Management Strategies for Potassium Deficiency and Low pH on Sugarcane Growth, Yield and Quality in the Mumias Sugar Zone of Western Kenya

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Agronomy in the University of Nairobi

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DECLARATION

This is my original work and has not been presented for a degree award in any other University.

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DEDICATION

To the Almighty God; for knowledge, wisdom and the gift of life.

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ABBREVIATIONS AND ACRONYMS

%	- percent
AAESC	- American alternative energy systems corporation
AE	- agronomic efficiency
Al	- aluminium
BD	- bulk density
BMP	- best management practice
BSES	- bureau of sugar experimental stations
Brix	- total dissoluble solids
C	- carbon
C/N	- carbon nitrogen ratio
Ca	- calcium
CEC	- cation exchange capacity
CL	- clay loam
cm	- centimetre
CO	- Coimbatore, India
CO_2	- carbon dioxide
CV	- coefficient of variation
DAP	- diammonium phosphate
EDTA	-ethylenediaminetetraacetic acid
FAO	- food and agriculture organization
FC	- fertilizer cost
Fe	- iron
g	- gram
g/cm^3	- grams per cubic centimetre
GM	- gross margin
GR	- gross return
H^+	- hydrogen ions
Ha	- hectare

HCO_3^-	- bicarbonate ions
ISSCT	- International Society of sugarcane technologists
K	- potassium
K_2O	- potassium for plant uptake
KCl	- potassium chloride
KESREF	-Kenya sugar research foundation
Kg	- kilogram
KSB	- Kenya sugar board
Ksh	- Kenya Shillings
LSD	- least significant difference
LTM	- long term mean
m	- metre
m.e	- milliequivalent
MC	- moisture content
Mg	- Magnesium
ml	- millilitre
MOP	- muriate of potash
MSC	- Mumias sugar company
MSZ	- Mumias sugar zone
N	- Nitrogen
NAE	- nutrient agronomic efficiency
NE	- nucleus estate
NO_3^-	- nitrate ions
NPE	- nutrient physiological efficiency
NR	- net return
NRE	- nutrient recovery efficiency
NUE	- nutrient use efficiency
^oC	- degree Celsius
OC	- organic carbon
OG	- Out grower
OH^-	- hydroxide ions

OM	- organic matter
P	- phosphorus
Pc	- plant crop
P_2O_5	- phosphate
pH	- log [H^+]
PhD	- doctor of philosophy
Pol %	- percent polarization
ppm	- parts per million
RASITC	- Robert Antoine sugar industry training institute
Rc	- ratoon crop
RCBD	- randomized complete block design
S	- Sulphur
SCL	- silty clay loam
SO_4^{-2}	- sulphate ions
t/ha	- tons per hectare
TCD	- tons cane per day
TCH	- tons cane per hectare
TERSH	-tons expected recoverable sugar per hectare
TVC	- total variable cost
TVD	- top visible dewlap
VCR	- value cost ratio
v/v	- volume by volume
w/v	- weight by volume

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Abstract

Sugarcane production in Kenya has happened in monoculture systems over the last 60 years. In the last two decades serious concerns have emerged over yield decline by about 36% from a high of 110 t/ha in 1997 to a low of 69 t/ha in 2006 and only 51 t/ha in the year 2013 (KSB, 2013). This was way below the world yield average of 64.4 t/ha (FAO, 2012). The yield decline in Kenya is strongly linked to soil degradation as reported in other worldwide sugarcane production systems with long term monoculture; however, there is paucity of information on actual causes of the low yields. This study, therefore, sought to evaluate the impact of various management strategies for low pH and K-deficiency in the Mumias Sugar Zone of Western Kenya that accounts for 50-60% of national sugar production. Three field experiments were carried out from 2009-2011 to determine (i) the effects of nitrogen (N), potassium (K) and their interaction on sugarcane yield and quality (experiment 1); (ii) the effects of phosphorus (P), agricultural lime and their interaction, on sugarcane yield and quality (experiment 2); (iii) the effects of agricultural lime, organic manures and selected fertilizers on sugarcane yield and quality (experiment 3) and (iv) the agronomic efficiency and cost-effectiveness of the various management options through economic evaluation. The design in experiments 1 and 2 was RCBD with a factorial arrangement of the treatments and three replications while in experiment 3 was RCBD of eight treatments in three replications. Data was collected on soil characteristics, rainfall received, sugarcane emergence, tillering, stalk number, height and inter-node length, cane yield, sugar yield, juice quality and fibre content, diseases and pests attack, Agronomic Efficiency (AE) and Economic evaluation. Results from experiment 1 showed that application of K and N consistently increased

sugarcane tillering, stalk number, height and inter-node length. Cane and sugar yields per ha generally increased particularly at rates of 60-120 kg/ha K_2O and 46-92 kg/ha N. Increase in sugar yield due to K application was attributed to improved juice quality (Pol % cane). Agronomic efficiency (AE) was higher in plots supplied with K along with N . Nitrogen and K_2O application rates that produced optimum cane yields were: N = 46kg/ha and K_2O = 60 kg/ha; however, economically profitable rates were N = 46-92 kg/ha and K_2O at 60 kg/ha. Productivity gains did not offset costs when rates were higher than 120 kg/ha of K_2O and 138 kg/ha of N. The results imply that the inclusion of K in the sugar cane fertilization regime at Mumias will be beneficial. An initial rate of 60kg/ha K_2O (2 bags of 50 kg muriate of potash is recommended on soils with K-deficiency. There were strong indications that with K fertilization the current N recommendation of 120-150 kg N/ha could be reduced to only 80-120 kg/ha due to better N utilization from the interaction with K. Results from experiment 2 showed that emergence, tillering, stalk number, inter-node length, cane and sugar yields and Pol % cane increased significantly ($p< 0.05$) with liming and P application. Although incremental levels of P led to increased tillering, stalk population, cane, sugar yields and juice quality in the un-limed treatment, there was no significant difference ($p < 0.05$) in the components at P levels higher than 92 kg/ha P_2O_5. Agronomic efficiencies (kg sugarcane/kg nutrient) of P application were greater in plots with supply of agricultural lime along with P at 46-92 kg P_2O_5. Although higher value cost ratios (VCR) were recorded without liming, net returns were higher in the limed treatment due to improved sugarcane yields. The results of this study suggest that the inclusion of agricultural lime in the fertilizer regime at Mumias is necessary and cost effective on soils with low pH. Where agricultural lime is applied the recommended P dose of 92 kg/ha P_2O_5 could be reduced to 46 kg/ha P_2O_5 with no adverse effects on sugarcane yield. Results from experiment 3 showed that emergence, tillering, stalk number, height, inter-node length, cane and sugar yields differed significantly ($p \leq 0.05$) among the treatments in all locations. Highest cane and sugar yields were recorded in treatments where agricultural lime and compost were included. Sugarcane juice quality was highest in the SSP + Urea treatment ranging from 13.58 - 14.43 % Pol and lowest in the compost treatment ranging from 11.43- 13.37 % Pol. Smut incidence was notable in the compost and control treatments. Agronomic efficiency was highest in treatments where compost and agricultural lime were included, ranging from 90.3-481.5 kg sugarcane/kg nutrient. Highest net returns and value cost ratios were also recorded in treatments with compost and agricultural lime. Based on these results the inclusion of agricultural lime and organic manures in the cane production systems at Mumias is recommended.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Sugar is produced in 127 countries around the world. Seventy nine (79) countries produce sugar from sugarcane, thirty eight (38) only from sugar beets and ten (10) from both plants (F.O. Lichts, 2012). In the year 2011/12, total amount of raw sugar produced globally was reported to reach 175.9 million tons while consumption was estimated at 164.5 million tons (F.O. Lichts, 2012). The world's largest producer of sugar was Brazil followed by India, China, Thailand, Pakistan, Mexico, Columbia, Australia, USA and the Philippines. Africa's share of global sugar production was around 5.8 % with the leading country being S. Africa followed by Egypt, Sudan and Swaziland (F.O. Lichts, 2012). Sugar consumption in Africa remained stable at about 15 million metric tons. The largest African sugar consuming countries in order of importance were: Egypt, South Africa, Nigeria, Sudan and Kenya. East Africa is a net importer of sugar; production in the year 2011/12 stood at 1,018,572 tons while consumption was 1,501,477 tons creating a deficit of 366,397 tons that was imported (F.O. Lichts, 2012). In the year 2013, Kenya produced 600,179 tons of sugar against 839,798 tons required for consumption creating a deficit of 237,639 tons that was met by importation. The Kenya sugar industry is a major employer and contributor to the national economy with an estimated six million Kenyans deriving their livelihood directly or indirectly from the industry (KSB, 2013).

The sugar deficit in Kenya is caused by among other factors, low cane yields with fluctuating quality in virtually all sugarcane growing zones. Sugarcane performance is affected by climatic, edaphic, agronomic, varietal and indirectly by socio-economic factors .

Sugarcane production in Kenya is mainly rain fed with limited irrigation being undertaken under experimental conditions at KESREF, Kibos and about 500 ha under irrigation at Chemelil (Muturi *et al*., 2007). The erratic rainfall distribution in the last decade may be a factor responsible for persistent low sugarcane yields. Soil fertility depletion in small holder farms that contribute 80-90 % of total supply is also thought to be a fundamental biophysical root cause of the declining sugarcane yields. The low soil fertility is attributed to low inherent soil fertility and loss of nutrients through erosion and crop harvests (Gachene *et al*., 2000). Deficiencies of nitrogen, phosphorous and potassium are also wide spread in Western province leading to low and declining crop yields (Jaetzold *et al.*, 2007). Sugarcane varieties perform well when soils, climate, agronomic practices and socio-economic factors are appropriately addressed. Poor variety performance (low cane and sugar yields) would, therefore, arise from one or more of the environmental factors interacting or acting singly to affect variety performance even if the said variety is of acceptable yield potential. Socio-economic surveys (KESREF 2002, 2003 and 2004) identified high costs of farm inputs, land development and transportation as prohibitive to sugarcane production. Lack of credit facilities, delayed cane payments upon delivery to the factory have also contributed to the farmers' low morale thus affecting sugarcane development and maintenance, leading to low sugarcane yields. Average land size for cane production is declining due to population pressure (Wawire *et al.,* 2007).

Although socio-economic factors are observed to indirectly contribute to low sugarcane yields through poor crop management within the small scale farms, such low yields have also been recorded within the factory nucleus estates. This indicates that factors other than socio-economic issues are contributing to the low sugarcane yields.

1.2 Sugarcane Production in Mumias Sugar Zone (MSZ)

The Sugar belt area served by Mumias Sugar Company (MSC) covers about 60 sq km with 56,000 ha under sugarcane grown in the company owned Nucleus Estate (NE) and nine Out growers (OG) sub-zones. The sub-zones fall in four Counties namely Kakamega, Bungoma, Siaya and Busia. Small hold farms in the target area average 0.6 ha ranging in size from 0.4 - 3.5 ha. Contracted out growers who number about 104,000 supply up to 95% of the cane milled in the entire sugar zone (MSC, 2013).

Growing of sugarcane on the same land over the years with no well defined breaks, rotations or fallow periods between the previous crop and re-plant is a common practice and sugarcane intercropping is inconsistently practiced (Wawire *et al*., 1987). Continuous use of ammonium based fertilizers Diammonium phosphate (DAP) and Urea, and lack of balanced nutrition with Potassium, Calcium and Magnesium replenishment in the sugarcane farms is thought to have lowered soil pH values over the years (KESREF, 2004). Recent soil analysis results indicate that MSZ soils are characterized by low pH ($\leq$ 5.5), low P ($\leq$ 10 ppm), low to moderate K (0.1-0.7 m.e), low Ca and Mg (1-2 m.e.) and low CEC (< 9 m.e.) (MSC, 2013). The monoculture systems may have caused soil degradation which in turn has contributed to low sugarcane yields that averaged only 51 t/ha in the period 2012/13 (KSB, 2013). Further, use of heavy farm machinery for land preparation and cane haulage over the years may have caused soil compaction which in turn could have increased soil bulk densities that may have caused poor cane rooting systems thereby affecting sugarcane water and nutrient uptake, leading to the low cane yields (KESREF 2004).

According to Mutanda (1990), MSZ sugarcane yields for plant crops are largely related to climatic factors especially rainfall. Environmental processes (rainfall, radiation, temperatures) enhance biomass accumulation and improve the cane and sugar yields. Mumias sugar factory is situated 0^{o}21'N and 34^{o} 30'E at 1314 m above sea level. The zone receives bi-modal rainfall ranging from 1500-2000 mm per annum with long rains peaking in April-May and short rains in September-October (Jaetzold *et al.*, 2005). The dominant soil type in the zone is orthic Acrisol (60%) followed by Ferralsol, Nitosol, Cambisol and Planosol (40%). Acrisols are acidic soils with low base status; they are strongly leached but less weathered than Ferralsols. They develop mainly on basement rocks like granite, but also on colluviums from quartzite. The base saturation (BS) of the B horizon is < 50% thus indicating low fertility. Acrisols are rich in Aluminium (Al) and Iron Oxide elements; therefore, nutrient fixation may perhaps be the main chemical constraint, which demands special crop management practices in sugarcane (Jaetzold *et al.*, 2005).

1.3 Problem statement and Justification

Mumias Sugar Company is the leading sugar producer in Kenya. It has potential to produce over 260,000 metric tons of sugar or 50% of total national production and generate over 32 megawatt of electricity out of which 30 megawatts is exportable into the National grid. MSC has also established bio-fuel (ethanol) and water bottling plants. Despite the sweet success story, MSC faces a number of challenges, the major one being declining sugarcane yields both on the well managed company farm (Nucleus Estate) and farmers fields (Out growers). It is estimated that average sugarcane yields declined by about 36% 110 tons/ha (tch) in 1996 to 69 tch in 2006. The yields declined further to only 51 tch in 2012/13 (KSB, 2013) as shown in Figure 1. This has caused great concern to farmers, millers, economists and many others who support the sugar industry as it has forced the factory to crush immature cane or to haul cane over long distances at great cost to meet the daily mill requirement of 8,000 tons cane per day.

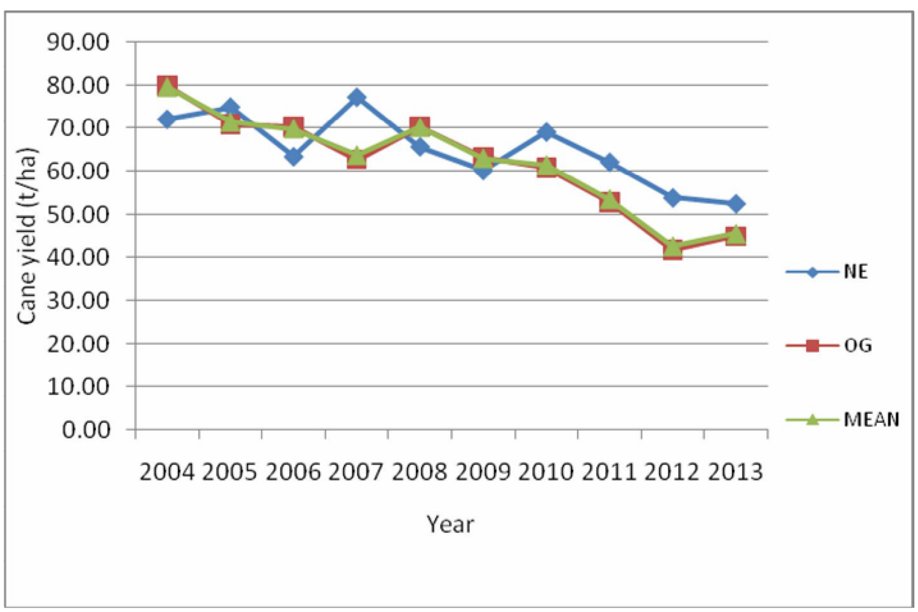


Figure 1: Average sugarcane yields in MSZ (2004-2013)

The sugarcane yield decline in MSC as well as other sugar factories in Kenya has been researched for a long time and it is now known that causes encompass soil, crop, environmental and socioeconomic factors but no research has been done to quantify the contribution of various factors to the decline. The main causes of the decline include land degradation, declining soil fertility, poor performing varieties, high dependence on rainfall which is unstable due to climate change phenomena, inadequate extension services and land fragmentation among many others. However, the main cause of yield decline is deterioration of soil quality due to continuous unsustainable sugarcane production practices. Sugarcane yields in soils managed conventionally have been observed to plateau or reduce over the longer term, both in Australia (Garside *et al.* 1997; Wood, 1985) and S. Africa (Meyer and Wood, 2001), with this often being attributed to soil degradation. The causes of the steep yield decline in MSZ have not been established and documented.

