.,* 1996), management practices are key factors influencing yields of sugarcane. In Kenya the management of sugarcane production is associated with economic inefficiencies that have been observed to cause stagnating or declining total factor production (Mulwa, 2006). Indeed, the industry has characteristics of poor management, corruption, and vested political interests that are stopping it from achieving its objectives (Wanyande, 2001). At the farm level, continuous cropping, lack of adherence to contracts by sugar companies, sugarcane fires have been cited as key factors affecting productivity (Marabu, 2013). At farmer level, high costs of farm inputs, lack of capital, inaccessibility to credit facilities, low cane prices, lack of or delayed supply of farm inputs, poor timing and supervision of farm operations, inadequate knowledge or information on new varieties, poor land preparation standards, cane losses due to pests, fires, poaching, poor handling and transportation, poor relationship between millers and farmers, delayed payment for delivered cane, delayed cane transportation, poor timing of planting, poor/marginal soils, delayed cane harvesting, poor harvesting programme & lack of extension services have been listed as major constraints to cane production (Wawire *et al.*, 2006b). These critical factors may be responsible for stagnating/declining cane yields in Kenya.

Table 4 : Effect of variety, nitrogen and potassium rates on yield (tons/ha) of sugar cane at harvest (21 MAP)

VARIETY	K Rates (Kg K_2O/ha)	N Rates (Kg N/ha)				Mean K Rates	Mean Variety
		0	50	100	150		
CO 421	0	139.3	145.5	143.0	159.5	146.8	
	100	137.3	130.5	146.5	162.3	144.2	
	Mean N rate	138.3	138.0	144.8	160.9		145.5
	CV (%)			3.7			
	$LSD_{(P\leq0.05)}$			2.7		NS	
KEN 83-737	0	106.8	131.3	150.8	162.0	137.7	
	100	131.5	137.5	146.5	159.3	143.7	
	Mean N rate	119.2	134.4	148.7	160.7		140.7
	CV (%)			5.7			
	$LSD_{(P\leq0.05)}$			8.3		5.9	
KEN 82-472	0	97.0	127.0	141.8	147.0	128.2	
	100	118.0	137.0	144.5	161.5	140.3	
	Mean N rate	107.5	132.0	143.2	154.3		134.2
	CV (%)			4.9			
	$LSD_{(P\leq0.05)}$			7.5		5.3	
Overall Mean	0	114.3	134.6	145.2	156.2	137.6	
	100	128.9	135.0	145.8	161.0	142.7	
	N rates	121.7	134.8	145.5	158.6		
	R^2			0.89			
	CV (%)			5.0			
	LSD $_{(P\leq0.05)}$			4.0		2.8	3.5

4.1.2 Relationship between growth parameters and yield

The growth parameters in MAP were correlated with final yield to establish if the parameters could be used as yield predictors or indicators. The regression coefficients (r^2) are presented in (Annex 5). The r^2 value between yields and tiller numbers were too low and insignificant for use as predictors. In the first 3 MAP, fertilizer treatments had not been applied. Tillers usually develop into millable canes. Thus the number of millable cane stalks and individual stalk weights constitute the yield of cane (Kapur *et al.,* 2011), although high numbers of tillers reduce stalk girth (Matsuoka and Stolf, 2012). In Texas, drought tolerant cane varieties showed good relationship between tiller numbers and yields than drought susceptible varieties (Silva *et al.,* 2008). In contrast to results presented herein, significant relationship between yields and tiller numbers were recorded in Sudan (Ahmed and Obeid, 2012) and Pakistan (Khan *et al.,* 2012).

Table 5: Relationship between growth parameters and yield

FACTOR	VAR	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP
TILLER	CO 421	0.05	0.0004	0.05	0.04	0.04
	KEN 83-737	0.03	0.03	0.34	0.01	0.05
	KEN 8KEN 82-472	0.16	0.01	0.02	0	0.01
	MEAN	0.08	0.04	0.001	0	0

FACTOR	VAR	12 MAP	13 MAP	14 MAP	15 MAP	16 MAP	17 MAP	18 MAP	19 MAP	21 MAP
GIRTH	CO 421	0.04	0.33	0.02	0.22	0.01	0.001	0.09	0.1	0.54
	KEN 83-737	0.004	0.02	0.21	0.4	0.38	0.44	0.62	0.78	0.69
	KEN 8KEN 82-472	0.16	0.52	0.59	0.58	0.71	0.51	0.59	0.48	0.66
	MEAN	0.08	0.23	0.68	0.42	0.59	0.47	0.7	0.76	0.8
HEIGHT	CO 421	0.13	0.11	0.21	0.46	0.71	0.77	0.53	0.68	0.52
	KEN 83-737	0.34	0.31	0.002	0.68	0.75	0.8	0.04	0.7	0.8
	KEN 8KEN 82-472	0.07	0.34	0.42	0.77	0.92	0.35	0.1	0.67	0.66
	MEAN	0.59	0.67	0.66	0.88	0.91	0.82	0.86	0.78	0.78
VOL	CO 421	0.002	0.01	0.11	0.13	0:26	0.59	0.72	0.52	0.6
	KEN 83-737	0.11	0.02	0.04	0.64	0.73	0.79	0.67	0.89	0.84
	KEN 8KEN 82-472	0.13	0.5	0.53	0.73	0.81	0.63	0.003	0.77	0.74

The lack of response observed in this study was possibly due to the timing of application of the fertilizer input at 4 MAP. The fertilizer treatments seemed not to have taken effect even up to 4 months after the application. The relationship between girth diameter of CO 421 and yield was only above 50% explained in the 21 MAP, which is the harvest time for the variety. It cannot therefore be used as a predictor for yield in this variety. The recommended harvesting period of KEN 83-737 and KEN 82-472 is 16 to 17 MAP (Jamoza, 2005). Over 50% of the relationship between yields and girth were after 18 and 13 MAP for KEN 83-737 and KEN 82-472, respectively. Thus girth diameter measurement is a good yield predictor for KEN 82-472 at 13 MAP, but marginal for KEN 83-737. On average when all the data for the varieties were together, girth diameter became useful at 14 MAP onwards although in some months (15 and 17 MAP) less than 50% of the relationships were explained. Several studies (Panhwar *et al.,* 2003; Shukla, 2003; Gana *et al.,* 2009; Khan *et al.,* 2012) have shown significant relationship between girth and yield of sugarcane. Girth measurement can therefore be an objective estimate of potential yields in sugarcane production in Kenya, provided the measurements are taken at least 13 MAP.

Stalk height predicted yields in all varieties. For Co 421 the stalk height could explain potential yields from 16-21 MAP, for KEN 83-737, the relationship was over 50% explained in 15 to 17, 19 to 21 MAP, and for KEN 82-472 the relationship were explained in 15 and 16 MAP and 19 and 21 MAP. It is not clear why these relationships were not consistent. Similar findings have been reported in several sugarcane growing countries (Nosheen and Ashraf, 2003; Panhwar *et al.,* 2003; Mui *et al.,* 1996; Singh and Sharma, 1982). These results corroborate data observed in other studies (Wiedenfield, 1995) that these growth parameters can be useful in assessing potential yield of sugarcane before harvest. Thus under Kenya sugarcane growing conditions, girth and stalk heights are good potential yield indicators.

4.2 Response of growth parameters of the sugarcane varieties to rates of nitrogen and use of growth parameters to predict yield.

The responses in growth parameters to nitrogen fertilizer rates are presented in (Annexes1-23, Figures 2 to 6). The tillers only responded ($p \leq 0.05$) sporadically to nitrogen rates (Annexes 1 to 12). In CO 421, significant ($p \leq 0.05$) response occurred in 5, 7 and 8 MAP, while it occurred only in the 6 MAP for KEN 82-472. In KEN 83-737 and for the overall mean, there was no response. Results contrast those observed in Nigeria (Abayomi, 1987), India (Rehman, 1995; Shukla, 2003,) and Pakistan (Ashraf *et al.,* 2008), where there were significant relationships between nitrogen fertilizer rates and tiller numbers. Fertilizer was applied 4 MAP, it is maybe possible that the early growth parameters did not respond to nitrogen application as the nutrient had not taken effect. The girth diameter (Figure 4), however, significantly ($p \leq 0.05$) responded to nitrogen fertilizer application in CO 421, KEN 83-737, and KEN 82-472 and overall mean from 12, 15, and 14 MAP, respectively. Cases the significant ($p \leq 0.05$) responses were between control (0 Kg N/ha) and 150 Kg N/ha. Such responses had been observed in other studies (Mahboob *et al.*, 2000; Shafshak *et al.,* 2001) and may provide explanation of responses of sugarcane to nitrogen fertilizer application. The changes in sugarcane heights due to nitrogenous fertilizer rates are presented in Figure 6, there were significant ($p \leq 0.05$) responses in plant heights to nitrogen fertilizer rates from 12 MAP onwards for all varieties and overall mean. The KEN 82-472 had the shortest ($p \leq 0.05$) height throughout the growth period. The control and 50kg N/ha fertilizer rates did not vary in height, similar to 100 and 150 KgN/ha for KEN 82-472 and overall mean. The heights were in the order 150>100>50>0 Kg N/ha in all the varieties. Thus the height of cane linearly increased with the amount of nitrogenous fertilizer applied. Similar observations had been made in other countries (Abayomi, 1987; Mui *et al.,* 1996; Shukla, 2003; Ashraf *et al.*, 2008). These results show that although nitrogen is vital for growth and cane yield, different varieties have different abilities of using nitrogen for growth, thus achieving varying heights. The results observed in this study suggest that yield responses observed due to nitrogenous fertilizer application were indeed products of the stalk girth and stalk height, but independent of tiller number during the early growth phase.

There were yields responses ($p \leq 0.05$) to increasing rates of nitrogen fertilizer application in all varieties. Similar yield responses to nitrogen have been recorded elsewhere (Abayomi, 1987; Sharma and Gupta, 1990; Hussain *et al.*, 1991; Mui *et al.,* 1996; Shukla, 2003). This suggests that the current recommendation for old varieties may also be used for the new varieties. Consequently, there is no need to change the current nitrogen fertilizer use recommendations for the Kenya sugar industry. There were no significant interactions between the varietal yields and nitrogen rates suggesting the pattern of responses were similar. The patterns responses mirrored that of girth diameter and stalk heights suggesting, these growth parameters could be useful predictors of yields.