Recent sugar industry policy proposals point to a shift to cane quality based payment systems as opposed to the current sugarcane tonnage system. Several factors including K and soil pH can affect cane quality hence sucrose yield per hectare. Potassium (K) performs a wide range of vital roles including photosynthesis, enzyme activation, and stomatal control and transporting plant sugars. It plays a key role in Nitrogen (N) metabolism such that plants inadequately supplied with K fail to transport nitrate efficiently to the shoots (Krauss, 2004). The effect of K and N and their interaction on sugarcane quality and yield has not been fully investigated. Whether K can improve sugarcane quality (high sucrose content) is an aspect that warrants investigation and documentation. There has been a long standing assumption that K was adequate in the soils of Mumias. Its inclusion in the fertilization policy of the company has not been emphasized.

1.4 Objectives

1.4.1 General Objective

To determine the effect of K, N and various soil amendments on sugarcane growth, yield and quality in MSZ.

1.4.2 Specific Objectives

i) To determine the effects of K, N and their interaction on sugarcane growth, yield and quality.

ii) To determine the effects of P, agricultural lime and their interaction, on sugarcane growth, yield and quality.

iii) To determine the effects of agricultural lime, organic manures and blended fertilizers on sugarcane growth, yield and quality.

iv) To determine the cost-effectiveness of various management options through economic evaluation.

1.5 Hypotheses

i) The application of K will improve sugarcane yield and quality through balanced nutrition.

ii) The management of low soil pH by use of agricultural lime, blended fertilizers and organic manure will influence nutrient release and improve sugarcane yield and quality.

iii) Liming will improve P availability and uptake by sugarcane.

iv) The management options will be agronomically efficient and cost-effective

1.6 Expected Outputs

i) Cost-effective management strategies for low pH and K deficiency in sugarcane production in the Mumias Sugar Zone of Western Province, Kenya.

ii) PhD Thesis on Management Strategies for Low pH and Potassium Deficiency in Mumias Sugar Zone of Western Province, Kenya.

iii) Three Scientific publications on the study subject.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botany of Sugarcane

Sugarcane (*Saccharum*) is a genus of 6 to 37 species of tall perennial grasses native to warm temperate to tropical regions of the world. It belongs to the *Graminae* family and of the *Andropogoneae* tribe. The sugarcane plant is made up of roots, stalks and leaves. The stem exists above ground. It is of economic importance because it is the reservoir for sucrose storage. The stem comprises of nodes, lateral buds and a root band. It is also used as a vegetative propagation material and supports the leaves. The leaves are attached to the stem alternately for efficient capture of sunlight (MSIRI, 2000). Sugarcane is one of the most efficient photo synthesizers, able to convert up to 2-3% solar energy to biomass, being a C4 crop. All of the sugar cane species interbreed, and the major commercial cultivars are complex hybrids (American Alternative Energy Systems Corporation (AAESC), 2008).

2.2 Sugarcane growth and development

2.2.1 Germination

Sugarcane germination is a process of development of small shoots enclosed in the bud scales. This development is affected by both plant physiological and environmental factors mainly temperature and soil moisture. Optimal temperature for germination range between 27-33^oC while soil moisture, particularly in the top 10 cm, is critical for cane setts root development (MSIRI, 2000).

2.2.2 Tillering

This represents the 2nd phase of cane development. Its rate and duration has influence on the subsequent phase and the final yield. Apart from varietal characteristics, tillering is also influenced by light, soil moisture, temperature, nutrients and spacing. The optimal temperature for tiller emergence is 30^oC while nitrogen (N) and phosphorous (P) levels of 100-150 kg/ha N and 80-100 kg/ha P_2O_5 respectively favour tillering. Nitrogen not only influences tiller emergence but also survival. Row spacing of 1.2-1.5 m is recommended in sugarcane (KESREF, 2002).

2.2.3 Ripening

During ripening there is an increase of sucrose content in the sugarcane stalk. The optimal conditions for sucrose accumulation in the stalk are those that favour photosynthesis during the day and reduced growth at night. A mature sugarcane stalk constitutes approximately 75% of the entire plant. It is typically composed of 15-18 % fibre, 12-16 % soluble sugars, 2-3 % non-sugars and 63-71 % water. Ripening is affected by variety, N, soil moisture, sunshine hours and temperature. In sugarcane, sucrose is transported from the leaves to other parts of the plant via the leaf sheath. Sucrose synthesized during a 24 hour period is partly stored in the mature ripening internodes and the rest finds its way to the root system, the apical region and sometimes to the other suckers of the same stool. Both amount and rate of sucrose translocation in sugarcane are affected by environmental factors. Optimal temperature for sucrose translocation is 35^{o}C but no movement occurs at 5^{o}C (MSIRI, 2000). Young stalks contribute more sucrose towards growth process while in the older ones storage predominates (MSIRI, 2000).

2.3 Constraints to sugarcane production

Sugarcane production is sensitive to climate, soil type, irrigation, fertilization, pests and diseases, varieties and the harvest period. In the year 2013, average yield of sugarcane in Kenya was 51 tons/ha compared with a world average of 64.4 t/ha (KSB, 2013). The mean yield in Kenya could potentially be 70-100 tons/ha depending on knowledge and crop management approach in sugarcane cultivation (KESREF, 2004).

2.3.1 Socio-economic factors

Socio-economic surveys (KESREF 2002, 2003 and 2004) identified high costs of farm inputs, land development and transportation as prohibitive to sugarcane production. Lack of credit facilities, delayed cane payments upon delivery to the factory have also contributed to the farmers' low morale thus affecting sugarcane development and maintenance, leading to low sugarcane yields. Average land size for cane production is declining due to population pressure (Wawire *et al.*, (2007). Major cane production costs in the Kenyan sugar industry include: Land preparation, Seed cane, Fertilizer and herbicides, Labour (planting, weeding, fertilizing, harvesting, loading), cane transportation and levies. Ranked overall cost centers in cane production are as follows: Cane transport (28% for Pc and 42% for Rc), Fertilizers (22% for Pc and 31% for Rc), Seedcane (21 % for Pc), (Labour costs (17 % for Pc and 21% for Rc), Levies (18% for Pc and 14% for Rc) and Land preparation; Pc - 13% (Wawire *et al.,* 2007). Cost of production per ha in selected sugar factories was estimated at Ksh 111,433, Ksh 139,537, Ksh 146,412 and Ksh 156,658 for plant crop cane in West Kenya, Mumias, Chemelil and South Nyanza respectively. Ratoon cane costs were estimated at Ksh 61,191, Ksh 73,347, Ksh 78,571 and Ksh 81,535 for West Kenya, Chemelil, Mumias and South Nyanza factories respectively (Figure 2) (Wawire *et al.,* 2007).

Although socio-economic factors are observed to indirectly contribute to low sugarcane yields through poor crop management within the small scale farms, such low yields have also been recorded within the factory nucleus estates where best management practices are observed. This indicates that factors other than socio-economic issues are contributing to the low sugarcane yields (KESREF, 2004).

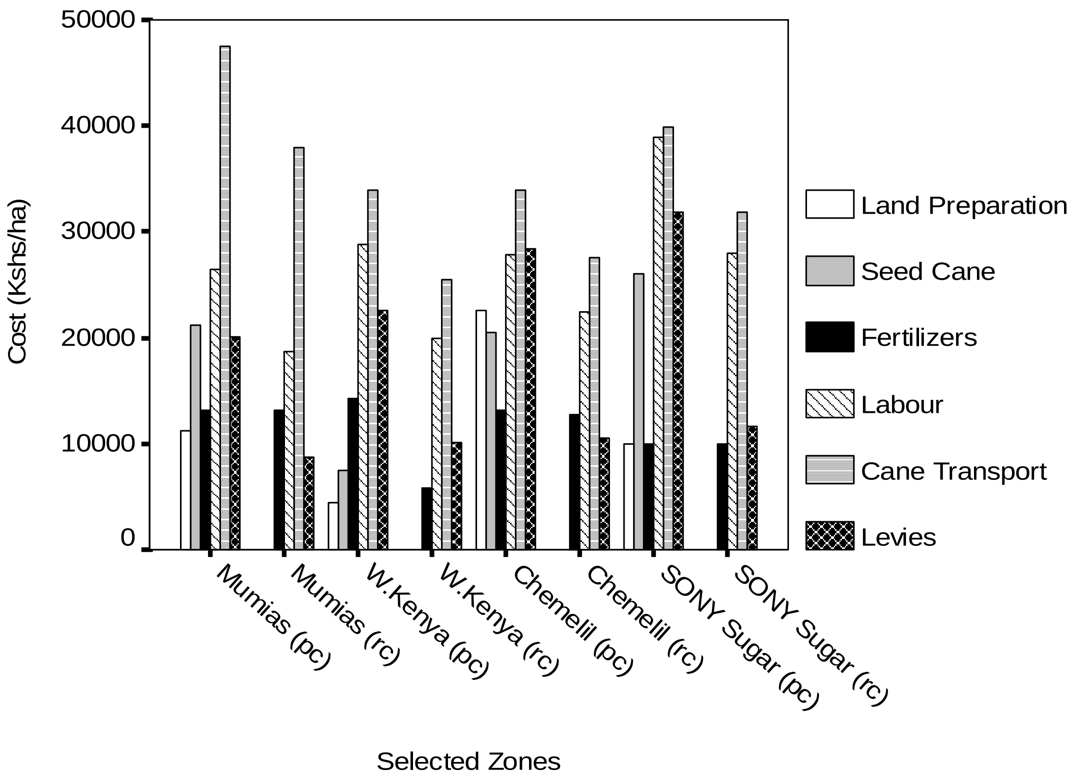


Figure 2: Overall cost centres in cane production by factory

2.3.2 Agronomic practices

Agronomic practices constitute the largest contribution to crop yields; they entail the following aspects to nurture the crop in order to achieve its full yield potential: Land preparation, seed quality and rate, weed control, nutrition, water management, crop protection and harvesting (MSIRI, 2000). Whereas well prepared land is necessary for crop establishment, it also enhances weeds, diseases and pests control. Sugarcane is vegetatively propagated for commercial production through cane setts (stem cuttings). Planting material should be fresh and healthy (disease and pest free) to enhance a well established crop stand. Between 25,000-30,000 setts per hectare or 6-10 t/ha is ideal seed rate (KESREF, 2006).

Weeds are effective competitors with cane for soil moisture, light and nutrients. For example, weeds take up 4 times N and P, and 2.5 times K compared to sugarcane during the first 50 days period (NETAFIM, 2008). Weeds also harbour diseases and pests that affect the cane, thus leading to indirect losses. Weed management practices adapted should ensure weed free field conditions in the first 6 months. This is because sugarcane is planted in wide inter-row spaces, germinates and slowly develops during the same period.

Sugarcane, being a long duration crop producing huge amounts of biomass, is classified as a high water requirement crop though it can tolerate short drought conditions. Water is essential for germination, growth and development, temperature regulation and soil nutrient transport and up-take. In many countries, the crop is mainly produced under irrigated conditions although in Kenya it is produced under rain-fed conditions (KESREF, 2006).

Harvesting of sugarcane should be done at a proper time (18-20 months) to ensure maximum sugar yields with least field losses. When harvesting is done on under-aged or over-aged cane, it leads to losses in cane yield, sugar recovery and juice quality, and also leads to milling problems due to extraneous matter (MSIRI, 2000).

Major nutrient elements in sugarcane production are N, P and K. Of the three major nutrients nitrate-N is volatile and is not adsorbed by soil particles thereby making it subject to leaching losses. Unlike N, P and K are not volatile and are adsorbed by clay particles. Therefore, they are not subject to leaching losses except through eroded soils (Krauss, 2004). If lost to aquatic environment P contributes to eutrophication whereas there is no practical environmental or health hazard known for K (Krauss, 2004).

Nitrogen is important because when applied in in-adequate doses it limits sugarcane productivity while when excessively applied may contaminate underground waters as it is also liable to losses such as leaching, volatilization and de-nitrification. Nitrogen cycle terms are the major contributors to the acidification under cropping systems, and N fertilizer management is likely to be the most critical acidification factor (Moody and Aitken, 1997). Unbalanced fertilization is a cause of low fertilizer use efficiency by plants (Krauss, 2004). Potassium plays a key role in N metabolism, and that plants inadequately supplied with K fail to transport nitrate efficiently to the shoots (Krauss, 2004). Therefore, with inadequate K supply, plant yields remain low since soils depleted in K do not have capacity to supply the element to meet the crop needs.

2.3.3 Crop protection

Diseases and pests weaken the sugarcane crop system through interference with bio-chemical functions resulting in low expression of yield potential. The recorded diseases and pests incidences in western Kenya include: sugarcane smut, sugarcane mosaic virus, rust, brown eye spot and brown stripe; termites, shoot and stalk borers, scale insects and mealy bugs (Rono *et al.*, 2007) and nematodes (Chirchir *et al.*, 2011). Preliminary results indicate that sugarcane yield reduction due to smut disease on susceptible, intermediate tolerant and resistant/immune varieties were: 38%, 17% and 20-33% respectively. Hence, the approach to mitigate the effects of diseases and pests has been through development of tolerant varieties (Nzioki and Jamoza, 2006).

Sugarcane smut is caused by *Ustilago scitaminea* H & P. Sydow., a bacidiomycetes fungus (Rott *et al*., 2000). It was first reported in Natal South Africa in 1877 and has since been reported in all other countries that lie between 20^{o} N and 20^{o} S of the equator. The disease was first reported in Kenya in 1958 in Nyanza and Coastal Provinces. As a result, planting of smut resistant varieties was made compulsory in Kenya in 1963. Presently, sugarcane smut occurs in all sugarcane growing areas of Kenya (Wawire *et al*., 1987; KESREF, 2002). Symptoms of sugarcane smut include black whip like structures from terminal meristem or meristems of lateral buds of infected stalks. The whips reduce the yield and quality of sugarcane (Nzioki *et al*., 2010). The reduction in yield and quality of sugarcane varies widely in different sugarcane growing areas of the world and is dependent mainly on the races of the pathogen present, the sugarcane variety and the prevailing environmental conditions (Lee-Lovick, 1978). The disease may not cause any losses for many years but may reappear to cause extensive crop damage (Ferreira and Comstock, 1989).Primary transmission of smut fungus occurs through planting diseased seed cane. Secondary spread is through windblown spores (James, 1973). Spores in or on soil are carried to different fields via rain or irrigation water where they cause new infections to cane (Agnihotri, 1983; Rott *et al.*, 2000).

Smut is controlled by an integration of several methods. Planting resistant or tolerant cultivars is the most practical, cheap and reliable method. Hot water treatment of seed cane for 20 minutes at 52-54^{o}C or 30 minutes at 50^{o}C gets rid of seed borne smut spores or dormant smut infection. Rogueing of infected stools is another control measure. As the disease is systemic, it is necessary to remove the whole stool during rogueing before emergence of the whip but if the whips have already emerged, they should first be covered with a gunny/plastic bag, removed and burned. Scattering of spores should be avoided during the rogueing operation. Reduction of the number of ratoons is recommended in susceptible cultivars. Any plant crop that has over 10% smut infection should not be ratooned (Agnihotri, 1983). According to Kenya Legal Notice No. 390 of the Plant Protection Ordinance, cultivars that show more than 21% stools smutted in the ratoons are not considered for commercial production and it is illegal to grow such cultivars. Seed protectant fungicides are effective in ridding seed cane of dormant smut spores and/or dormant smut infections (Agnihotri, 1983; Fauconnier, 1993; Rott *et al*., 2000).

Infestation of sugarcane by pink mealy bugs (*Saccharicoccus sacchari* (Cockerell)) is a common occurrence in sugarcane plantations and is of no economic importance. Scale insects (*Eulacapsis tegalensis* Zehnt.) are occasionally noted on the crop from the 9th month to maturity. This is thought to be a response to the sucrose in the stalks as the crop matures (KESREF, 2006). Studies in S. Africa have shown that infestation of sugarcane by stalk borer (*Eldana sccharina* Walker) are exacerbated by high plant N and water stress (Atkinson and Nuss, 1989). Nitrogen overuse can increase susceptibility to lodging, stem cracking and may encourage diseases and pests such the stem borers. These factors need to be taken into account when considering the agronomic management of the crop (Atkinson and Nuss, 1989).

2.3.4 Variety performance

Variety performance is a phenotypic expression (genotype interacting with the environment). Sugarcane varieties perform well when environmental conditions (soils, climate, agronomic practices and socio-economic factors) are appropriately addressed. Poor variety performance (low cane and sugar yields) would therefore arise from one or more of the environmental factors interacting or acting singly to affect variety performance even if the said variety is of acceptable yield potential. Sugarcane yields have not correspondingly improved in the last decade, despite the release of six Kenyan varieties bred for earliness (KESREF, 2002).

Large acreage of sugarcane in Mumias growing zone is still dominated by old varieties: C0 945 (69.8%), C0 421 (14.3 %), and CO 617 (13 %) (KSB, 2012). Recent early to medium maturing varieties like KEN 83737 and KEN 82-472 developed and released for commercial production could not fit well into the current harvesting programs of some sugar factories with low crushing capacities; therefore, their adoption has been slow or nonexistent in some zones due to delayed harvesting (KSB, 2012).