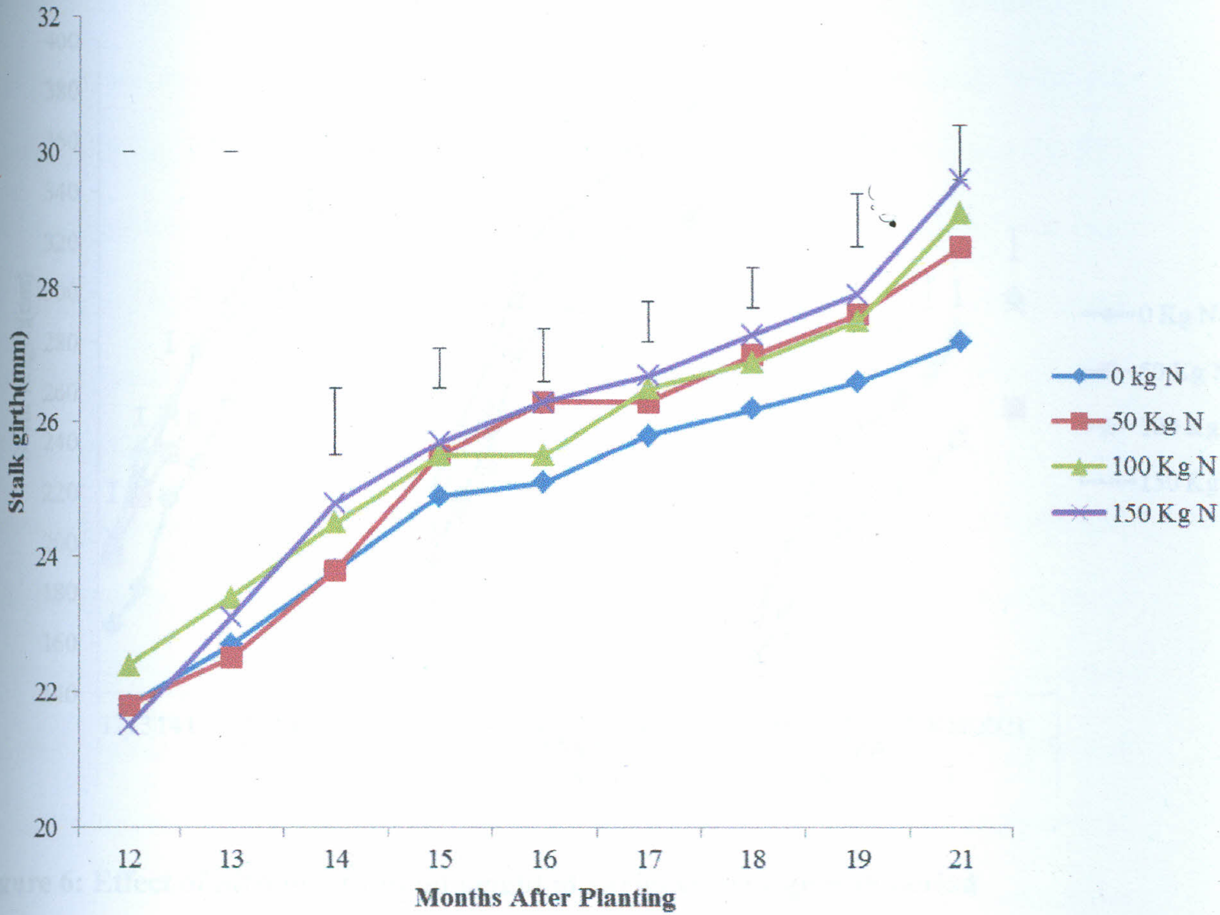


Figure 5: Effect of nitrogen rates on girth of varieties with age

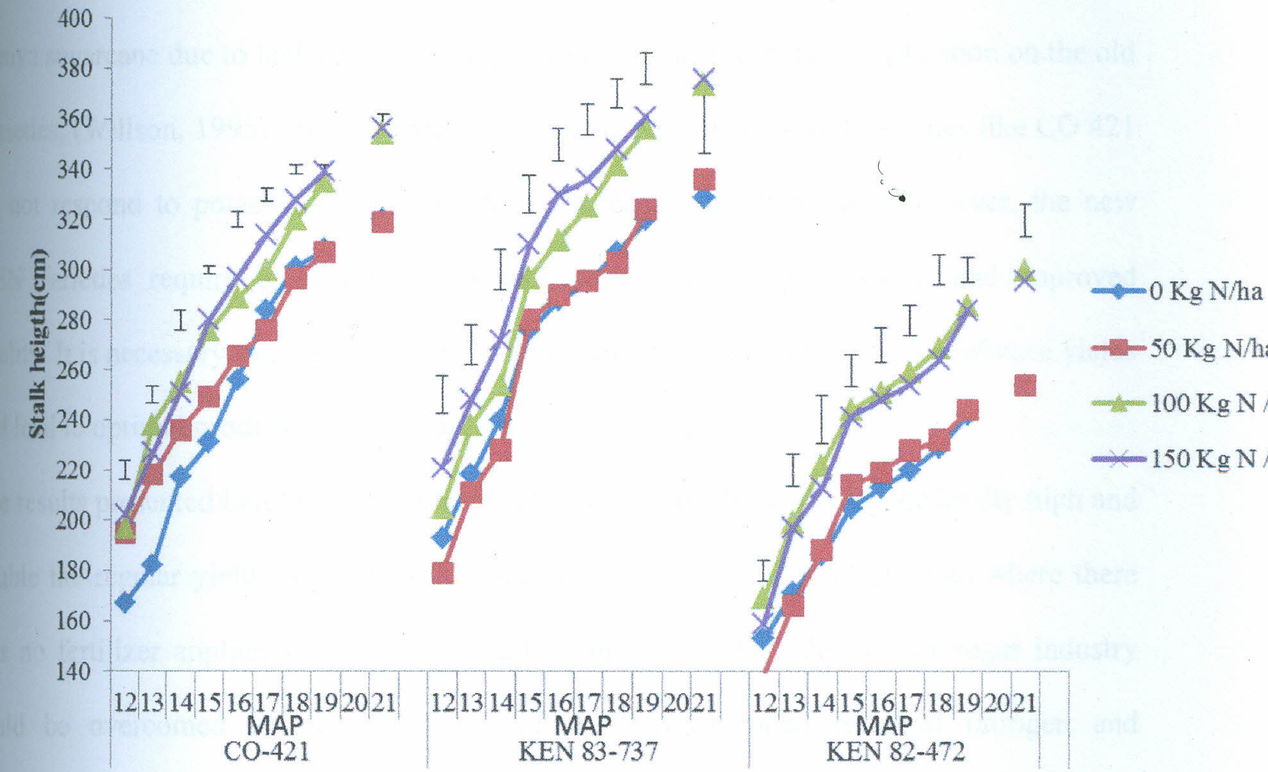


Figure 6: Effect of nitrogen rates on height of varieties over growth period

4.3 Response of growth parameters of the sugarcane varieties to rates of potassium and use of growth parameters to predict yield.

The early growth parameters did not significantly respond to potash fertilization. These results corroborates with the findings of Abayomi (1987) where tiller density was not affected by K manuring, unless there is a severe K deficiency, but are contrary to findings by Akhatar and Akhatar, (2002), in which cane height increased with K rate. Whereas yield of variety CO 421 did not respond to potash fertilization rates, KEN varieties responded ($p \leq 0.05$) to these rates. There were significant ($p \leq 0.05$) yield increases in KEN varieties due to potash fertilizer Annex 4). In studies conducted elsewhere, potassium application increased yields (Donaldson *et al.*, 1990; Malik *et al.*, 1993), similar to observations on the

KEN varieties. The use of potash fertilizers in sugarcane plantations was discontinued in Kenya sugarcane due to lack of relationship between yield and potash application on the old varieties, (Willson, 1995). Results presented here confirm that the old varieties like CO 421 do not respond to potash fertilizer justifying the earlier observations. However, the new KEN varieties require application of potassium to realize higher yields and improved quality. It is necessary to establish the appropriate rates of potassium that can enhance yields and lead to optimal productions of sugarcane in KEN varieties.

The results presented here have other implications. Yields obtained were generally high and double the regular yields obtained in the industry (Amolo *et al.*, 2006), even where there was no fertilizer application. The low yields being realized in the Kenya sugar industry could be overcomed by continued use of the recommended rates of nitrogen and introduction of potassium application to the new KEN varieties. However, it is more critical to ensure that all sugarcane management practices (Thornburn, 2004) are optimized for the realization of high yields.

4.5 Nutrient leaf content

Analysis of leaf has been used in sugarcane growing countries like South Africa and Mauritius to diagnose nutrient deficiencies and imbalances, and evaluating the effectiveness of the existing nutrient management program (Meyer *et al*., 1998). In Kenya little has been undertaken in the use of this tool for nutrient management. The results of evaluating the influence of N and K fertilizer on leaf N, P, K leaf content of varieties are presented in (Annexes 24-41, Figures 7-9).

Varieties differed significantly ($P \leq 0.05$) in their nutrient leaf content between 4 and 6 MAP for P and N but 4 and 9 MAP for K. Similar finding on other varieties were also found by (Inman –Bamber, 1984, Ambachew and Abiy, 2012).

Phosphorus mean leaf content of varieties was significantly ($P \leq 0.05$) different at 4 and 5 MAP Annexes 24 and 25), with the new varieties having higher P% than the standard. This early uptake is because phosphorous was applied before planting and is basically for root development, similar results were found by (Ambachew *et al.*, 2012). The P leaf content was within and above optimal range. This shows that the phosphorus basal application was sufficient for the three varieties and did not limit productivity. This confirms that P should be applied at planting for root development which then serves for uptake of the later applied nutrients like nitrogen and potassium for cane development and sucrose formation. Varietal difference was basically due to genetic makeup of these varieties. There may be need to also study the rooting systems of the various varieties for their ability to increase nutrient uptake and thus yield in future studies. Leaf K% content of varieties significantly ($p \leq 0.05$) differed throughout the sampling period (Annexes 30-35, Figure 9), ranging from high percentage at 4 MAP to low percentage at 9 MAP showing that potassium applied was taken up adequately during the active growth period 4-7 but later reduced (below critical) level due to age dilution effect of nutrients similar observations were made by (Ambachew and Abiy, 2012). Potassium unlike phosphorous is needed throughout the growth period since is for sucrose transportation and maturity.

Leaf N % content of varieties significantly ($p \leq 0.05$) differed at 5 and 8 MAP. At the grand growth period 4 to 6 MAP nitrogen content was within the optimal range having been applied at 4 MAP, but reduced to below critical limit at nine months when metabolism for growth has taken place and sucrose formation and translocation to the stalks has commenced. (Annex, Figure 11). There was a decrease of nutrients in the leaves of all varieties after six months suggesting that optimal sampling time be between 5 and 6 MAP. Increasing N supply promotes growth, and thereby increases the demand for other nutrients. This demand can result in increased or decreased concentrations of other nutrients, depending on their supplies in the root zone (Ambachew and Abiy, 2012; The results of nitrogen effect on leaf N, P, and K leaf contents are in (Annexes 24-41,Figures 7, 9 and 11). Nitrogen fertilizer application significantly ($p\leq 0.05$) affected leaf P%, at 5 MAP, since nitrogen was applied at 4 MAP and was absorbed closer to time of application. The highest foliar P was obtained at the lowest N rate applied indicating that nitrogen had a dilution effect on leaf P % and its uptake may have depended on the nutrient reserve of soils and type of nutrient applied (Ambachew and Abiy, 2012; Franco *et al.*, 2010).

There was significant ($p\leq 0.05$) effect of nitrogen rates on leaf K%,(Annexes 30-35 , Figure 9) of the new varieties at 4 and 9 MAP, showing the need of K at end of grand growth period . Like P the highest foliar K was obtained at the lowest N rate applied indicating dilution effect of N on K and its uptake. Similar findings were observed by Ambachew and Abiy, (2012). The significance shows the need of balanced fertilization for increased yields, since Interactions between nutrients may induce deficiencies, toxicities, modified growth responses (Robson and Pitman, 1983; Wilkinson *et al.*, 2000).

Nitrogen rates significantly ($p\leq 0.05$) affected leaf N % of new varieties than the old Co 421. The foliar N content were within optimal range (2.00-2.60) from 4-7 MAP but below critical level (1.8%) at 8 and (MAP, indicating that nitrogen fertilization was adequate at boom stage but later trans located from leaves to be stored as sucrose in the stalks. The highest foliar N obtained was at 100 Kg N at 6 MAP (Figure 12), indicating optimal uptake time and rate for cane production. Similar findings on other varieties in Ethiopia were reported by Ambachew and Abiy (2012).

Potassium fertilizer application did not affect leaf nutrient content significantly although levels were in the optimal range at early growth stages contrary to (Akhtar and Akhtar, 2002) in whose study potassium fertilizer application increased leaf nutrient content.

Leaf N positively correlated with yield at 4 MAP (Annex 6) with R^2 (0.67) and K at 6 MAP R^2 (0.90), while P had no strong correlation. Similar correlations of nitrogen were observed at 4 and 5 MAP at different sites by Ambachew and Abiy, 2012).These strong relationships indicate that leaf sampling is to be between 4 and 8 MAP.

Foliar diagnosis may thus be used for determination of nutrient status in fertilizer advisory services for sugarcane cultivation in Kenya.