2.3.5 Climatic factors

Sugarcane production in Kenya is mainly rain fed. Some limited irrigation is being undertaken under experimental conditions at KESREF and only 500 ha are under drip irrigation at Chemelil (Muturi *et al*., 2007). Hence, most of the crop is produced under rain fed rather than irrigated conditions. In the last decade rainfall has been erratic and this may have led to the significant drop in sugarcane yields (KESREF, 2002).Other principle climatic components that control cane growth, yield and quality are: solar radiation, temperature, and moisture availability (NETAFIM, 2008).

2.3.6 Soil properties

Soil fertility depletion in small holder farms is the fundamental biophysical root cause of declining per capita food production in Africa and its replenishment should be considered as an investment in natural resource capital (Sanchez and Palm, 1996). Studies have shown that the current soil fertility management practices of recycling crop residues, biomass transfer, short fallows and other organic practices are inadequate to replenish nutrient outflow (Bekunda *et al*., 2002). Consequently, a number of case studies have shown crop yield decline in the East Africa region (Bekunda *et al*., 2002). Low soil fertility is a causal factor for declining sugarcane yields in Kenya (Odada, 1986; Wawire *et al*., 1987; Nyongesa, 1992; Kariaga and Owelle, 1992). The low soil fertility was attributed to low inherent soil fertility and loss of nutrients through erosion and crop harvests with little or no nutrient replenishment through organic and in-organic sources (Gachene *et al*., 2000; Mureithi *et al*., 2000). Soil productivity in the densely populated Western province is low and on the decline (Jaetzold *et al.*, 2005). Deficiencies of N, P and K are wide spread in Western province leading to low and declining crop yields (Jaetzold *et al.*, 2005).

2.3.6.1 Soil physical properties

One of the soil physical properties that constrain crop production is bulk density. High values affect sugarcane crop's roots through increased resistance to root expansion, reduced air supply, thereby enhancing build up of toxic products and risk of water logging due to reduced permeability. A study on Mumias soils, found out that dry bulk densities ranging from 1.40 - 1.76 g/cm^3 restricted sugarcane root growth (Kanabi, 1990). A subsequent study also established that the bulk density of Mumias soils remained high 1.48 – 1.85 g/cm^3 (Muturi *et al.*, 2010). Bulk density in the range of 1.1 – 1.4 g/cm^3 is recommended for sugarcane (KESREF, 2002).

2.3.6.2 Soil chemical properties

The soil chemical property that constrains sugarcane performance is acidification plus presence or absence of minerals (Tang and Rengel, 2003). Soil acidification is a slow natural process that occurs during pedogenesis and can be either accelerated or slowed down by farming practices (Tang and Rengel, 2003). For example, soil acidification trend is accelerated when trash – harvesting replaces pre-harvesting burning and sulphate of ammonium becomes the dominant N-fertilizer (Hartemink, 1998). Major causes of soil acidification in agricultural systems are the imbalances in C and N cycles (Tang and Rengel, 2003). The principle adverse effects of acidity occur at soil pH 5.5 due to dissolution of aluminium (Al) ions and the onset of Al toxicity. Aluminium phytotoxicity results in rapid inhibition of root growth due to impedance of both cell division and elongation, resulting in reduced volume of soil explored by root system and direct influence of Ca and P uptake across cell membrane of damaged roots (Wong and Swift, 2003). This will often lead to reduced sugarcane yield and quality. In contrast, in South Africa, soil aggregate stability (0.5-1.0 mm), high pH values, low Al, Na and high levels of P are reported to be associated with high sugarcane yielding points (Antwerpen *et al.*, 2007).

In the Mumias sugar zone of western Kenya, the continuous use of ammonium based fertilizers, crop removal through harvests, lack of rotation and high precipitation are factors thought to have lowered soil pH values to 4.5-5.4 over the years (MSC, 2012). Acidification of soil also results in loss of exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, a decrease in effective cation exchange capacity (C.E.C), and an increase in exchangeable Al^{3+} (Graham *et al.*, 2002). Adverse acidification decreases water and nutrient retention capacity in soils and reduces biotic activity (Kinraide, 2003).Sugarcane makes heavy demands on soil nutrient reserves as large amounts of nutrients are removed with the harvest. Therefore, commercial sugarcane production is likely to have affected soil conditions over time. The effects of commercial cane production on soil chemical properties in MSZ have not been determined (KESREF,2007).

2.3.6.3 Soil biological properties

Soil organic matter is an indicator of biological activity in the soil as it provides substrate for soil micro-organisms (MSIRI, 2000). The micro-organisms are responsible for converting un-available plant and animal nutrients into forms that can be assimilated by plants. One of the products of soil organic matter decomposition is humus which is one of the most important chemical properties in cation exchange capacity. The organic matter also improves soil structure and water holding capacity (MSIRI, 2000). Both cultural bacteria, *Burkholderia* and fungi, *Trichoderma* are favoured by the presence of high sugarcane root density and assist in control of other pathogenic soil microbes (Antwerpen *et al*., 2007). The soil food web is a potential indicator of soil health (Antwerpen *et al*., 2007).

Soil quality requires the integration of three (3) major components: Sustainable biological productivity, Environmental quality and Plant health. Soil quality indicators or parameters can be used to investigate soil degradation and sustainability under continuous sugar cane production. The indicators/parameters for biological productivity include: Organic matter, Organic carbon, Total nitrogen and C/N ratio; Microbial-Biomass, carbon-Biomass, nitrogen-Biomass and C/N ratio. Chemical parameters include pH, Cation exchange capacity, Exchangeable bases K, Ca, Mg-Base saturation while physical parameters encompass Particle size distribution, Aggregate size distribution, Water stability of aggregates, Bulk density, Water holding capacity and Stabilized infiltration rate. Regular monitoring of these parameters can be used to check the health status of the soil, detect problems early and recommend best management practices (BMPs) which ensures continuous good soil health. The use of organic manures and agricultural lime for soil amendment has not been fully adopted at Mumias.

2.3.6.4 Sugarcane cropping systems

Recent research indicated that sugarcane production could cause a large decline in soil organic matter content and that practices such as green cane harvesting, zero tillage, and use of green manure crops could be promoted to help alleviate the problem (Dominy *et al.,* 2002). Where sugarcane is grown as a monoculture, deleterious fungi and nematodes retard plant establishment and early growth that leads to the decline of sugarcane yields (Pankhurst *et al.,* 2004). Results from 10 years of yield decline research undertaken by the Sugar Yield Decline Joint Venture in Australia indicated the decline, though expressed through adverse effects of pathogens on sugarcane root system, is a complex issue caused by a number of factors out of balance in sugarcane cropping system (Garside *et al.,* 2005). Further, research showed that long term monoculture, uncontrolled traffic from heavy machinery use and excessive tillage together with those practices that deplete soil organic matter contribute to the yield decline (Garside *et al.,* 2005; Pankhurst *et al.,* 2003). Practices in the sugarcane cropping systems that conserve organic matter, break the monoculture, control the traffic and minimize tillage were the most appropriate ways to combat yield decline (Garside *et al.,* 2005; Pankhurst *et al.,* 2003).

2.3.6.5 Nutrient cycles

Nutrient cycling in an agricultural system is important because any nutrient imbalance may cause soil acidification or in-efficient nutrient use. Carbon commonly enters and leaves terrestrial systems as carbon dioxide ($C0_2$), therefore if growth and development processes are in equilibrium there is little acidification caused by carbon cycle (Bolan and Hedley, 2003). Sulphur cycling within eco-system generates little soil acidity because it enters as $S0_4^{-2}$ in fertilizers and rainfall and similarly leaves as $S0_4^{-2}$ in drainage and in plant products (Bolan and Hedley, 2003). Further, $S0_4^{-2}$ ions are strongly adsorbed by soil particles therefore it is not subject to leaching. Nitrogen cycle terms are the major contributors to the acidification under cropping systems, and N fertilizer management is likely to be the most critical acidification factor (Moody and Aitken, 1997). Nitrogen leaving a terrestrial system with more negative charge than the form of N entering the cycle acidifies the soil, whereas N leaving in a form with less negative charge than the form entering the cycle makes the soil alkaline (Bolan and Hedley, 2003). In the former case, the charge balance in the soil is achieved through the release of H^+ ions accompany the leaving nitrate anion (NO_3^-), leading to soil acidification. In the later case, the charge balance is achieved through the release of OH^- or HCO_3^- ions, leading to soil alkalization. Unlike SO_4^{2-} ions that are strongly adsorbed on the soil particles, most soils have less ability to retain NO_3^- ions making it susceptible to leaching (Bolan and Hedley, 2003). Therefore, soil acidification is accelerated by N inputs into farming systems in excess of the plant needs. The continuous use of acid-forming DAP and Urea in sugarcane cultivation in MSZ is a likely cause of soil acidification.

2.3.6.6 Concepts of nutrient use efficiency (NUE)

Nutrient use efficiency (NUE) is the balance between nutrient input and output in an agricultural system. Since agricultural systems contain complex components (soils, soil microbes, roots, plants and crop rotations) improvement in any of the components may not lead to overall efficiency of the cropping system (Snyder *et al*., 2007). For N, three ways of expressing use efficiency are; N agronomic (that is yield) efficiency (NAE), N-recovery (that is uptake) efficiency (NRE) and N-physiological (that is utilization) efficiency (NPE) (Simmonis, 1988). The NAE is the yield increase as a result of fertilizer N application per unit of fertilizer N applied while NRE is the proportion of fertilizer N applied recovered in the plant tissue and NPE is yield increase as a result of total N uptake (both soil- and fertilizer derived N) (Janssen, 1998). In case of sugarcane grown for sugar, yield is both fresh cane weight and sucrose content at maturity. Currently, sugarcane is being paid on fresh cane tonnage but there are future plans to pay on quality (that is sucrose content). Phosphorous use efficiency is the efficiency with which plant accumulates P at a given level of soil P or the amount of dry matter produced per unit of P accumulated (Elliot and Lauchli, 1985). Potassium use efficiency is defined in both uptake and utilization efficiencies (Janssen, 1998). It is important to use N efficient crop varieties to produce high yields and reduce environmental contamination (Lee *et al*., 2004). One of the keys to maximize nitrogen use efficiency is to manage N sources to minimize N losses due to leaching, denitrification and volatilization (Nielsen, 2006). In South Africa, results from over 200 trials showed that responses to applied N can be highly variable. Nitrogen use efficiency by sugarcane can be influenced by ecological factors such as season, rainfall, nature of soil, variety, irrigation, N- form, rate, timing and method of N placement (Meyer *et al*., 2007). Another cause of low fertilizer use efficiency is unbalanced fertilization. For example, plants inadequately supplied with K fail to transport nitrate efficiently into the shoot (Krauss, 2004). Under South African conditions, though K is required to increase sugarcane production, superfluous absorption of the K leads to a decrease in leaf photosynthesis rate and stem sugar accumulation (Azama *et al.*, 2007).

In Kenya, information on sugarcane NUE is lacking. Therefore, there is need to undertake such studies in order to improve the current sugarcane performance. Further, lack of K in the current sugarcane production systems is an indication of unbalanced fertilizer use which is likely to have contributed to in-efficient N use thereby making the latter prone to losses such as leaching, de-nitrification and volatilization. The effects of balanced fertilizer application on NUE have not been determined in Mumias (.KESREF, 2002).

2.4 Potassium (K) in sugarcane

Potassium plays a key role in sugarcane metabolism. It is the most abundant cation accumulating in the cell sap of the plant. By acting mainly as an enzyme activator, K is fundamental to the synthesis and translocation of sucrose from the leaves to the storage tissues in stalks. It also plays a significant role in controlling the hydration and osmotic concentration within the stomata guard cells (Kwong, 2000). Responses of sugarcane to K fertilization reflect to a large extent the available K status of soil, significant responses being obtained only in soils low in available K. Evaluating the response of sugarcane to K fertilization must also take into account the semi-perennial nature of sugarcane plant. In this context as sugarcane is able to mine the soil of its K reserves, responses to K fertilizers are frequently not observed in plant cane and often even in first and second ratoons (Kwong, 2000). The importance of a balanced nutrition particularly between nitrogen (N) and K in the attainment of the maximum yield should also not be overlooked. In general sugarcane responds to K fertilizers by an increase in cane yield without any change in sucrose concentration in the cane. As an excessive uptake of K by the sugarcane depresses the recovery of sucrose during milling, K fertilization of sugarcane must be kept just adequate to produce an optimum yield and to help regulate maturity so that maximum sugar is recovered from the millable canes (Kwong, 2000). Accumulation of K by sugarcane is most rapid during the first 6 months. The nutrient is subject to luxury consumption by sugarcane; therefore, it is important to find the optimum level of fertilization. Potential K uptake by sugarcane is in the range of 145-480 kg/ha K_2O (Kwong, 2000). Potassium deficiency effects in sugarcane are localized with mottling or chlorosis; leaf borders and tips show yellow-orange chlorosis, and necrotic lesions are located between veins along margins and leaf tips. Older leaves may become entirely brown or ‘fired’. Red discoloration of upper surfaces of the midrib may occur. Under moderate K deficiency, young leaves remain dark green and stalks become slender. Long-term deficiency stress may affect meristem development, indicated by spindle distortion and ‘bunched’ or fan appearance (MSIRI, 2000).

Potassium depleted soils have in-efficient N fertilizer use even if recommended doses are applied (Krauss, 2004). Yara (2011) has observed that it is important to have sufficient potassium available to utilize the assimilated nitrogen in the cane to bring about good crop maturity and ensure that reducing sugars are converted to sucrose. In terms of quality, K promotes sugar synthesis and its translocation to the storage tissue. So adequate potassium nutrition is important for high sugar yields. Yield response curves from most countries (India, Brazil, Pakistan and Guatemala) where K is used commonly show that rates per annum range from 150-250 kg K/ha (180-300 kg/ha K_2O) (Rossetto *et al*., 2004). On crop quality, Phonde *et al*. (2005) observed that adequate potassium supply ensured a higher sugar yield. In addition, potassium improved Pol quality and reduced fibre content (Malavolta, 1994; Mahamuni *et al*., 1975; Khosa, 2002). Juice purity was also improved; however, very high levels of potassium reduced sucrose levels (Perez and Melgar, 2002; Meyer, 2013 *pers. comm*.). The improvement in juice quality is thought to be due to an increase in activity of sucrose synthesizing enzymes which also help increase the sucrose yield (Jayashree *et al*., 2008). Mahamuni *et al*. (1975) observed that maximum sucrose extraction required low levels of reducing sugars (commonly 0.5%) and higher K use could help secure this at the same time as increasing yield. However, luxury consumption of potassium adversely affected the crystallization of sugar and resulted in poor recovery of raw and refined sugar leading to higher sugar losses in molasses. Excess K also increased the ash content in sugarcane juice. In general sugarcane responded to K fertilizers by an increase in cane yield without any change in sucrose concentration in the cane. Since excessive uptake of K by the sugarcane depresses the recovery of sucrose during milling, K fertilization of sugarcane must be kept just adequate to produce an optimum yield and to help regulate maturity so that maximum sugar is recovered from the millable canes (Singh *et al*., 2008).

Gupta and Shukla (1973) have reported that K and N need to be in balance; that while N responses can be small, use of K alongside N ensures better yields of cane. In S.E Asia, Haerdter and Fairhurst (2003) reported a 16% N recovery when traditional N and P were applied to maize. The crop's N recovery improved to 76% in plots treated with N, P and K as K is involved in N metabolism. Phosphorous and K recoveries also improved respectively from 1 to 22 % in P and from 13 to 61 % in balanced N, P and K application.

Potassium can be applied as a straight fertilizer or as part of a blended or compound fertilizer with N and P. Potassium Chloride (KCl) commonly referred to as muriate of potash (MOP) is the most common source used in agriculture, accounting for about 95% of all potash fertilizers used worldwide (NETAFIM, 2008). However, there are reports that K has a highly negative correlation with sucrose content in juice of sugarcane in Okinawa, Japan (Kawamitsu *et al.*, 1997). This has been attributed to the possibility that the chloride ions (Cl^-) as well as K itself, are related to the decrease in sugar content.

2.5 Nitrogen (N) in sugarcane

Nitrogen is essential in sugarcane metabolism affecting essential physiological processes. It is one of the main building blocks of proteins and essential for photosynthesis and sugar production. Nitrogen helps provide strong productive growth and high yielding, high dry matter production leading to cane with high sugar contents. However, used in excess, N prolongs vegetative growth, delaying maturity and ripening. Late application of N lowers the juice quality hence sugar quality characteristics, including sugar purity, colour and clarification (MSIRI, 2000). When applied in in-adequate doses, N limits sugarcane productivity while when excessively applied may contaminate underground waters as it is also liable to losses such as leaching, volatilization and de-nitrification. Nitrogen cycle terms are the major contributors to the acidification under cropping systems, and N fertilizer management is likely to be the most critical acidification factor (Moody and Aitken, 1997).