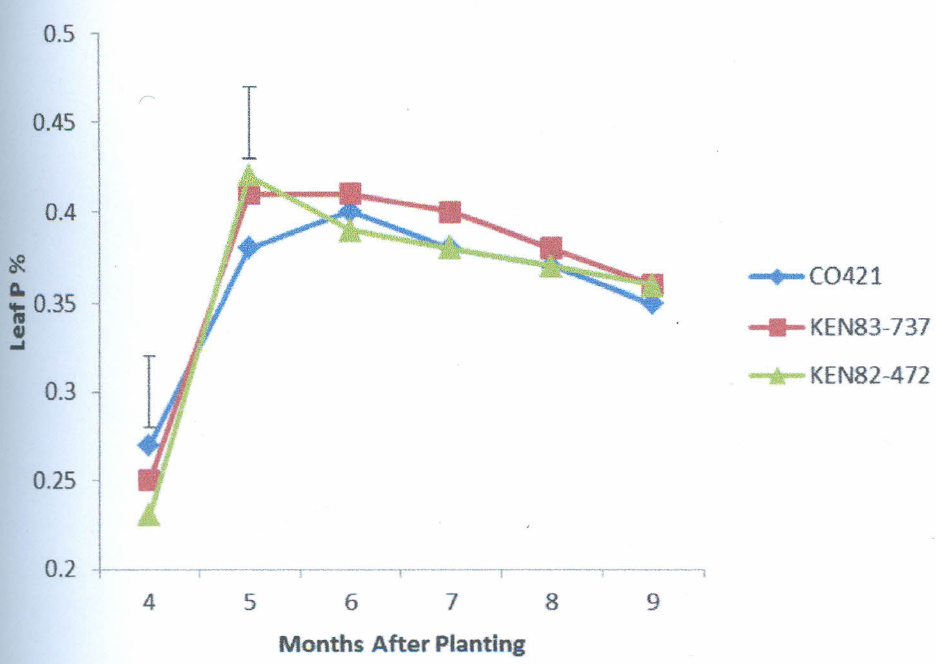


Figure 7: Variation of leaf P content of varieties with age

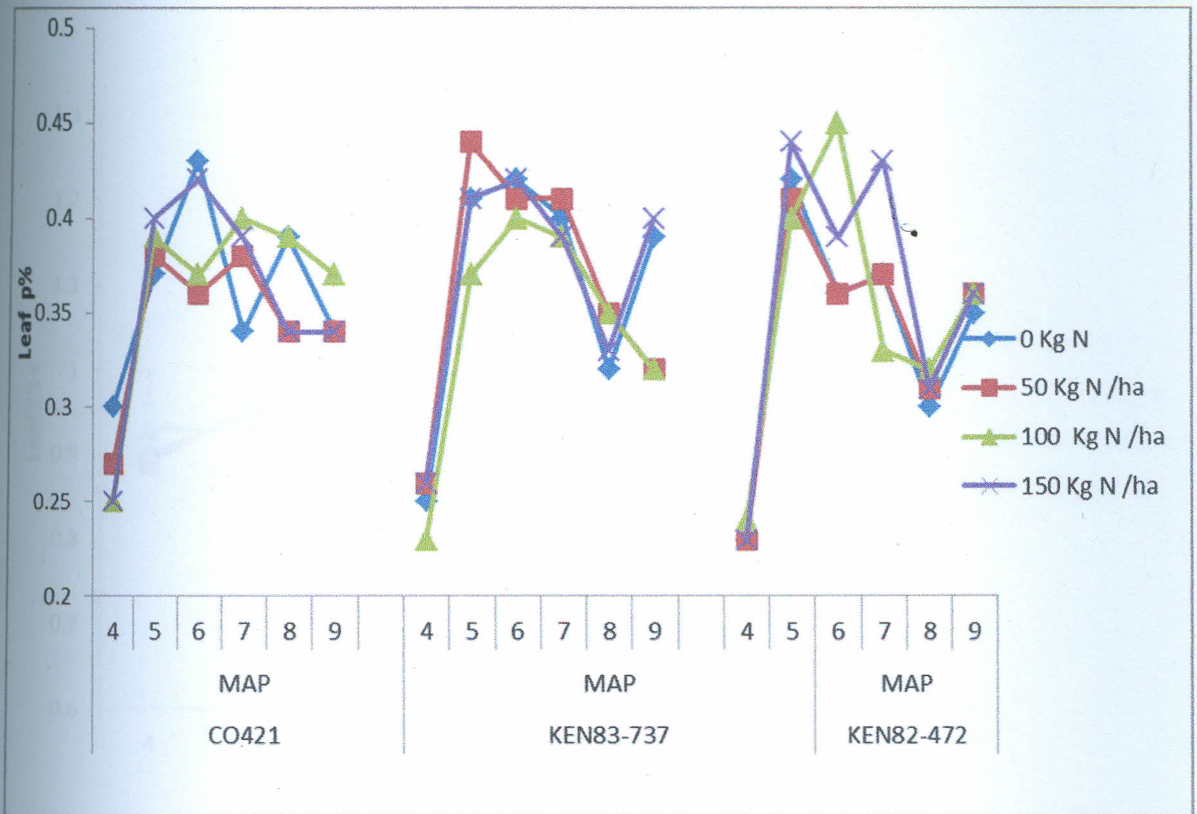


Figure 8: Effect of nitrogen rates on leaf P content

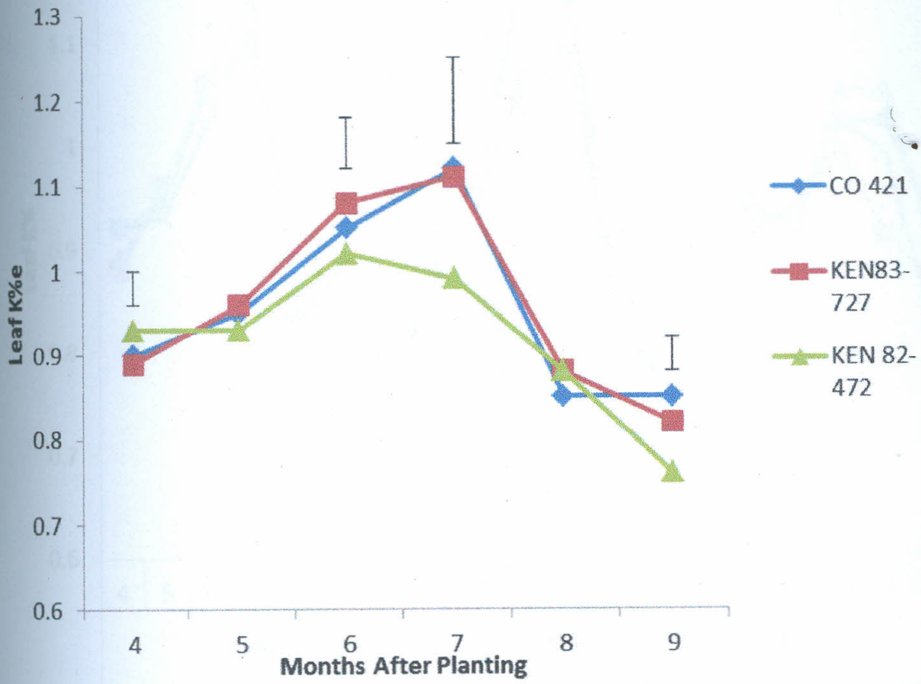


Figure 9: Variation of leaf K% of varieties with age

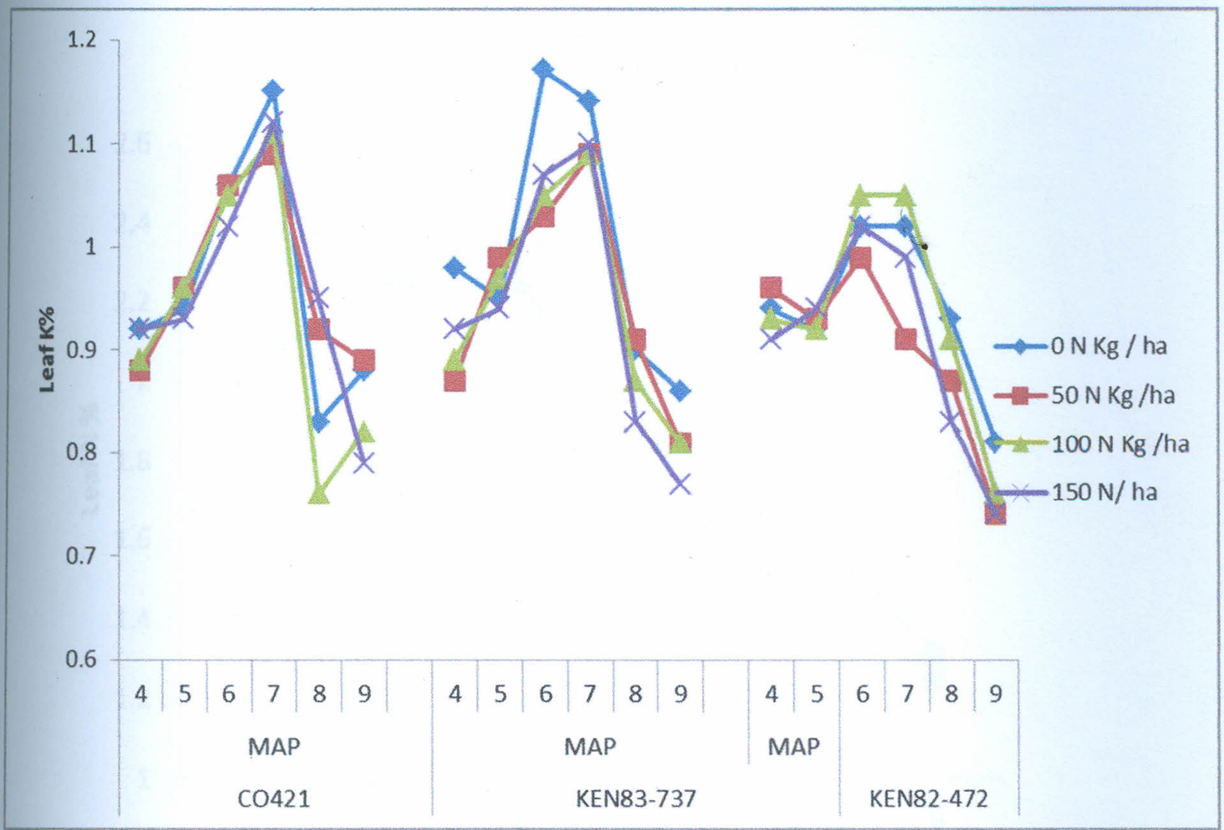


Figure 10: **Effect of nitrogen rates on leaf K content**

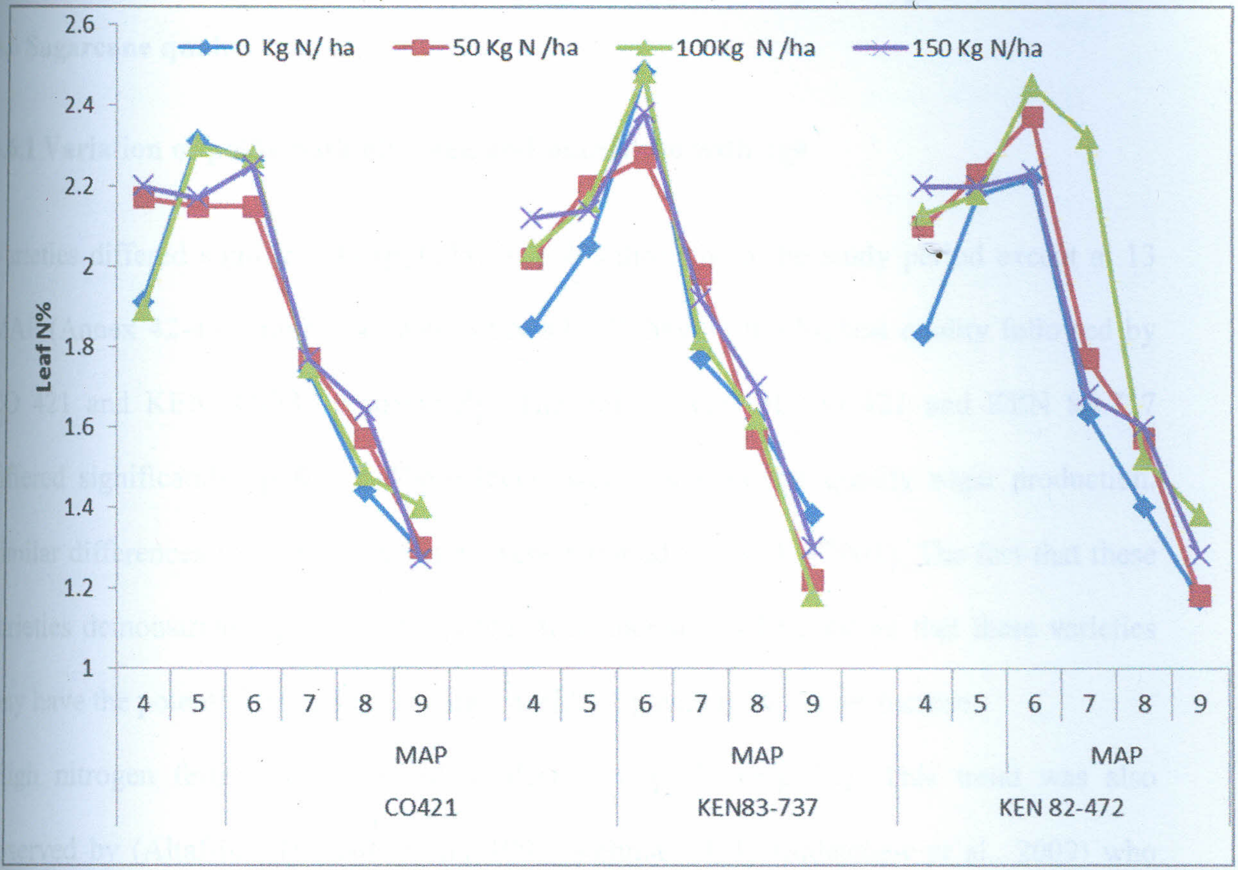


Figure 12: Effect of nitrogen rates on leaf N content of varieties

Table 6: Relationship (R^2) between yield and nutrient leaf contents

		4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP
N%	CO 421	0.14	0.02	0.03	0.07	0.68	0.61
	KEN 83-737	0.6	0.007	0.01	0.01	0.14	0.009
	KEN 8KEN 82-472	0.78	0.02	0.04	0.05	0.6	0.21
	MEAN	0.67	0.08	0.01	0.06	0.68	0.03
P%	CO 421	0.26	0.0005	0.016	0.21	0.02	0.02
	KEN 83-737	0.0003	0.10	0.61	0.08	0.02	0.07
	KEN 8KEN 82-472	0.04	0.03	0.34	0.12	0.01	0.48
	MEAN	0.04	0.03	0.34	0.12	0.01	0.48
	CO 421	0.15	0.25	0.69	0.08	0.10	0.54
K%	KEN 83-737	0.41	0.14	0.34	0.11	0.11	0.48
	KEN 8KEN 82-472	0.29	0.01	0.01	0.13	0.08	0.21
	MEAN	0.47	0.02	0.90	0.00	0.19	0.17

4.6 Sugarcane quality

4.6.1 Variation of pol% with nitrogen and potassium with age

Varieties differed significantly ($p \leq 0.05$) in pol% throughout the study period except at 13 MAP (Annex 42-47, Figure 14) with KEN 82-472 having the highest quality followed by CO 421 and KEN 83-737 respectively. The pol% levels of CO 421 and KEN 83-737 differed significantly ($p \leq 0.05$). These levels were adequate for quality sugar production. Similar differences in pol% of varieties were reported by Cock, (2001). The fact that these varieties demonstrated their genetic potential to increase pol % shows that these varieties may have the potential of increasing sugar yield for payment based on sucrose.

High nitrogen fertilization resulted in decreased pol% (Fig 14). This trend was also observed by (Altaf-ur-, Hussain *et al.,* 1991; Rehman1995; Ambachew et al., 2009) who found that N had adverse effect on the quality characteristics (brix %, pol %, purity % and CCS %) towards maturity, contrary to Najran *et al.* (2012) who found no effect on cane and sucrose juice. This phenomenon of pol % with nitrogen fertilization may be due to rapid growth and formation of biomass and the crop reverting to vegetative growth phase with increased contents of reducing sugars (glucose and fructose) by invertase enzyme cleaving the accumulated sucrose molecule (Abayomi,1987). There was no consistent nitrogen rate effect on pol% (Figure 14) but the lowest pol% was attained by 150 Kg N /ha. These results show that excessive application of N may be deleterious to cane quality and that100 Kg/Ha may still be adequate for quality. Although nitrogen application benefits yield there is need to balance this with quality considerations so that a compromised rate is developed.

Correlation of age with pol % showed that the varieties attained maximum pol% between 15 and 16 MAP indicating harvesting age for high sucrose attainment (Annexes45 and 46).

Potassium fertilizer application is essential to realize high yield and quality, converting reducing sugars to recoverable sugars. This nutrient helps to flush out N and tissue moisture to assist sugarcane to reach a stage of maturity. In this study potassium did not significantly affect quality (Annexes 42-47).This was also found by Gulati *et al*., (1998) and Woods (1990). However; this is contrary to findings by Hunsigi (2011) who reported that K increased pol% cane.