Studies (Meyer *et al*., 2007; Perez and Melgar, 1998) have shown that crop response to nitrogen fertilization is varied and complex, and often linked to availability of nitrogen held in soil organic matter. Correct N nutrition not only increases cane yield, but also improves the sucrose content in the harvested cane. This response to N rate varies with variety. It is important though to balance nitrogen use with potassium, so as to maximize sugar conversion, content and juice quality (Meyer and Wood, 2001). N responses also vary with region, temperature, number of sunny days and watering regime.

In Australia's dry sunny region of Burkedin N application significantly raised yields compared to other rain fed regions. Used in excess, nitrogen prolonged vegetative growth, delaying maturity and ripening. Late nitrogen also reduced sugar quality characteristics, including sugar purity, colour and clarification (Yara, 2011).

In Brazil, 120-150 kg/ha N is a common application rate in ratoon crops in both burnt and green cane. Responses are only slightly lower if vinasse (ethanol distillery stillage) has been applied. However, in other sugarcane producing countries up to 200 kg/ha of N is commonly applied particularly from the third ratoon onwards. Plant and ratoon crops will also benefit from higher rates of N fertilizer when grown in sandy soils or where natural soil nitrogen supplies are low. Roots can also store significant nitrogen that will be used in the next crop (Vitti, 2003). The use of mill by products also influences N requirements.

The amount of nutrients they supply needs to be taken into account when assessing a fertilizer programme for the coming season (Meyer *et al.*, 2007).

It is important though to balance N use with K, so as to maximize sugar conversion, content and juice quality. Responses to N also vary with region, temperature, number of sunny days and watering regime. Results from Australian studies in the dry sunny region of Burkedin, indicate that N application significantly raised yields compared to other rain fed regions; however, used in excess, N prolonged vegetative growth, delaying maturity and ripening. Late N application also reduced sugar quality characteristics, including sugar purity, colour and clarification (Yara, 2011).

2.6 Agricultural lime and soil amelioration

Agricultural lime is a soil additive made from pulverized limestone or chalk; the primary active component is calcium carbonate. Additional chemicals vary depending on the mineral source and may include calcium oxide, magnesium oxide and magnesium carbonate. Lime increases the pH of acidic soils under which the major plant nutrients N, P and K, as well as Ca and Mg, show a marked reduction. Liming also mitigates the effects of P fixation by Al and Fe oxides at low pH thus making the P available to sugarcane plants (NETAFIM, 2008).

Leong (1980) reports that in Malaysia, liming of sugarcane on acid latosols and lateritic latosols increased cane tonnage by about 10 t/ha principally through increases in the production of millable stalks as well as increases in stalk length and internode number.

Singha (2006) also reports that agricultural lime applied on a clay loam soil with pH 4.8 significantly increased sugarcane yield by 5.2 to 16.9% over the control. Residual effect of liming on the cane yield in ratoon sugarcane crop were significant. However, a study in S. Africa (Meyer, 1976) contradicts Singha's finding by reporting that in one trial on a high N mineralizing soil, lime treatments significantly depressed sucrose % cane from an average of 13.4 % in the control to 12.4 % in the lime treatment. The decline was accompanied by a general increase in foliar-N values in excess of 2.5 %.

Yadav *et al*. (2009) report that in acid soils, deficiency of Ca and Mg is usually encountered, hence application of limestone at 1-3 t/ha to the plant crop in acid soils of Thiruvella, Kerala, India improved the yield and juice quality of subsequent ratoons. Soon and Arshad (2005) found a significant increase in crop yield and soil labile N pools due to liming with zero tillage compared to liming with conventional tillage.

In North Carolina, USA (Colleen, 2004) reported that agricultural lime increased fertilizer use efficiency and saved money. The study concluded that money spent on fertilizer is not well invested unless soil pH is properly adjusted first. Elsewhere, Abreha Kidanemariam *et al*. (2013) found out that yield and yield attributes of wheat showed significant response to the main effects of lime and fertilizer applications. Fertilizer x lime interaction effect was significantly different in grain yield, total biomass and N and P uptake. The highest agronomic efficiency and apparent recovery efficiency were also recorded in the soils treated with limes along with recommended P and NP fertilizers.

CHAPTER THREE

3.0 EFFECTS OF POTASSIUM AND NITROGEN APPLICATION ON SUGARCANE GROWTH, YIELD AND QUALITY

3.1 Abstract

Sugarcane fertilization in Kenyan plantations is largely concentrated on Nitrogen (N) and Phosphorus (P). Use of Potassium (K), secondary nutrients and micronutrients is altogether missing. Recent soil analysis results indicate that soils in the Mumias Sugar zone (MSZ) of western Kenya that account for 50-60 % of national sugar production are K- deficient. In examining the quality factor in sugarcane payment systems as envisaged in recent legislation, adoption of balanced nutrition by inclusion of K would help improve sugar cane productivity and enhance sugar recovery. This paper reports the effect of K, N and their interaction on sugarcane yield and juice quality on acrisols. Four experiments were established in several locations from 2009-2011. The treatments included a factorial combination of four rates of K at 0, 60, 120 and 180 kg/ha K_2O and four rates of N at 0, 46, 92 and 138 kg/ha N. Recommended basal phosphate was included in every plot at 92 kg/ha P_2O_5. Each experiment was harvested after 18 months of growth. Results showed that application of K and N consistently increased sugarcane tillering, stalk number, height and inter-node length. Cane and sugar yields per ha generally increased particularly at rates of 60-120 kg/ha K_2O and 46-92 kg/ha N. Increase in sugar yield due to K application was attributed to improved juice quality (Pol % cane). Agronomic efficiency (AE) was higher in plots supplied with K along with N . Nitrogen and K_2O

application rates that produced optimum cane yields were: N = 46kg/ha and K_2O = 60 kg/ha; however, economically profitable rates were N = 46-92 kg/ha and K_2O at 60 kg/ha. Productivity gains did not offset costs when rates were higher than 120 kg/ha of K_2O and 138 kg/ha of N respectively. The results imply that the inclusion of K in the sugar cane fertilization regime at Mumias will be beneficial. An initial rate of 60kg/ha K_2O (2 bags of 50 kg muriate of potash is recommended on soils with K-deficiency. The results suggest that with K fertilization the current N recommendation of 120-150 kg N/ha could be reduced to only 80-120 kg/ha due to better N utilization from the interaction with K.

3.2 Introduction

A major challenge facing the sugar industry in Kenya is declining crop yields over the last two decades. Sugar production in the year 2013 totaled 600,179 metric tons (MT) against 839,798 MT required for consumption creating a deficit of 237,639 MT that was met by importation (KSB, 2013). The sugar deficit was caused by among other factors, low cane yields with fluctuating quality in virtually all sugarcane growing zones. In the Mumias Sugar Zone of Western Kenya that contributes 50-60 % of national sugar production, mean sugarcane yields declined from 110 tons/ha in 1996 to only 55 t/ha in 2012 (Figure 1). Average Pol in cane was 11.16% compared with the industry target of 13.50 % (KSB, 2012).

The sugarcane production practices in the Mumias sugar zone (MSZ) are thought to have led to serious deterioration of the soil physical and chemical quality parameters which appears to be the main contributory factor to the sharp yield decline over the years. Growing of sugarcane on the same land is a common practice with no well defined breaks, rotations or fallow periods between the previous crop and re-plant (Wawire *et al.*, 2007). Sugarcane fertilization in the plantations is largely concentrated on nitrogen (N) and phosphorus (P) with N and P sources being Urea and DAP respectively. The current recommendation for sugarcane is 120-150 kg/ha N and 80-95 kg/ha P_2O_5. Balanced nutrition through use of potassium (K), secondary nutrients and micronutrients is altogether missing as K was thought to be adequate in the soils (Wawire *et al.*, 2007). However, recent laboratory analysis results indicate that soils in MSZ are characterized by low pH ($\leq$ 5.5), low P ($\leq$ 10 ppm), low to moderate K (0.1-0.7 m.e), low Ca and Mg (1-2 m.e.) and low CEC (< 9 m.e.) (MSC, 2012).

Sugarcane is capable of rapidly depleting soil of nutrients, particularly potassium. Under South African conditions, for instance, the aerial parts of an adequately fertilized 12 month old rain fed plant cane crop has been reported to contain 214 kg K/ha (Wood, 1990). Under irrigation, a cane crop of similar age and variety may remove as much as 790 kg K/ha. In the Histosols of Florida, an average of 343 kg K/ha was removed from the field at harvest of the sugarcane (Coale *et al.*,1993). In Mauritius, more than 250 kg K/ha was recovered by sugarcane from soils high in available K even when no K was applied (Cavalot *et al.*,1990). In Australia the average kg K/ha in the aboveground biomass of a crop of 84 tonnes cane per ha was 198 kg K/ha (Chapman, 1996). It is thus clear that for the long term and sustainable use of sugarcane lands, the removal of such large quantities of K needs to be balanced by adequate K inputs if a decline in soil fertility is to be avoided – hence the importance of K manuring in sugarcane cultivation.

Jaetzold *et al*. (2005) reported low and declining soil fertility in the densely populated Western Kenya with deficiencies of N, P and K wide spread leading to low and declining crop yields. Krauss (2004) reported that K depleted soils have in-efficient N fertilizer use even if recommended doses are applied. Potassium plays a key role in N metabolism, and plants inadequately supplied with K fail to transport nitrate efficiently to the shoots (Krauss, 2004). Yadav *et al*. (2009) observed that adoption of balanced and judicious use of all nutrients can help improve cane productivity and enhance sugar recovery by enhancing resistance against biotic and abiotic stresses, and better synthesis and storage of sugar. Potassium plays a key role in sugarcane metabolism and is known to be actively involved in the translocation of sucrose (MSIRI, 2000). Gupta and Shukla (1973) observed that K and N need to be in balance; that while N responses can be small, use of K alongside N ensures better yields of cane. Yara (2011) have observed that it is important to have sufficient potassium available to utilize the assimilated nitrogen in the cane to bring about good crop maturity. Kolln *et al*. (2013) have observed that increases in soil K content increased sugarcane productivity in Brazil. In S.E Asia, Haerdter and Fairhurst (2003) reported a 16% N recovery when traditional N and P were applied to maize. The crop's N recovery improved to 76% in plots treated with N, P and K as K is involved in N metabolism. Phosphorous and K recoveries also improved respectively from 1 to 22 % in P and from 13 to 61 % in balanced N, P and K application.

Nitrogen is essential in sugarcane metabolism affecting essential physiological processes. It is one of the main building blocks of proteins and essential for photosynthesis and sugar production (MSIRI, 2000). Correct N nutrition not only increases cane yield, but also improves the sucrose content in the harvested cane. However, excessive N use can reduce sugar quality, leading to lower sucrose contents and discolouration of sugar crystals (Meyer and Wood, 2001). This response to N rate varies with variety. It is important though to balance N use with K, so as to maximize sugar conversion, content and juice quality (Meyer and Wood, 2001). In Australia's dry sunny region of Burkedin, N application significantly raised yields compared to other rain fed regions. However, used in excess, N prolonged vegetative growth, delaying maturity and ripening. Late N also reduced sugar quality characteristics, including sugar purity, colour and clarification (Yara, 2011).

In examining the quality factor in sugarcane payment systems, K and N fertilization become a key consideration because they affect yield and sucrose accumulation. Potassium is not included in the current fertilizer regime at Mumias. Whether K can improve sugarcane quality (high sucrose content) is an aspect that warrants investigation and documentation. The objective of this study, therefore, was to determine the effects of K, N and their interaction on sugarcane growth, yield and quality.

3.3 Materials and methods

3.3.1 Experimental site

Four experiments were conducted in 2009-2011 on the miller owned Nucleus estate (NE) fields D 51 and E 35 and out growers (OG) fields at Musanda and Khalaba in the Mumias sugar zone (0^{o}21'N and 34^{o} 30'E at 1314 m above sea level). The zone receives bi-modal rainfall ranging from 1500-2000 mm per annum with long rains peaking in April-May and short rains in September-October each year. The dominant soil type in the zone is orthic Acrisol (60%) followed by Ferralsol, Nitosol, Cambisol and Planosol (40%) (Jaetzold *et al*., 2005).

3.3.2 Soil characterization and rainfall data

Prior to planting, soil was sampled at 0-30 cm and 30-60 cm depth for determination of textural class, bulk density and chemical properties. Soil pH was determined in a soil suspension with a soil: water ratio of 1:1(w/v) using a glass electrode and pH meter S/N K 3386 Mettler Toledo 345. Soil organic matter (C), extractable P, K and total N were determined by the Calorimetric, Mehlich Double Acid, Flame photometry and Kjeldahl procedure (Blamire, 2003), respectively. Exchangeable cations were extracted with neutral 1N NH_4Oac and determined by flame emission for Na and K and by EDTA titration for Ca and Mg (Okalebo *et al*., 2002).

Rainfall received throughout the crop growth period of 18 months was recorded and compared with the long term mean (LTM).

3.3.3 Experimental design and treatments

The experimental design was RCBD with a 4×4 factorial arrangement of the treatments and three replications. Treatments included four rates of K (0, 60, 120 and 180 kg/ha K_2O) and four rates of N (0, 46, 92 and 138 kg/ha N). Fertilizers Urea (46 % N) and Muriate of potash MOP (60 % KCl) were used as N and K source respectively. Gross plot size was 1.5 m x 6 rows x 10 m = 90 m^2 in NE and 1.2 m x 6 rows x 10 m = 72 m^2 in OG based on the standard practice for spacing in the two sectors. The net plot size for data collection was 1.5 m x 4 rows x 10 m= 60 m^2 in NE and 1.2 m x 4 rows x 10 m= 48 m^2 in OG. Recommended basal P at 92 kg/ha P_2O_5 was supplied from single superphosphate (SSP) in plots where no N was applied or diammonium phosphate (DAP) where N was applied at 46, 92 or 138 kg/ha N. The rate of N applicable was adjusted based on the content in DAP. All fertilizers were hand applied using graduated cups specific for each treatment after weighing on a Salter top balance in the laboratory. Fertilizer MOP was applied into the furrow alongside DAP at planting while Urea was applied as top dress at 3 months after planting. Urea was incorporated into the soil in each plot to avoid contamination in the neighbouring plots. Other necessary agronomic practices like weed management, , pest and disease observation were carried out as per (KESREF, 2002) recommendations.

Predominantly grown sugarcane variety CO 945 was used in the study as a test crop. Variety CO 945 is a medium maturing sugarcane cultivar harvested between 17 and 20 months. Apparent sucrose content at maturity is estimated at 12-14 % with fibre at 15-18 % (Jagathesan *et al.*,1990). All experiments assessed the plant crop data over 18 months growth period in two seasons.

Plate 1: Variety CO 945 with characteristic corky cracks, the main identification feature

3.3.4 Emergence and tillering

A physical count of emerged shoots was done at 30, 45 and 60 days after planting in the net plots. Average emergence was calculated as the highest number of emerged shoots expressed as a percentage (%) of the expected.

Tillering was assessed from 3-9 months after planting. A physical count of the total number of shoots in the net plot was done and extrapolated to establish the number of tillers/ha.

3.3.5 Foliar sampling and analysis

Nutrient uptake by the plants was monitored monthly from 3-9 months after planting from the four net rows. Each time the 3rd leaf below the top visible dew lap (TVD) or spindle was sampled. Ten leaves per row were collected making 40 leaves per plot. The centre of gravity of each bundle of leaves was determined by placing on a specifically constructed table. The bundle was chopped with a sharp knife at the fulcrum and at the 20 cm measured length of the remainder towards the tip. Midribs of the sub sample were removed before weighing and recording the sample. Samples were then oven dried at 80^{o}C for 24 hours. Dry leaves were ground in an apex cutter. The sample was weighed and placed in a clean dry polythene bag ready for analysis. Foliar N, P and K were analyzed by Kjeldahl, Molybdenum blue and Flame photometry methods respectively (Okalebo *et al.*, 2002).

3.3.6 Stalk height, inter-node length and population

Stalk height and the number of internodes per stalk were recorded on 20 plants in the net plot at harvest to establish the inter-node length. The randomly selected plants were 2 m from the edge of either side of the plot to avoid the border effect. Stalk height and inter-node length were expressed in cm. Physical count of all stalks in the net plot was done and extrapolated to establish the stalk population per ha.