Table 7: Quadratic model for pol (%) of varieties with time

Variety	Constant	Coefficient (x)	Coefficient (x^2)	r^2	Max
CO 421	9.953	2.048	-0.211	0.992	15
KEN 83-737	10.474	1.775	-0.178	0.938	15
KEN 82-472	10.929	1.884	-0.188	0.925	16

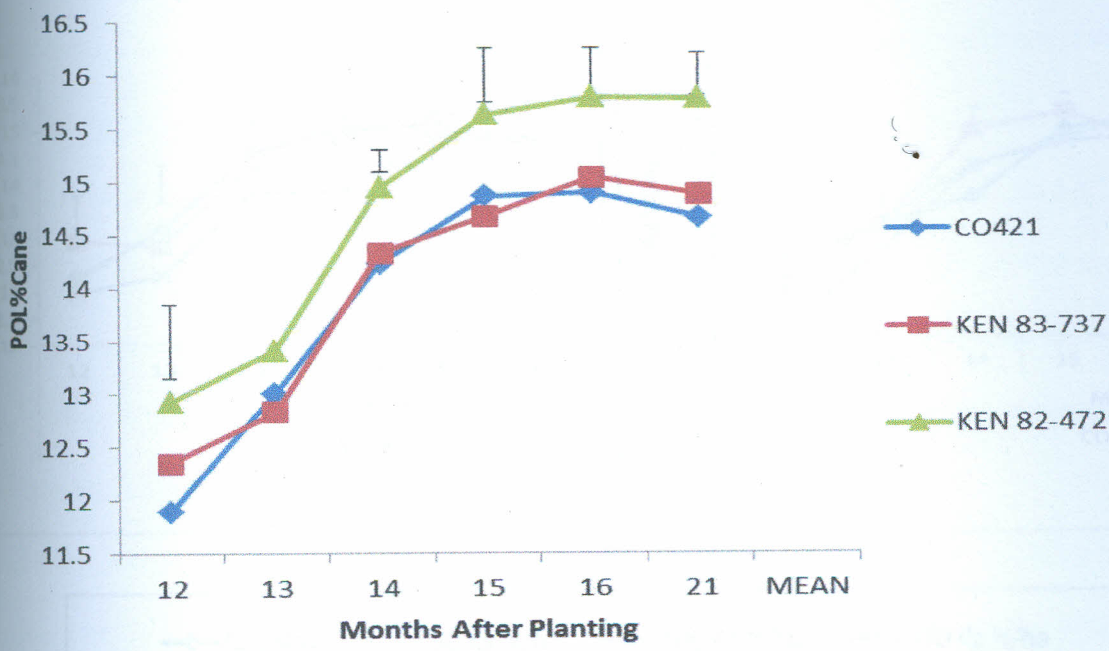


Figure 13: Variation of pol (%) of varieties with age (Bars are LSD)

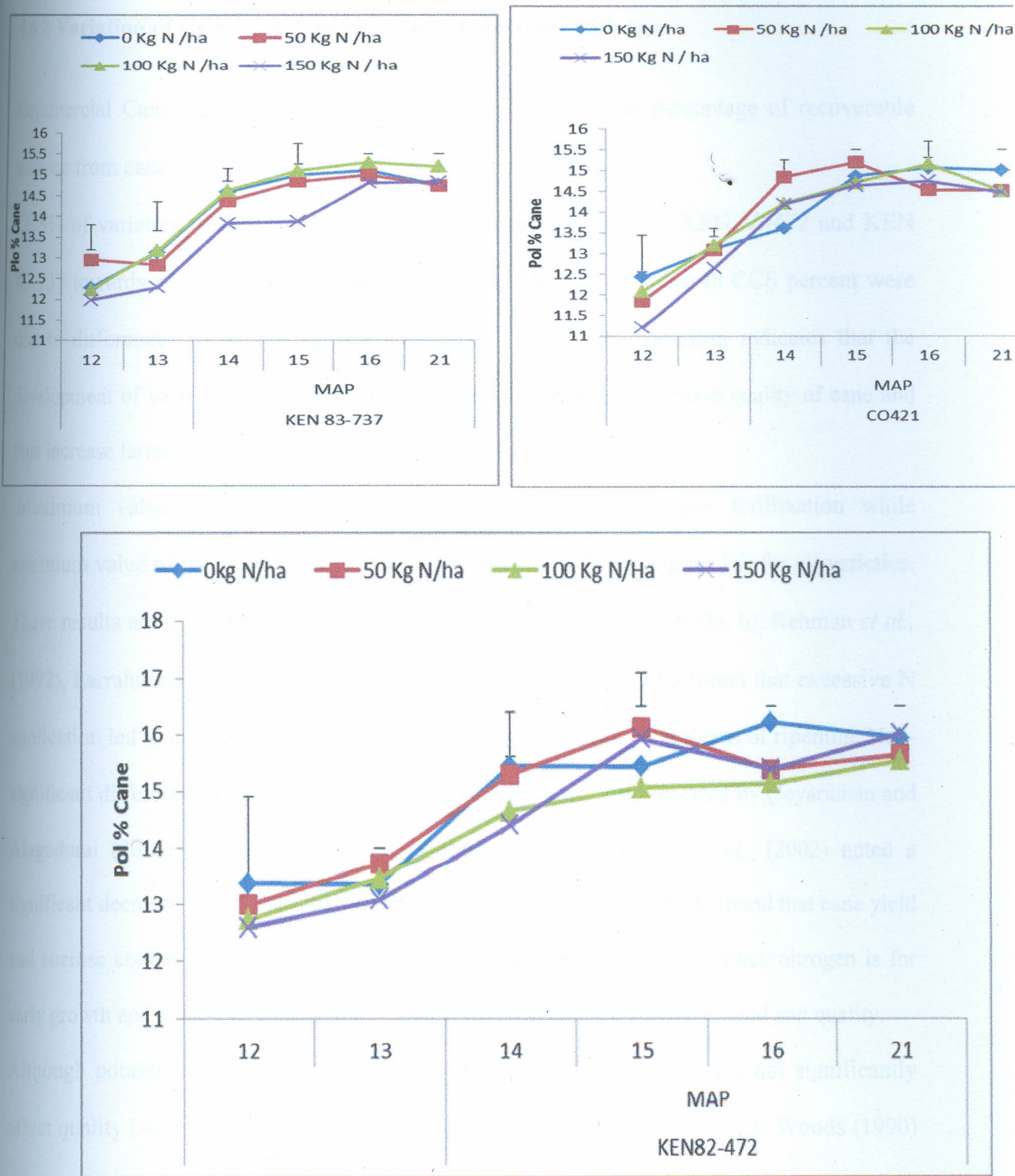


Figure 14: Effect of nitrogen rates on pol% of sugarcane varieties

4.6.2 Variation of CCS% with nitrogen and potassium with age

Commercial Cane Sugar (CCS %) provides an estimate of the percentage of recoverable sucrose from cane.

CCS% of varieties were significantly ($P \leq 0.05$) different CO 421, KEN 82-472 and KEN 83-737 towards maturity (Annexes 48-52, Fig 15). These differences in CCS percent were due to differences in the earlier reported yield. This genetic variation indicates that the development of varieties with high sucrose maybe an approach to increase quality of cane and thus increase farmers' income.

Maximum value of CCS percent were attained without nitrogen fertilization while minimum value of CCS percent was attained with 150 Kg N/ha (Figure 16) for all varieties. These results are in agreement with Habib *et al* (1991), Atta *et al* (1992a, b), Rehman *et al.*, (1992), Larrahando and Villagas,1995 and Ali *et al.* Alm.2002) who found that excessive N application led to undesirable reduction in sucrose due to its slowing down of ripening. Non-significant difference in CCS % at varied levels of N has also been reported by (Jeyaraman and Alagudurai (2003), Patel *et al.* (2004), Saleem, (2012). While Ali *et al.*, (2002) noted a significant decrease in CCS % at higher rates of N. Gawander *et al.* (2004) found that cane yield and sucrose content are significantly interrelated with applied fertilizers. Since nitrogen is for early growth and quality its rate should be that which will balance adequate yield and quality.

Although potassium is vital for cane quality, in this study potassium did not significantly affect quality (Annexes 48-52), this was also found by Gulati *et al*, (1998) & Woods (1990) this is contrary to results of Hunsigi (2011) where K increased pol% cane. These results show that potassium application is not necessary.

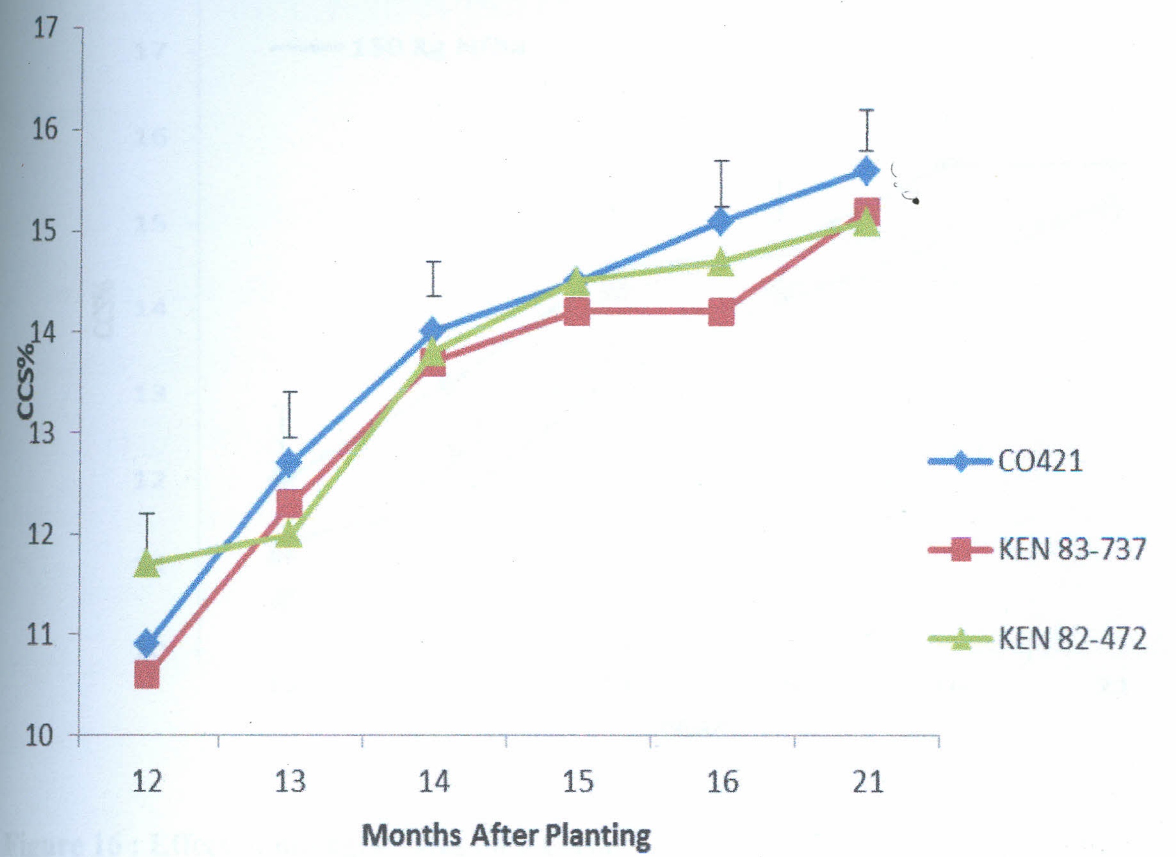


Figure 15: CCS % of varieties with age.

CHAPTER 5

5 SUMMARY, CONCLUSSIONS AND RECOMMENDATIONS

5.1 Summary

Significant ($p \leq 0.05$) difference in the tillers numbers girth and stalk height among varieties indicated that yield and yield contributing traits of sugarcane largely depend on genotype. The standard variety CO 421 had similar yields as KEN 83-737 but was superior to KEN 82-472. Nitrogen fertilizer significantly ($p \leq 0.05$) increased yield and yield contributing components of sugarcane like tillers, cane thickness and height. Potassium on the hand did not significantly affect yield and its contributing components. The relationship between nitrogen and potassium application on stalk girth, height, volume and their effect on cane yield was significant for all varieties $r^2 \geq 0.5$ towards harvest time of 15-16 MAP showing that they may be used to predict yield with certainty of over 50%.

Leaf nutrient status of varieties varied significantly ($p \leq 0.05$) with the new varieties having higher nutrient content than the standard, but N,P and K nutrient levels decreased with increasing age Optimal sampling time ranged between 4 and 7 MAP. Nitrogen fertilizer significantly ($p \leq 0.05$) increased N, P and K uptake with 100 Kg N /ha giving the highest N nutrient levels. Potassium had no significant effect on leaf nutrient status.

Significant ($p \leq 0.05$) difference in the quality characters studied among varieties indicated that quality of sugarcane largely depend on genotype, with KEN 82-472 having the highest quality. All the varieties reached maturity after 15 months shown by the levels of pol% and CCS. Nitrogen treatments had an adverse effect on pol% and CCS%, with the highest N rate (150 Kg N /ha) giving the lowest quality, Potassium did not influence the overall quality of cane.

5.2 Conclusion

Sugarcane varieties Co 421 and KEN 83-737 had similar yields but higher than KEN 82-472. Nitrogen rate of 100 Kg N/ha increased yields ($P \leq 0.05$) demonstrating its benefit for sugarcane production. Application of potassium increased ($P \leq 0.05$) yields, especially in KEN varieties, but not in Co 421. The mean level of leaf nutrient concentration suggests that there is a large potential for yield increase with improved nutrition with sampling between 4 and 7 MAP. KEN 82-472 had the highest quality attained after 15 months shown by the levels of pol% and CCS.

Optimum harvesting age for the studied varieties should be 15- 16 MAP for optimum sucrose yield.

5.3 Recommendations

1. All growth traits should be used for prediction of yield potentials.
2. 100 Kg N/Ha is still appropriate for plant crops of sugarcane, but there's need for review of K use for improved varieties.
3. Foliar diagnostic tool should be used to guide fertilizer plant requirement between 5 to 7 MAP.
4. Appropriate harvesting time for improved varieties is15 - 16 MAP.

5.4 Future Studies

1. Economic assessment of fertilizer rates for review of use.
2. Investigation of other non-sucrose factors that may affect quality.

3. Further research to determine the effect of crop cycles on foliar nutrient for a comprehensive fertilizer guide.

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