3.3.7 Cane yield, sugar yield, juice quality and fibre %

Cane yield at harvest was determined by weighing all stalks from the net plots. A tripod stand and calibrated suspension balance S/N: C1080JC/574-1267 Avery were used. The weight (kg) realized was extrapolated to determine the cane yield in t/ha. Cane quality parameters at harvest were determined from 4 stalks per net plot. Each stalk was chopped into 3 equal portions i.e. top, middle and bottom. The sub samples were chopped into smaller pieces and shredded in a Jeffco cutter machine model WD02 Jefress Engineering

Pty Ltd. Juice extraction was done in the disintegrator machine model WD02 Jefress Engineering Pty Ltd. A shredded sample of 1000 g was put in the cold digester with 2 liters of water and left to run for 20 minutes. The sample was sieved and 150 ml put in a conical flask. One gram of Lead sub acetate was added for clarification before filtration. From the sieved and digested juice, Brix (total dissoluble solids) was determined directly from the Refractomer Abbemat-WR Anton Paaroptotec GmbH. From the clarified juice, Pol (apparent sucrose) was read on a Polarimeter model AA-5 Optical Activity Ltd. A crushed and sieved cane sample of 100 g was placed in an oven model BR 6000 Binder world at 105^{o}C for 4 hours then re-weighed for moisture determination. From Brix, Pol reading and moisture % calculations, cane juice quality (Pol % cane), fibre % cane and sugar yield per ha were derived by the South African Sugar Technologists Association (SASTA) formulae (Schoonees-Muir *et. al*., 2009):

Pol % cane = ^{o}Brix*[3-(fibre %*0.0125)], where Brix = total dissoluble solids,

Fibre % cane = [(100-(Brix*3) + moisture %)/(1-(Brix*0.0125)],

Sugar yield (t/ha) = Pol % cane*cane yield (t/ha).

3.3.8 Diseases and pests

Diseases and pests were observed monthly from 3-9 months after planting. Smut was scored on percentage of tillers infected versus overall tiller population per ha in accordance with the International Society of Sugarcane Technologists (ISSCT) rating (MSIRI, 2000). Sampling for pests was done as documented by Sutherland *et al*. (1996). Pink sugarcane mealy bugs (*Saccharicoccus sacchari* (Cockerel)) and scale insects

(*Eulacapsis tegalensis* Zehnt.) were targeted due to their occurrence in the zone and the likely negative effect on juice quality.

3.4 Agronomic Efficiency (AE)

Agronomic efficiencies (AE) for K and N application were evaluated. The AE is the yield increase as a result of fertilizer K, N application per unit of fertilizer K, N applied (Singh *et al*., 2008). In case of sugarcane grown for sugar, yield is both fresh cane weight and sucrose content at maturity. AE was arrived at by the formula:

$$AE = \frac{\text{Increase in yield (kg sugarcane)}}{\text{Nutrient applied (kg nutrient)}} \quad \text{or} \quad AE = \frac{\text{Increase in yield (kg sugar)}}{\text{Nutrient applied (kg nutrient)}}$$

3.5 Economic evaluation

The costs and sugarcane yield from the K x N treatments were recorded. Cost-benefit analysis was done using Gross returns (GR), Net returns (NR) and Value Cost Ratios (VCR) computed as described by Jennifer Greene and Andrew Stellman (2007) and Shehu *et al*. (2010) where:

Gross Return (GR) = sugarcane yield (t/ha) x cost per ton (Ksh)

Net Return (NR) = gross return (Ksh) – total variable costs (Ksh)

Value Cost Ratio (VCR) = value of increased yield / cost of fertilizer used

3.6 Data analyses

The data collected on cane growth and yield parameters were subjected to analysis of variance using GenStat Release 13.2 (PC/Windows 7) Copyright 2010, VSN

International Limited and means compared by Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance (Steel and Torrie, 1987). Agronomic efficiencies (AE) were calculated as described by Singh *et al*. (2008) and Value Cost Ratios (VCR) computed as described by Jennifer Greene and Andrew Stellman (2007) and Shehu *et al*. (2010).

3.7 Results

3.7.1 Emergence (%)

In the NE experiment of season 1, setts fertilized with K or N had high % emergence compared to the control. However, fertilization beyond 46 kg/ha N and 60 kg/ha K_2O/ha did not change the % emergence. In season 2, there was no clear pattern for cane emergence but highest emergence was recorded at 138 kg/ha N and 120 kg/ha K_2O (Table 1).

In OG, the K×N interaction significantly ($p \leq 0.05$) affected sugarcane emergence in both seasons. In season 1, cane emergence increased with addition of K and N at 60 kg/ha K_2O and 46 kg/ha N respectively, relative to the control beyond which there was no further increase. In season 2, emergence increased only at 138 kg/ha N when no K was added and at 180 kg/ha K_2O when no N was added (Table 2).

3.7.2 Tillering

In Nucleus Estate (NE) experiment, sugarcane tillering was significantly ($p \leq 0.05$) affected by the K×N interaction in both seasons (Tables 3 and 4). Tiller numbers increased with K application up to 120 kg/ha K_2O at 0-46 kg/ha N beyond which tillering did not differ.

In Outgrowers (OG) season 1, tillering was high in setts that received K or N fertilizer relative to the control. Similarly in season 2, high tiller numbers were also recorded in setts that received K fertilizer and N up to 92 kg/ha N.

Table 1: Emergence (%) in the Nucleus Estate

Season 1	*N rate (kg/ha N)*	*K rate (kg/ha K_2O)*				*Mean*
		0	*60*	*120*	*180*	
	0	63.00	72.97	66.50	70.53	*68.25*^{c}
	46	72.33	80.97	74.37	75.47	*78.29*^{a}
	92	70.60	74.37	71.10	74.50	*72.64*^{b}
	138	76.43	75.47	76.43	78.57	*76.72*^{a}
	Mean	70.59^{b}	75.94^{a}	72.10^{b}	74.77^{ab}	
	$LSD_{0.05}$	(N) = 2.71***, (K) = 2.71*, (N×K) = 5.42*, CV = 4.4%				
Season 2	*0*	66.7	78.7	60.0	71.7	*69.2*^{bc}
	46	57.0	58.0	75.7	74.3	*66.2*^{c}
	92	69.3	78.3	78.7	75.7	*75.5*^{a}
	138	62.3	79.0	89.3	69.0	*74.9*^{ab}
	Mean	63.8^{b}	73.5^{a}	75.9^{a}	72.7^{a}	
	$LSD_{0.05}$	(N)= 5.84**, (K) = 5.84***, (N×K) = 11.69***,CV = 9.8 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 2: Emergence (%) in Out growers

Season 1	*N rate (kg/ha N)*	*K_2O (kg/ha)*				*Mean*
		0	*60*	*120*	*180*	
	0	62.31	71.67	73.17	71.17	70.11^{c}
	46	71.83	77.63	76.43	68.80	79.09^{a}
	92	68.60	76.43	77.77	75.97	75.19^{b}
	138	74.34	68.80	74.50	68.37	75.06^{b}
	Mean	69.27^{c}	73.63^{ab}	75.47^{a}	71.08^{ab}	
	$LSD_{0.05}$	(N) = 3.17***, (K) = 3.17*, (N×K) = 6.35*, CV = 5.1%				
Season 2	*0*	55.67	60.33	60.67	64.33	60.25^{c}
	46	58.00	66.67	65.33	66.67	64.17^{b}
	92	60.33	67.33	68.33	71.33	66.83^{a}
	138	62.67	69.67	70.67	70.33	68.33^{a}
	Mean	59.17^{b}	66.00^{a}	66.25^{a}	68.17^{a}	
	$LSD_{0.05}$	(N)= 2.53***, (K) = 2.53*, (N×K) = 5.07*, CV = 4.7%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 3: Tillers/ha (`000) in the Nucleus Estate

Season 1	N rate (kg/ha N)	K rate (kg/ha K_2O)				Mean
		0	*60*	*120*	*180*	
	0	119.96	121.48	142.85	140.78	*131.29*[c]
	46	135.59	153.37	141.07	155.19	*146.31*[b]
	92	147.89	142.78	149.85	154.89	*148.85*[a]
	138	155.93	144.30	151.26	152.89	*151.09*[a]
	Mean	139.84[c]	140.48[c]	146.26[b]	150.94[a]	
	$LSD_{0.05}$	(N) = 2.43***, (K) = 2.43***, (N×K) = 4.86***, CV = 2.0%				
Season 2	*0*	113.11	135.49	125.88	143.00	*129.37*[c]
	46	119.14	145.39	143.21	133.60	*135.34*[b]
	92	143.42	134.30	138.37	143.35	*139.86*[a]
	138	132.19	135.42	145.10	148.19	*140.23*[a]
	Mean	126.97[c]	137.65[ab]	138.14[ab]	142.03[a]	
	$LSD_{0.05}$	(N)= 4.32***, (K) = 4.32*** , (N×K) = 8.63***,CV = 3.8 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 4: Tillers/ha ('000) in the Out growers

Season 1	N (kg/ha)	K_2O (kg/ha)				Mean
		0	*60*	*120*	*180*	
	0	161.30	216.40	201.90	228.50	202.00[b]
	46	166.60	204.20	255.70	192.20	204.70[b]
	92	155.00	171.80	226.30	246.20	199.80[b]
	138	170.20	215.30	249.90	257.60	238.30[a]
	Mean	163.30[c]	201.90[b]	233.40[a]	231.10[a]	
	$LSD_{0.05}$	(N) = 6.9***, (K) = 6.9***, (N×K) = 13.82***,CV = 3.9%				
Season 2	*0*	103.41	138.28	130.09	131.18	128.37[bc]
	46	110.45	129.29	125.85	131.49	125.02[c]
	92	117.32	145.72	143.52	136.65	134.08[a]
	138	131.18	131.49	129.75	128.49	131.95[ab]
	Mean	115.59[b]	136.20[a]	134.03[a]	133.61[a]	
	$LSD_{0.05}$	(N)= 3.9*** (K) = 3.9*** ,(N×K) = 7.81***, CV = 3.6 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

3.7.3 Foliar N (%) content

In the NE experiment for season 1, there were no significant differences ($p \leq 0.05$) in foliar N content with K or N application (Table 5). In season 2, nitrogen application resulted in higher foliar N, the decrease was not pronounced.

In the OG experiment in season 1, foliar-N content was high in all plots that received either K or N fertilizer but was lowest in the control treatment. In season 2, foliar-N was high in treatments that received K, further increase in K did not result in differences in foliar N (Table 6).

3.7.4 Foliar P (%) content

In season 1of the NE experiment, there was no significant ($p \leq 0.05$) response in foliar-P content with application of either K or N. However, in season 2, foliar-P was high in all treatments that received K, except the control (Table 7).

In the OG experiment of season 1, significant foliar-P content was recorded with K application at 180 kg/ha K_2O with 46 kg/ha N treatment. In season 2, however, foliar P content was only lowest in the control treatment (Table 8).

Table 5: Foliar N (%) in the Nucleus Estate

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	60	120	180	
	0	1.70	1.71	1.76	1.78	*1.74*
	46	1.71	1.76	1.79	1.84	*1.78*
	92	1.72	1.74	1.78	1.79	*1.76*
	138	1.84	1.71	1.77	1.94	*1.82*
	Mean	1.74	1.73	1.78	1.84	
	$LSD_{0.05}$	(N) = 0.17^{ns}, (K) = 0.17^{ns}, (N×K) = 0.35^{ns}, CV = 11.9%				
Season 2	*0*	2.20	2.21	2.02	2.07	*2.12^{d}*
	46	2.35	2.01	2.47	2.50	*2.33^{b}*
	92	2.07	2.56	2.52	2.75	*2.4^{a}*
	138	2.02	2.24	2.47	2.28	*2.25^{c}*
	Mean	2.16^{c}	2.26^{b}	2.37^{a}	2.40^{a}	
	$LSD_{0.05}$	(N)= 0.05***, (K) = 0.05***, (N×K) = 0.11*** ,CV = 2.8 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 6: Foliar N (%) in the Out growers

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	*60*	*120*	*180*	
	0	1.45	2.15	2.14	1.89	*1.91^{b}*
	46	2.17	2.20	2.14	2.21	*2.18^{a}*
	92	2.15	2.19	2.22	2.11	*2.1^{a}*
	138	2.15	2.23	2.22	2.22	*2.21^{a}*
	Mean	2.01^{b}	2.19^{a}	2.18^{a}	2.11^{a}	
	$LSD_{0.05}$	(N) = 0.10***, (K) = 0.10***, (N×K) = 0.19***, CV = 5.4%				
Season 2	*0*	1.61	1.91	1.91	1.73	*1.79^{d}*
	46	1.75	2.00	2.03	1.82	*1.90^{c}*
	92	1.88	2.40	2.15	2.06	*2.12^{a}*
	138	1.85	1.99	2.22	2.06	*2.03^{b}*
	Mean	1.77^{c}	2.08^{a}	2.08^{a}	1.92^{b}	
	$LSD_{0.05}$	(N)= 0.07***, (K) = 0.07***, (N×K) = 0.14***, CV = 4.3%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 7: Foliar P (%) in the Nucleus Estate

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	*60*	*120*	*180*	
	0	0.19	0.20	0.18	0.18	*0.19*
	46	0.18	0.20	0.19	0.19	*0.19*
	92	0.18	0.20	0.18	0.22	*0.19*
	138	0.19	0.21	0.19	0.20	*0.19*
	Mean	0.19	0.20	0.18	0.19	
	$LSD_{0.05}$	(N) = 0.02^{ns}, (K) = 0.02^{ns}, (N×K) = 0.04^{ns}, CV = 11.9%				
Season 2	*0*	0.06	0.11	0.12	0.13	*0.11^{a}*
	46	0.10	0.11	0.13	0.13	*0.12^{a}*
	92	0.10	0.12	0.13	0.13	*0.12^{a}*
	138	0.11	0.12	0.13	0.12	*0.12^{a}*
	Mean	0.09^{b}	0.12^{a}	0.13^{a}	0.13^{a}	
	$LSD_{0.05}$	(N) = 0.01*(K) = 0.01*, (N×K) = 0.02*,CV = 10.2%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 8: Foliar P (%) in the Out growers

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	*60*	*120*	*180*	
	0	0.17	0.18	0.19	0.17	*0.18^{a}*
	46	0.17	0.16	0.16	0.23	*0.18^{a}*
	92	0.14	0.16	0.16	0.16	*0.16^{a}*
	138	0.18	0.19	0.18	0.17	*0.18^{a}*
	Mean	0.17^{a}	0.18^{a}	0.18^{a}	0.18^{a}	
	$LSD_{0.05}$	(N) = 0.03^{ns} (K) = 0.03^{ns}, (N×K) = 0.06^{ns} CV = 22.9%				
Season 2	*0*	0.09	0.11	0.10	0.12	*0.11^{b}*
	46	0.12	0.11	0.12	0.12	*0.12^{a}*
	92	0.10	0.11	0.13	0.14	*0.12^{a}*
	138	0.14	0.10	0.15	0.14	*0.13^{a}*
	Mean	0.11^{b}	0.11^{b}	0.13^{a}	0.13^{a}	
	$LSD_{0.05}$	(N)= 0.01***, (K) = 0.01***,(N×K) = 0.02***,CV = 9.9 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

3.7.5 Foliar K (%) content

In the NE experiment of season 1, foliar-K content did not change with K application except with N application of 46 kg/ha N where it was higher than the control. In season 2, all K treatments resulted in high foliar K compared with the control (Table 9). However, no differences in foliar K were recorded among the K treatments.

In the OG experiment, foliar-K content increased significantly with K application in 46 kg/ha N and 92 kg/ha N treated canes in season 1. Similarly, application of K resulted in high foliar K in all N treated canes except 138 kg/ha N (Table 10).

3.7.6 Stalk height (cm)

In the NE season 1 experiment, stalk height significantly ($p \leq 0.05$) increased with K application of 60-120 kg/ha K_2O at N levels up to 92 kg/ha N. however, at N level of 138 kg/ha N, increase in K had no effect on stalk height. In season 2, stalk height was increased with K application only in 138 kg/ha N treated canes. Shortest stalks were recorded in the control treatment (Table 11).

In the OG experiment, stalk height was not affected by K application except in control and 92 kg/ha N treated canes in season 1. In season 2, stalk height increased to a maximum at 60 kg/ha K_2O with increase in N application up to 92 kg/ha N. however, stalk height decreased with increase in K from 120 to 180 kg/ha K_2O for 138 kg/ha N treated canes (Table 12).

Table 9: Foliar K (%) in the Nucleus Estate

Season 1	N (kg/ha)	K_2O (kg/ha)				Mean
		0	60	120	180	
	0	0.93	1.15	0.97	0.90	0.99
	46	0.78	1.06	0.80	1.17	0.95
	92	0.90	0.98	0.89	1.03	0.95
	138	1.04	1.09	1.10	0.93	1.04
	Mean	0.91^{b}	1.07^{a}	0.94^{a}	1.01^{a}	
	$LSD_{0.05}$	(N) = 0.14^{ns}, (K) = 0.14*, (N×K) = 0.27*, CV = 16.5%				
Season 2	0	0.73	1.01	0.82	0.86	0.85^{c}
	46	0.76	0.94	1.05	2.37	1.28^{a}
	92	0.86	1.02	1.04	1.03	0.99^{b}
	138	0.88	1.05	1.04	0.94	0.98^{b}
	Mean	0.81^{c}	1.00^{b}	0.99^{b}	1.30^{a}	
	$LSD_{0.05}$	(N)= 0.05*** (K) = 0.05***, (N×K) = 0.10***, CV = 6.0 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 10: Foliar K (%) in the Out growers

Season 1	N (kg/ha)	K_2O (kg/ha)				Mean
		0	60	120	180	
	0	0.82	0.85	0.84	1.02	0.88
	46	0.43	0.74	1.07	0.98	0.81
	92	0.73	0.85	0.78	1.04	0.85
	138	1.02	0.98	1.04	0.76	0.80
	Mean	0.69^{c}	0.81^{bc}	0.93^{ab}	0.95^{a}	
	$LSD_{0.05}$	(N) = 0.13^{ns}, (K) = 0.13*, (N×K) = 0.26*, CV = 18.9%				
Season 2	0	0.68	0.69	0.93	0.98	0.82^{c}
	46	0.88	0.90	0.95	0.91	0.91^{b}
	92	0.86	1.03	1.00	1.05	0.99^{a}
	138	0.82	0.75	1.00	0.95	0.88^{b}
	Mean	0.81^{b}	0.85^{b}	0.97^{a}	0.97^{a}	
	$LSD_{0.05}$	(N)= 0.04***, (K) = 0.04***,(N×K) = 0.07***, CV = 4.7 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 11: Mean stalk height (cm) in the Nucleus Estate

Season 1	N (kg/ha)	K_2O (kg/ha)				Mean
		0	60	120	180	
	0	221.6	235.07	245.87	256.27	*239.70* ^{c}
	46	238.9	242.30	251.20	257.97	*247.60* ^{b}
	92	246.8	248.83	258.07	256.80	*252.62* ^{a}
	138	249.2	261.80	248.23	248.10	*251.83* ^{a}
	Mean	239.13 ^{c}	247.00 ^{b}	250.84 ^{ab}	254.78 ^{a}	
	LSD $_{0.05}$	(N) = 4.68***, (K) = 4.68***, (N×K) = 9.37***,CV = 2.3 %				
Season 2	*0*	232.37	254.43	254.60	257.37	249.73 ^{b}
	46	252.60	266.70	286.43	269.90	268.92 ^{a}
	92	270.63	251.07	263.37	258.13	260.80 ^{a}
	138	263.90	255.03	261.70	290.67	267.82 ^{a}
	Mean	254.90 ^{b}	256.84 ^{b}	266.53 ^{ab}	269.04 ^{a}	
	$LSD_{0.05}$	(N)= 12.03** (K) = 12.03*, (N×K) = 24.07*, CV = 5.5%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 12: Mean stalk height (cm) in the Out growers

Season 1	N (kg/ha)	K_2O (kg/ha)				Mean
		0	60	120	180	
	0	94.50	105.60	110.07	108.00	*104.54*
	46	111.30	106.43	102.93	107.20	*106.97*
	92	97.77	102.37	115.53	110.37	*106.51*
	138	103.40	107.67	106.50	108.00	*106.39*
	Mean	101.74 ^{b}	105.52 ^{ab}	108.76 ^{a}	108.00 ^{a}	
	LSD $_{0.05}$	(N) = 4.93 ^{ns}, (K) = 4.93*, (N×K) = 9.85*, CV = 5.6%				
Season 2	*0*	157.10	173.60	162.60	163.30	*164.15* ^{b}
	46	159.50	179.90	165.80	170.90	*169.03* ^{b}
	92	174.50	190.50	180.50	178.00	*180.80* ^{a}
	138	188.70	187.00	173.80	178.30	*181.95* ^{a}
	Mean	169.95 ^{b}	182.75 ^{a}	170.68 ^{b}	172.62 ^{ab}	
	$LSD_{0.05}$	(N)= 10.1*, (K) = 10.1*, (N×K) = 20.2*, CV = 6.3%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

3.7.7 Inter-node length (cm)

In NE season 1, inter-node length was not affected by K or N application except in 46 kg/ha N treated canes with K level at 120 kg/ha K_2O. In season 2, there was no difference in inter-node length at all levels of K and N except at 180 kg/ha K_2O with in 46 and 138 kg/ha N treated canes (Table 13).

In the OG experiment of season 1, inter-node length increased with K application at 120 kg/ha K_2O in the control and 92 kg/ha N treated canes. In season 2, inter-node length was not affected at all levels of K and N except at 120 kg/ha K_2O in 46 kg/ha N treated canes (Table 14).

3.7.8 Millable stalks

In season 1 of the NE experiment, stalk population increased significantly ($p \leq 0.05$) with K application at 120 kg/ha K_2O in the control and 138 kg/ha N treated canes. In season 2, stalk population increased with K application at 60 and 180 K_2O in 46 kg/ha N treated canes (Table 15).

In the OG experiment, stalk numbers increased with K application at 60 kg K_2O at all levels of N except at 92 kg/ha N in season 1. In season 2, K application at 60 kg/ha K_2O increased stalk population at all levels of N except 138 kg/ha N. Generally, low stalk population was recorded in the control treatment (Table 16).

Table 13: Mean inter-node length (cm) in the Nucleus Estate

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	60	120	180	
	0	10.78	10.21	10.52	11.04	*10.64*
	46	9.96	10.42	11.29	10.82	*10.62*
	92	10.58	10.89	10.84	10.75	*10.76*
	138	10.49	11.03	11.05	10.60	*10.79*
	Mean	10.45^{b}	10.64^{ab}	10.92^{a}	10.80^{a}	
	LSD $_{0.05}$	(N) = 0.28^{ns}, (K) = 0.28**, (N×K) = 0.56**, CV = 3.2%				
Season 2	*0*	9.67	9.23	9.87	9.70	*9.62*
	46	9.60	9.70	10.37	10.57	*10.06*
	92	9.90	9.67	9.90	9.70	*9.79*
	138	9.57	10.03	9.93	10.63	*10.04*
	Mean	9.68^{b}	9.66^{b}	10.02^{ab}	10.15^{a}	
	$LSD_{0.05}$	(N)= 0.45^{ns}, (K) = 0.45*, (N×K) = 0.91*, CV = 5.5%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 14: Mean inter-node length (cm) in the Out growers

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	60	120	180	
	0	4.43	4.83	5.03	5.10	*4.85*
	46	4.77	4.90	4.60	4.77	*4.76*
	92	4.43	4.23	4.80	5.10	*4.64*
	138	4.73	4.90	4.90	4.53	*4.77*
	Mean	4.59	4.72	4.83	4.88	
	$LSD_{0.05}$	(N) = 0.22^{ns}, (K) = 0.22*, (N×K) = 0.44*, CV = 5.5%				
Season 2	Nutrient	K_0	K_{60}	K_{120}	K_{180}	*Mean*
	0	5.90	6.80	6.60	6.30	*6.40^{b}*
	46	6.30	7.40	7.50	6.30	*6.88^{b}*
	92	7.30	7.10	6.70	7.30	*7.10^{ab}*
	138	7.70	7.10	7.80	7.40	*7.50^{a}*
	Mean	6.80	7.10	7.15	6.83	
	$LSD_{0.05}$	(N) = 0.51*, (K) = 0.51^{ns}, (N×K) = 1.02*, CV = 5.7 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 15: Millable stalks/ha ('000) in the Nucleus Estate

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	60	120	180	
	0	107.67	109.97	114.77	120.37	*113.19* [a]
	46	120.77	128.43	117.93	124.97	*123.03* [a]
	92	124.77	114.63	120.13	122.47	*120.50* [a]
	138	115.97	109.77	124.40	116.27	*116.60* [a]
	Mean	117.29 [a]	115.70 [a]	119.31 [a]	121.02 [a]	
	LSD $_{0.05}$	(N) = 3.42***, (K) = 3.42*, (N×K) = 6.84***, CV = 3.5 %				
Season 2	*0*	94.33	107.28	99.67	113.22	*103.62*[b]
	46	89.56	115.11	113.39	105.78	*105.96*[b]
	92	113.56	106.33	109.56	113.50	*110.7* [a]
	138	104.67	107.22	114.89	117.33	*111.03*[a]
	Mean	100.53[c]	108.99[b]	109.37[ab]	112.46[a]	
	$LSD_{0.05}$	(N)= 3.42***, (K) = 3.42***,(N×K) = 6.84***,CV = 3.8 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 16: Millable stalks/ha ('000) in the Out growers

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	*60*	*120*	*180*	
	0	85.97	101.27	93.10	86.97	*91.82*[b]
	46	79.03	95.63	88.80	110.30	*93.44*[b]
	92	91.43	98.40	94.00	88.80	*93.16*[b]
	138	91.50	109.23	101.17	103.53	*101.36*[a]
	Mean	86.98[c]	101.13[a]	94.27[b]	97.40[b]	
	LSD $_{0.05}$	(N) = 3.59***,(K) = 3.59*, (N×K) = 7.19***,CV = 4.5 %				
Season 2	*0*	83.61	111.81	105.18	114.58	*103.80*[b]
	46	89.31	104.54	101.76	108.75	*101.09*[b]
	92	94.86	117.82	116.04	104.91	*108.41*[a]
	138	106.06	106.32	110.49	103.89	*106.69*[a]
	Mean	93.46[b]	110.12[a]	108.37[a]	108.03[a]	
	$LSD_{0.05}$	(N)= 3.16***,(K) = 3.16***,(N×K) = 6.31***,CV = 3.6 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

3.7.9 Cane yield (t/ha)

In the NE experiment, K application at all levels of N increased the cane yields in season1; however, differences among the K treatments were not significant ($p \leq 0.05$). In season 2 except for cane that received 46 kg/ha N, application of K led to high cane yields. Similar to season 1, there were no differences in sugarcane yields among the K treated canes (Table 17 and Figure 3 and 4).

For OG grown sugarcane, high yields were observed in treatments where K was applied at 60 and 180 kg/ha K_2O compared with the control in season 1. In cane that received 46 and 92 kg/ha N, sugarcane yields were high with application of K at 120 and 180 kg/ha K_2O. In season 2, increase in K level led to increase in cane yield for sugarcane which received increasing levels of N to 92 kg/ha N; however, in cane that received N at 138 kg/ha N there was no difference in the yields. Generally, increase in N application led to increased sugarcane yields ((Table 18 and Figure 5 and 6).

3.7.10 Juice quality (Pol % cane)

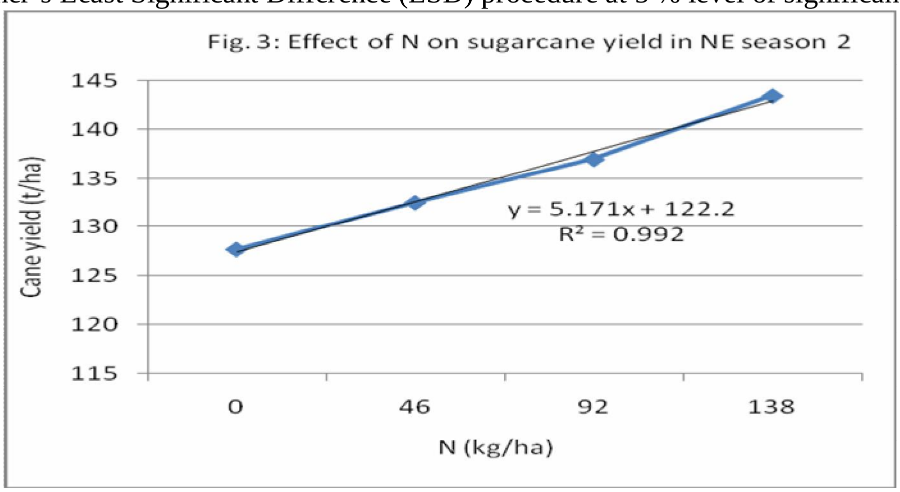
In the NE experiment, Pol % cane increased with K application at all levels of N in both seasons; however, there was no difference among the K treatments. Generally, Pol % cane increased with incremental K levels but dropped with incremental N levels and was lowest in canes that were treated with 138 kg/ha N and no K (Table 19 and Figure 5).

In the OG experiment of season 1, K application increased Pol % cane significantly($p \leq 0.05$) at all levels of N; however, there was no difference among the K treatments. In season 2, the same pattern was observed except there were differences in Pol % cane with K application beyond 120 kg/ha K_2O (Table 20 and Figure 6). Generally, Pol % cane dropped with increase in N application particularly in canes that were not treated with K.

Table 17: Cane yield (t/ha) in the Nucleus Estate

Season 1	N (kg/ha)	K_2O (kg/ha)				Mean
		0	60	120	180	
	0	101.70	114.17	114.70	119.67	112.56 [c]
	46	111.70	126.77	125.17	134.63	124.57 [a]
	92	116.77	125.77	127.73	125.57	123.96 [ab]
	138	107.00	124.87	121.00	132.00	121.22 [b]
	Mean	109.29[c]	122.89[b]	122.15[b]	127.97[a]	
	$LSD_{0.05}$	(N) = 2.83***,(K) = 2.83***,(N×K) = 5.66***,CV = 2.8 %				
Season 2	0	122.20	123.40	125.83	139.43	127.72[d]
	46	130.10	130.90	142.60	126.43	132.51[c]
	92	123.07	130.80	145.90	148.10	136.97[b]
	138	124.67	149.53	146.73	152.93	143.47[a]
	Mean	125.01 [c]	133.66 [b]	140.27 [a]	141.72 [a]	
	$LSD_{0.05}$	(N)= 1.63***,(K) = 1.63***,(N×K) = 3.26***,CV = 3.6 %				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance



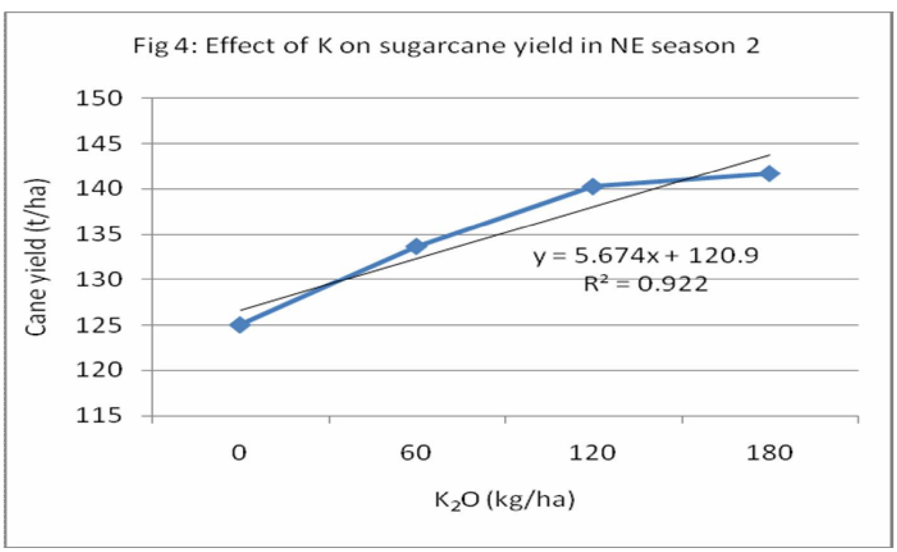
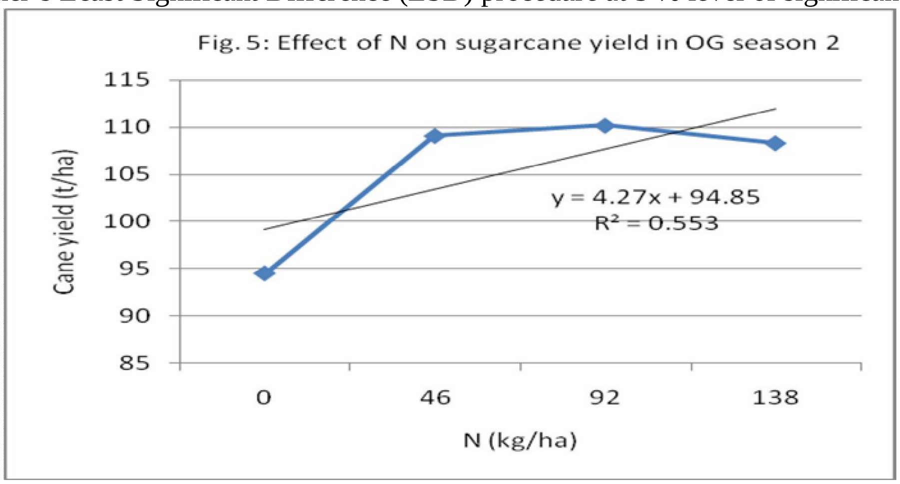


Table 18: Cane yield (t/ha) in the Out growers

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	*60*	*120*	*180*	
	0	88.60	100.87	76.80	111.60	*94.47*[b]
	46	86.87	102.93	128.97	117.67	*109.11*[a]
	92	88.67	91.47	125.17	123.87	*107.2*[a]
	138	103.40	87.80	114.07	128.10	*108.34*[a]
	Mean	91.88[c]	95.77[c]	111.25[b]	120.31[a]	
	$LSD_{0.05}$	(N) = 4.05***, (K) = 4.05***, (N×K) = 8.10***,CV = 4.6 %				
Season 2	*0*	65.08	67.67	68.10	74.20	*64.92*[b]
	46	65.70	69.30	75.63	68.50	*69.28*[b]
	92	66.90	79.70	82.87	95.67	*81.28*[a]
	138	69.93	88.63	85.03	88.97	*83.14*[a]
	Mean	62.56[c]	76.33[b]	77.91[b]	81.83[a]	
	$LSD_{0.05}$	(N)= 2.61***,(K) = 2.61***,(N×K) = 5.23***,CV = 4.2 %				

*significant ** highly significant; *** very highly significant, ns- not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance



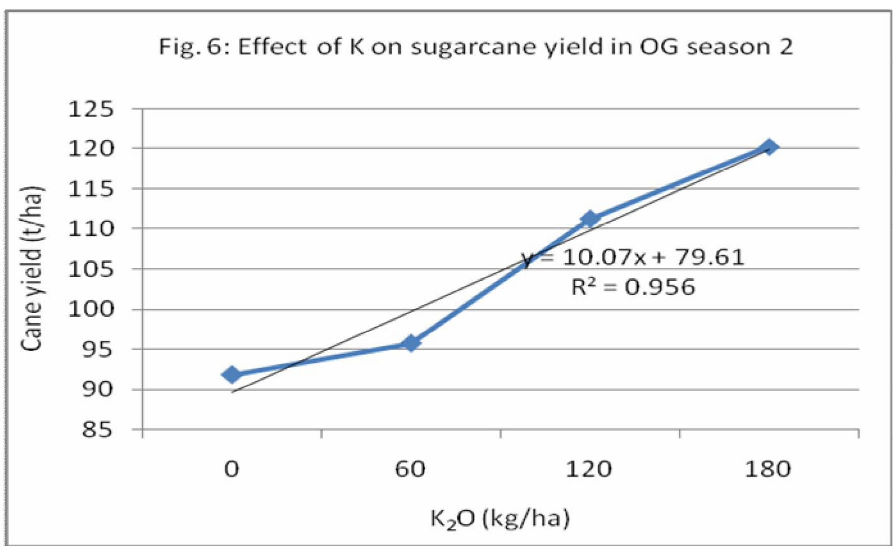


Table 19: Pol % cane in the Nucleus Estate

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				Mean
		0	60	120	180	
	0	14.27	14.27	14.43	14.57	14.39^{a}
	46	14.33	14.37	14.38	14.70	14.44^{a}
	92	13.47	13.77	14.23	13.81	13.82^{b}
	138	13.11	13.89	14.25	14.38	13.91^{b}
	Mean	13.80^{b}	14.08^{b}	14.32^{ab}	14.37^{a}	
	$LSD_{0.05}$	(N) = 0.28***,(K) = 0.28***,(N×K) = 0.57*, CV = 2.4%				
Season 2	*0*	13.64	14.03	14.31	14.60	14.15^{a}
	46	13.26	13.88	13.96	13.99	13.77^{b}
	92	12.55	13.55	13.65	13.98	13.44^{c}
	138	12.51	12.69	13.18	13.25	12.91^{d}
	Mean	12.99^{d}	13.54^{c}	13.78^{b}	13.96^{a}	
	$LSD_{0.05}$	(N)= 0.02***,(K) = 0.02***,(N×K) = 0.04***,CV = 0.2%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 20: Pol % cane in Out growers

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	60	120	180	
	0	13.78	14.20	14.46	14.45	*14.22^{a}*
	46	13.79	14.13	14.42	14.43	*14.19^{a}*
	92	13.67	14.41	14.39	14.44	*14.23^{a}*
	138	13.47	13.89	13.95	14.38	*13.92^{b}*
	Mean	13.68^{b}	14.16^{a}	14.31^{a}	14.43^{a}	
	$LSD_{0.05}$	(N) = 0.18*, (K) = 0.18***, (N×K) = 0.37*, CV = 1.5%				
Season 2	*0*	13.03	13.50	13.77	14.48	*13.70^{a}*
	46	12.91	13.03	13.73	14.27	*13.49^{b}*
	92	12.31	12.55	14.10	14.15	*13.28^{c}*
	138	12.03	12.28	13.21	13.55	*12.77^{b}*
	Mean	12.57^{d}	12.84^{c}	13.70^{b}	14.11^{a}	
	$LSD_{0.05}$	(N)= 0.13***,(K) = 0.13***,(N×K) = 0.26***,CV = 1.2%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

3.7.11 Sugar yield (t/ha)

In NE season 1, sugar yield increased significantly ($p \leq 0.05$) with K application at all levels of N (Table 21). In season 2, the same pattern was observed where sugar yield increased with increase in K application at all levels of N except for sugarcane that received 46 kg/ha N where yield decreased with K application at 180 kg/ha K_2O.

In the OG experiment of season 1, sugar yield increased with increase in K application at all levels of N (Table 22). In season 2, sugar yield, though generally low due to low cane yields at the study site, increased with K application at all levels of N.

3.7.12 Fibre % cane

In season 1 of the NE experiment, there was no difference in fibre % cane with K application at 60 kg/ha K_2O at all levels of N except 0 kg/ha N; however, K application at 120 kg/ha K_2O gave significant ($p \leq 0.05$) differences in fibre % cane with N application at 92 and 138 kg/ha N relative to 60 kg/ha K_2O. Incremental K up to 180 kg/ha K_2O also gave differences in fibre % cane relative to 120 kg/ha K_2O with N application at 46 kg/ha N. In season 2, K application at 120 and 180 kg/ha K_2O increased fibre % cane relative to the control and 60 kg/ha K_2O (Table 23).

In Out growers, there was no significant difference ($p \leq 0.05$) in fibre % cane among the treatments in season 1 except where K was applied at 60 kg/ha K_2O and N at 138 kg/ha N. In season 2, K application at 180 kg/ha K_2O increased fibre % cane at all levels of N relative to the control except at 46 kg/ha N where a significant drop in fibre was recorded (Table 24).

Table 21: Sugar yield (t/ha) in the Nucleus Estate

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	60	120	180	
	0	15.94	16.31	16.55	17.44	*16.56* [a]
	46	14.58	18.22	18.00	19.77	*17.64* [a]
	92	15.72	17.32	18.17	17.35	*17.14* [a]
	138	14.04	17.34	17.24	18.99	*16.90* [a]
	Mean	15.07 [a]	17.30 [a]	17.49 [a]	18.39 [a]	
	$LSD_{0.05}$	(N) = 0.52*, (K) = 0.52***, (N×K) = 1.03*, CV = 3.6%				
Season 2	*0*	17.67	17.32	18.01	20.36	*18.34* [a]
	46	17.25	18.17	19.91	17.69	*18.26* [a]
	92	17.95	17.73	19.93	20.71	*19.08* [a]
	138	15.60	18.97	19.34	20.26	*18.54* [a]
	Mean	17.12 [a]	18.05 [a]	19.30 [a]	19.76 [a]	
	$LSD_{0.05}$	(N)= 0.23***,(K) = 0.23***,(N×K) = 0.45***,CV = 1.5%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 22: Sugar yield (t/ha) in the Out growers

Season 1	*N (kg/ha)*	*K_2O (kg/ha)*				*Mean*
		0	60	120	180	
	0	12.21	14.32	14.11	16.12	*14.19* [c]
	46	12.70	14.85	18.86	16.63	*15.76* [a]
	92	12.10	13.27	18.01	17.79	*15.32* [a]
	138	13.26	12.61	16.46	18.88	*15.30* [a]
	Mean	12.57 [b]	13.77 [b]	16.84 [a]	17.38 [a]	
	$LSD_{0.05}$	(N) = 0.59***,(K) = 0.59***,(N×K) = 1.18***, CV = 4.7%				
Season 2	*0*	8.48	9.14	9.37	10.75	*9.44* [b]
	46	7.96	9.03	10.37	9.78	*9.29* [b]
	92	8.24	10.00	11.68	13.54	*10.87* [a]
	138	8.42	10.88	11.24	12.05	*10.65* [a]
	Mean	8.28 [d]	9.76 [c]	10.67 [b]	11.53 [a]	
	$LSD_{0.05}$	(N)= 0.34***,(K) = 0.34***,(N×K) = 0.67***,CV = 4.1%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 23: Fibre % cane in the Nucleus Estate

Season 1	N (kg/ha)	K_2O (kg/ha)				Mean
		0	60	120	180	
	0	16.75	17.22	17.03	17.13	*17.03* [a]
	46	17.13	16.91	16.84	17.30	*17.05* [a]
	92	16.48	16.70	17.01	17.01	*16.80* [a]
	138	16.79	16.51	16.96	17.01	*16.82* [a]
	Mean	16.79 [a]	16.84 [a]	16.96 [a]	17.11 [a]	
	LSD $_{0.05}$	(N) = 0.14***, (K) = 0.14***, (NK) = 0.29***, CV = 1.0%				
Season 2	*0*	17.09	17.03	17.33	17.61	*17.27* [a]
	46	17.36	17.00	17.41	17.19	*17.24* [a]
	92	17.06	17.06	17.03	16.97	*17.03* [a]
	138	17.13	17.19	17.01	17.11	*17.12* [a]
	Mean	17.16 [a]	17.07 [a]	17.19 [a]	17.22 [a]	
	LSD $_{0.05}$	(N)= 0.08***,(K) = 0.08***,(N×K) = 0.15***,CV = 0.5%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

Table 24: Fibre % cane in the Out growers

Season 1	N (kg/ha)	K_2O (kg/ha)				Mean
		0	60	120	180	
	0	16.52	16.75	16.41	16.60	*16.57*
	46	16.47	16.44	16.57	16.66	*16.53*
	92	16.51	16.39	16.55	16.70	*16.54*
	138	16.30	16.80	16.54	16.55	*16.55*
	Mean	16.45	16.60	16.52	16.63	
	LSD $_{0.05}$	(N) = 0.18 [ns], (K) = 0.18 [ns], (N×K) = 0.35*, CV = 5.5%				
Season 2	*0*	17.28	17.23	17.41	17.45	*17.34* [b]
	46	17.36	17.41	17.30	17.18	*17.31* [b]
	92	17.37	17.15	17.24	17.67	*17.36* [b]
	138	17.17	17.55	17.59	17.47	*17.45* [a]
	Mean	17.30 [b]	17.34 [b]	17.39 [ab]	17.44 [a]	
	LSD $_{0.05}$	(N)= 0.06***,(K) = 0.06**,(N×K) = 0.12***,CV = 0.4%				

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance

3.7.13 Diseases and pests

No smut was observed on the crop both in NE and OG in both seasons. However, infestation by pink sugarcane mealy bugs (*Saccharicoccus sacchari* (Cockerell)) and scale insects (*Eulacapsis tegalensis* Zehnt.) was observed from the 9th month of growth to maturity phase of the crop both in NE and OG. The incidence of mealy bugs was pronounced in the treatment with K and N application at 180 kg/ha K_2O and 138 kg/ha N respectively in OG Musanda 22 in season 1 (Plate 2). In season 2, the incidence of mealy bugs was pronounced in the treatment with K and N application at 180 kg/ha K_2O and 92 kg/ha N respectively in NE field E 35 while scale insects were observed in the treatment with K application at 180 kg/ha K_2O and no N in OG Khalaba 49 (Plates 3 and 4).

3.7.14 Agronomic Efficiency (AE) of the treatments

(i) Sugarcane yield (t/ha)

In season 1 of the NE experiment, highest AEs were observed with K application at 60 kg/ha K_2O at all levels N, with the highest reading at 46 kg/ha N (Table 25). Agronomic efficiencies decreased with increase in K. In season 2, high AEs were similarly observed in sugarcane that received K at 60 kg/ha K_2O; however, this was for cane that received 92 and 138 kg/ha N (Table 26).

In OG season 1, highest AEs were observed with K application at 120 kg/ha K_2O at all levels of N except at 138 kg/ha N in season 1 (Table 27). In season 2, highest AE was recorded with K application at 60 kg/ha K_2O at all levels of N. Agronomic efficiency decreased with increase in K application (Table 28).

Plate 2: Incidence of mealy bugs(*Saccharicoccus sacchari* (Cockerell)) on sugarcane in OG Musanda 22

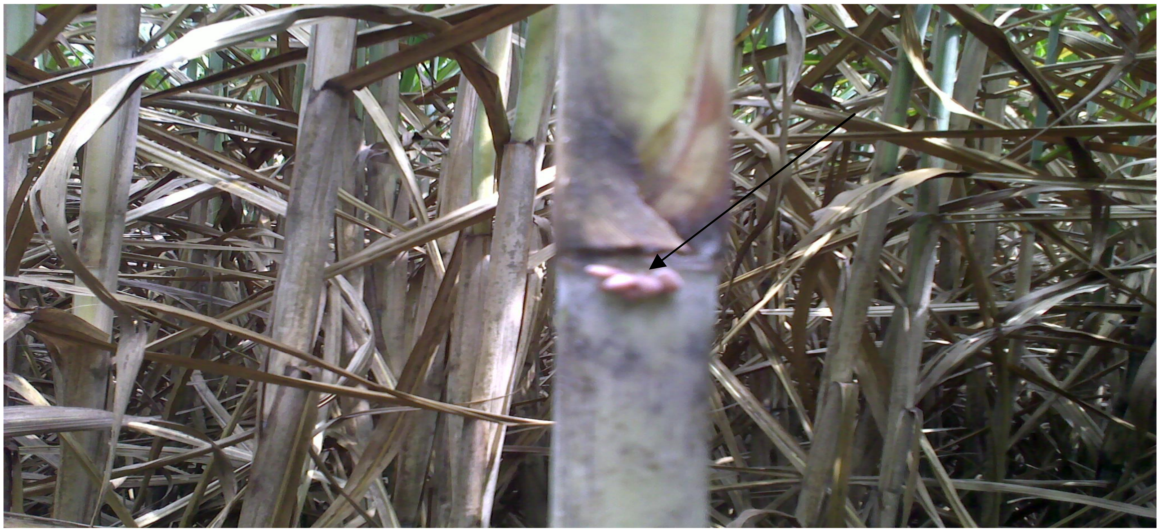


Plate 3: Incidence of mealy bugs (*Saccharicoccus sacchari* (Cockerell)) on sugarcane in NE field E 35

Plate 4: Incidence of scale insect (*Eulacapsis tegalensis* Zehnt.) on sugarcane in OG Khalaba 49

Table 25: Sugarcane yield (t/ha) and AE of K, N rates on NE in season 1

N rate (kg/ha)	*K rate (kg/ha)*	*Y*(t/ha)*	*YI (t/ha)*	*%*	*AE(kg sugarcane/ kg nutrient)*
0	0	101.7^{i}			
	60	114.2^{f}	12.5	12.3	208.3
	120	114.7^{f}	13.0	12.8	108.3
	180	119.7^{ef}	18.0	17.7	100.0
46	0	111.7^{gh}	10.0	9.8	
	60	126.8^{bc}	25.1	24.7	236.8
	120	125.2^{cde}	23.5	23.1	141.6
	180	134.6^{a}	32.9	32.4	145.6
92	0	116.8^{fg}	15.1	14.8	
	60	125.8^{cd}	26.0	25.6	171.1
	120	127.7^{bc}	26.0	25.6	122.6
	180	125.6^{cd}	23.9	23.5	87.9
138	0	107.0^{hi}	5.3	5.2	
	60	124.9^{cde}	23.2	22.8	117.2
	120	121.0^{de}	19.3	19.0	74.8
	180	132.0^{ab}	30.3	29.8	95.3

Table 26: Sugarcane yield (t/ha) and AE of K, N rates on NE in season 2

N rate (kg/ha)	*K rate (kg/ha)*	*Y* (t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
0	0	122.2^{h}			
	60	123.4^{g}	1.2	1.0	20.0
	120	125.8^{g}	3.6	3.0	30.0
	180	139.4^{e}	17.2	14.1	95.6
46	0	130.1^{f}	7.9	6.5	
	60	130.9^{f}	8.7	7.1	82.1
	120	146.6^{de}	20.4	16.7	121.9
	180	126.4^{g}	4.2	3.5	18.6
92	0	123.1^{g}	0.9	0.7	
	60	130.8^{f}	23.7	19.4	155.9
	120	145.9^{cd}	23.7	19.4	111.8
	180	148.1^{bc}	25.9	21.2	95.2
138	0	124.7^{gh}	2.5	2.0	
	60	149.5^{b}	27.3	22.4	137.9
	120	146.7^{bc}	24.5	20.1	95.0
	180	152.9^{a}	30.7	25.1	96.5

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)

[*]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance.

Table 27: Sugarcane yield (t/ha) and AE of K, N rates on OG in season 1

N rate (kg/ha)	*K rate (kg/ha)*	*Y*(t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
0	0	88.6 ^{f}			
	60	100.9 ^{e}	12.3	13.9	205.0
	120	116.8 ^{cd}	28.2	31.8	235.0
	180	111.6 ^{d}	23.0	26.0	127.8
46	0	96.9 ^{e}	8.3	9.4	
	60	102.9 ^{e}	14.3	16.1	134.9
	120	129.0 ^{a}	40.4	45.6	243.4
	180	117.7 ^{bcd}	29.1	32.8	128.8
92	0	88.7 ^{f}	0.1	0.1	
	60	91.5 ^{ef}	2.9	3.3	19.1
	120	125.2 ^{ab}	36.6	41.3	172.6
	180	123.9 ^{abc}	35.3	39.8	129.8
138	0	103.4 ^{e}	14.8	16.7	
	60	117.8 ^{bcd}	29.2	33.0	147.5
	120	124.1 ^{abc}	35.5	40.1	137.6
	180	128.1 ^{a}	39.5	44.6	124.2

Table 28: Sugarcane yield (t/ha) and AE of K, N rates on OG in season 2

N rate (kg/ha)	*K rate (kg/ha)*	*Y*(t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
0	0	49.7 ^{i}			
	60	67.7 ^{gh}	18.0	36.2	300.0
	120	68.1 ^{gh}	18.4	37.0	153.3
	180	74.2 ^{ef}	24.5	49.3	136.1
46	0	65.7 ^{h}	14.0	28.2	
	60	70.3 ^{fg}	20.6	41.4	194.3
	120	75.6 ^{de}	25.9	52.1	156.0
	180	68.5 ^{gh}	18.8	37.8	83.2
92	0	66.9 ^{gh}	17.2	34.6	
	60	79.7 ^{cd}	30.0	60.4	197.4
	120	82.9 ^{bc}	33.2	66.8	156.6
	180	85.7 ^{ab}	36.0	72.4	132.4
138	0	69.9 ^{fg}	20.2	40.6	
	60	88.6 ^{a}	38.9	78.3	196.5
	120	85.0 ^{ab}	35.3	71.0	136.8
	180	89.0 ^{a}	39.3	79.1	123.6

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)

*Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance.

(ii) Sugar yield (t/ha)

In NE season 1, highest AE was recorded with K application at 60 kg/ha K_2O for cane that received 46 kg/ha N. However, K application at 180 kg/ha K_2O also gave high AEs at 0 and 138 kg/ha N (Table 29). In season 2, AE was highest with K application at 180 kg/ha K_2O at all levels of N except at 46 kg/ha with K application at 120 kg/ha K_2O (Table 30).

From table 31, AE in OG was inconsistent in both seasons. However, highest AE was observed with K application at 120 kg/ha K_2O for cane that received 46 and 92 kg/ha N in season 1. In season 2, highest AEs were observed with application of K at 180 kg/ha K_2O for cane that received 0 and 92 kg/ha N (Table 32).

Table 29: Sugar yield (t/ha) and AE of K, N rates on NE in season 1

N rate (kg/ha)	*K rate (kg/ha)*	*Y*(t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugar/ kg nutrient)*
0	0	15.94 [e]			
	60	16.31 [de]	0.37	2.3	6.2
	120	16.55 [de]	0.61	3.8	5.1
	180	17.44 [cd]	1.50	9.4	8.3
46	0	14.58 [f]	-1.36	-8.5	
	60	18.22 [bc]	2.28	14.3	21.5
	120	18.00 [bc]	2.06	12.9	12.4
	180	19.77 [a]	3.83	24.0	16.9
92	0	15.72 [ef]	-0.22	-1.4	
	60	17.32 [cd]	1.38	8.7	9.1
	120	18.17 [bc]	2.23	14.0	10.5
	180	17.35 [cd]	1.41	8.8	5.2
138	0	14.04 [f]	-1.90	-11.9	
	60	17.34 [cd]	1.40	8.8	7.1
	120	17.24 [cd]	1.30	8.2	5.0
	180	18.99 [ab]	3.05	19.1	9.6

Table 30: Sugar yield (t/ha) and AE of K, N rates on NE in season 2

N rate (kg/ha)	*K rate (kg/ha)*	*Y*(t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugar/ kg nutrient)*
0	0	17.67 [efg]	0.00		
	60	17.32 [fg]	-0.35	-2.0	-5.8
	120	18.01 [de]	0.34	1.9	2.8
	180	20.36 [ab]	2.69	15.2	14.4
46	0	17.25 [g]	-0.42	-2.4	
	60	18.17 [d]	0.50	2.8	4.7
	120	19.91 [b]	2.24	12.7	13.5
	180	17.69 [efg]	0.02	0.1	0.1
92	0	17.95 [de]	0.28	1.6	
	60	17.73 [def]	0.06	0.3	0.4
	120	19.93 [b]	2.26	12.8	10.7
	180	20.71 [a]	3.04	17.2	11.9
138	0	15.60 [h]	-2.07	-11.7	
	60	18.97 [c]	1.30	7.4	6.6
	120	19.34 [c]	1.67	9.5	6.5
	180	20.26 [ab]	2.59	14.7	8.1

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
*Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance.

Table 31: Sugar yield (t/ha) and AE of K, N rates in OG season 1

N rate (kg/ha)	*K rate (kg/ha)*	*Y* (t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
0	0	13.21 ^{j}			
	60	14.32 ^{h}	1.11	8.4	18.5
	120	14.11 ^{i}	0.90	6.8	7.5
	180	16.12 ^{e}	2.91	22.0	16.2
46	0	12.70 ^{k}	0.51	-3.9	
	60	14.85 ^{f}	1.64	12.4	15.5
	120	18.86 ^{a}	5.65	42.8	34.0
	180	16.63 ^{d}	3.42	25.9	15.1
92	0	12.10 ^{l}	1.11	-8.4	
	60	13.27 ^{j}	0.06	0.5	0.4
	120	18.01 ^{b}	4.80	36.3	22.6
	180	17.79 ^{c}	4.58	34.7	16.8
138	0	13.26 ^{j}	0.05	0.4	
	60	14.61 ^{g}	1.40	10.6	7.1
	120	16.46 ^{d}	3.25	24.6	12.6
	180	18.88 ^{a}	5.67	42.9	17.8

Table 32: Sugar yield (t/ha) and AE of K, N rates in OG season 2

N rate (kg/ha)	*K rate (kg/ha)*	*Y*(t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugar/ kg nutrient)*
0	0	8.48 ^{ij}	0.00		
	60	9.14 ^{ghi}	0.66	7.8	11.0
	120	9.37 ^{gh}	0.89	10.5	7.4
	180	10.75 ^{de}	2.27	26.8	12.6
46	0	7.96 ^{j}	-0.52	-6.1	
	60	9.03 ^{hi}	0.55	6.5	5.2
	120	10.37 ^{ef}	1.89	22.3	11.4
	180	9.78 ^{fg}	1.30	15.3	5.8
92	0	8.24 ^{j}	-0.24	-2.8	
	60	10.00 ^{fg}	1.52	17.9	10.0
	120	11.68 ^{bc}	3.20	37.7	15.1
	180	13.54 ^{a}	5.06	59.7	18.6
138	0	8.42 ^{ij}	-0.06	-0.7	
	60	10.88 ^{de}	2.40	28.3	12.1
	120	11.24 ^{cd}	2.76	32.5	10.7
	180	12.05 ^{b}	3.57	42.1	11.2

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
*Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance.

3.7.15 Economic evaluation of the treatments

Following computation, VCRs for each treatment combination were highest for treatments where K was applied at 60 kg/ha K_2O for all N treatments in both seasons of the NE experiment (Tables 33 and 34). Of note is that the highest VCRs were observed with treatment combinations of 60 kg/ha K_2O and 46 kg/ha N in both seasons.

For OG experiment in season 1, except for sugarcane which received N at 138 kg/ha N, VCRs for each treatment combination were highest where K was applied at 120 kg/ha K_2O (Table 35). Where N was applied at 138 kg/ha N, highest VCR was observed with K applied at 60 kg/ha K_2O. In this experiment the highest VCR was computed for sugarcane that received 120 kg/ha K_2O and 46 kg/ha N. In season 2, VCRs for each treatment combination were highest where K was applied at 60 kg/ha K_2O for all N treatments. The highest VCR was obtained with treatment combination of 60 kg/ha K_2O and 46-138 kg/ha N (Table 36).

Table 33: Economic evaluation of K, N fertilization on sugarcane - NE season 1

N rate (kg/ha)	*K rate (kg/ha)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
0	0	381,375.00	29,700.00	207,815.90	
	60	428,250.00	36,700.00	238,653.40	6.5
	120	430,125.00	43,700.00	233,166.90	5.3
	180	448,875.00	50,700.00	241,301.90	4.8
46	0	418,875.00	21,508.00	246,277.90	
	60	475,500.00	28,508.00	284,985.60	10.0
	120	469,500.00	35,508.00	273,142.40	7.7
	180	504,750.00	42,508.00	294,596.20	6.9
92	0	438,000.00	27,428.00	255,795.60	
	60	471,750.00	34,428.00	276,038.60	8.0
	120	478,875.00	41,428.00	274,789.90	6.6
	180	471,000.00	48,428.00	261,433.20	5.4
138	0	401,250.00	33,348.00	220,211.00	
	60	468,375.00	40,438.00	267,304.30	6.6
	120	453,750.00	47,438.00	248,499.00	5.2
	180	495,000.00	54,348.00	274,886.00	5.1

Table 34: Economic evaluation of K, N fertilization on sugarcane - NE season 2

N rate (kg/ha)	K rate (kg/ha)	GR (Ksh)	FC (Ksh)	NR (Ksh)	VCR
0	0	458,250.00	29,700.00	268,158.60	
	60	462,750.00	36,700.00	264,774.20	7.2
	120	471,750.00	43,700.00	265,005.40	6.1
	180	522,750.00	50,700.00	298,982.20	5.9
46	0	487,875.00	21,508.00	300,153.30	
	60	490,875.00	28,508.00	295,563.70	10.4
	120	534,750.00	35,508.00	323,815.80	9.1
	180	474,000.00	42,508.00	268,005.20	6.3
92	0	461,625.00	27,428.00	273,142.30	
	60	490,500.00	34,428.00	289,342.40	8.4
	120	547,125.00	41,428.00	327,838.70	7.9
	180	555,375.00	48,428.00	327,467.30	6.8
138	0	467,625.00	33,348.00	272,043.10	
	60	560,625.00	40,438.00	339,675.50	8.4
	120	550,125.00	47,438.00	324,239.10	6.8
	180	573,375.00	54,348.00	336,009.70	6.2

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio
Price of SSP= Ksh 3,300, DAP= Ksh 3,897, MOP= Ksh 3,500, Urea= Ksh 2,960 per 50 kg bag; Price of sugarcane= Ksh 3,750 per ton

Table 35: Economic evaluation of K, N fertilization on sugarcane - OG season 1

N rate (kg/ha)	*K rate (kg/ha)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
0	0	332,250.00	29,700.00	155,049.40	
	60	378,375.00	36,700.00	183,461.10	5.0
	120	438,000.00	43,700.00	222,237.20	5.1
	180	418,500.00	50,700.00	200,266.40	4.0
46	0	363,375.00	21,508.00	187,137.10	
	60	385,875.00	28,508.00	197,411.10	6.9
	120	483,750.00	35,508.00	265,553.00	7.5
	180	441,375.00	42,508.00	226,020.30	5.3
92	0	332,625.00	27,428.00	157,609.30	
	60	343,125.00	34,428.00	158,670.50	4.6
	120	469,500.00	41,428.00	248,692.80	6.0
	180	464,625.00	48,428.00	237,950.10	4.9
138	0	387,750.00	33,348.00	194,010.60	
	60	441,750.00	40,438.00	228,378.20	5.6
	120	465,375.00	47,438.00	239,515.90	5.0
	180	480,375.00	54,348.00	244,121.90	4.5

Table 36: Economic evaluation of K, N fertilization on sugarcane - OG season 2

N rate (kg/ha)	*K rate (kg/ha)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
0	0	186,375.00	29,700.00	43,056.30	
	60	253,875.00	36,700.00	87,878.30	2.4
	120	255,375.00	43,700.00	82,029.90	1.9
	180	278,250.00	50,700.00	92,591.80	1.8
46	0	238,875.00	21,508.00	91,554.30	
	60	263,625.00	28,508.00	103,555.70	3.6
	120	283,500.00	35,508.00	111,814.40	3.1
	180	256,875.00	42,508.00	84,373.50	2.0
92	0	250,875.00	27,428.00	94,847.10	
	60	298,875.00	34,428.00	124,698.30	3.6
	120	310,875.00	41,428.00	126,911.10	3.1
	180	321,375.00	48,428.00	127,972.30	2.6
138	0	262,125.00	33,348.00	97,564.10	
	60	332,250.00	40,438.00	144,311.40	3.6
	120	318,750.00	47,438.00	126,947.00	2.7
	180	333,750.00	54,348.00	131,553.00	2.4

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio
Price of SSP= Ksh 3,300, DAP= Ksh 3,897, MOP= Ksh 3,500, Urea= Ksh 2,960 per 50 kg bag; Price of sugarcane= Ksh 3,750 per ton

3.8 Discussion

3.8.1 Emergence and tillering

Application of K and N enhanced sugarcane emergence relative to the control both in NE and OG experiments. However, a drop in emergence at the highest rate of 180 kg/ha K_2O was observed in season 2 of the NE experiment and season 1 of the OG experiment perhaps suggesting that high doses of muriate of potash (M.O.P) could depress sugarcane emergence. This observation was consistent with that of studies from Australia indicating that care should be taken when applying the mixture or straight potash at planting to ensure that `potash burn' does not occur. If the potash is in contact with, or very close to the cane setts, fertilizer burn can result in delayed or even prevention of germination of some of the eye buds of the setts. Root stubbing may also occur (BSES, 1994).

Tillering significantly increased with K and N application mainly at rates of 60-120 kg/ha K_2O and 46-92 kg/ha N both in NE and OG fields. This observation agreed with that of studies in Australia showing that N-deficient crops have reduced tillering and a lower root mass (BSES, 1994). In NE, application of K at 60 kg/ha K_2O appeared sufficient while up to 120 kg/ha K_2O was indicated in OG fields. This could perhaps be explained by previous cane management practices on the NE where organic wastes from the factory process like filter press that is rich in K were broadcast on the fields up to the mid 1990s. This observation agrees with that of studies in South Africa, suggesting that the use of mill by- products influences the amount of nutrients they supply and needs to be taken into account when assessing a fertilizer programme for the cropping season (Meyer *et al*., 2007). However the finding contradicted that of studies in Mauritius, showing that in the absence of adequate K supply, leaf area, tiller density and number of green leaves per mother shoot may not be affected (Ng Kee Kwong, 1994).

3.8.2 Stalk population, height and inter-node length

Application of K and N consistently increased stalk number, height and inter-node length in the NE and OG fields. This finding corroborated those of other studies (Perez and Melgar, 1998; Perez and Melgar, 2000; Yara 2011) indicating that K aids photosynthesis and hence promotes productive growth, stronger stalk development with less lodging and a bigger root mass. A deficiency restricts intermodal length while root development is also reduced leading to smaller root system. The finding also agreed with that of studies in Australia (BSES, 1994) and Brazil (Vitti, 2003) showing that with N deficiency, the crops have reduced tillering and sugarcane stalks are thin and stunted with reduced lengths between internodes. Low nitrogen supply also increases the risk of an early switch from vegetative to generate growth causing development of unwanted flower panicles. In Mauritius, studies have shown that in the absence adequate K supply, the height of millable stalks at harvest and to a lesser degree the number of stalks may be impaired (Ng Kee Kwong, 1994).

3.8.3 Sugarcane yield

Application of K and N significantly increased sugarcane yields. It was also evident that with K application, the rate of N applied could be reduced to modest levels of 46-92 kg/ha N. This finding appeared to confirm that K plays a key role in N metabolism, and that plants inadequately supplied with K fail to transport nitrate efficiently to the shoots (Krauss, 2004). It was also agreed with several others studies. Gupta and Shukla (1973) observed that K and N need to be in balance; that while N responses can be small, use of K alongside N ensures better yields of cane. Similarly, Yara (2011) observed that it is important to have sufficient potassium available to utilize the assimilated nitrogen in the cane to bring about good crop maturity. Kolln *et al*. (2013) also observed that increases in soil K content increased sugarcane productivity in Brazil. Prasad *et al.* (1996), on the other hand, found in a sandy loam calcareous soil of North Bihar that cane yield was increased from 50 t/ ha without K fertilization to 74.5 t/ha with only 60 kg K/ha. At 11 locations in Sao Paulo State of Brazil, Korndorfer (1990) indicated that raising application of K to 150 kg K/ha progressively increased cane yield. Rabindra *et al.* (1993) demonstrated that sugarcane grown continuously from 1971 on a red sandy loam soil at Karnataka in India gave cane yield of 63 t/ha in 1971 with and without fertilizers, but in 1988 while the cane yield with N alone (250 kg N/ha) was 30-34 t/ha, application of NPK with K at 125 kg K/ha gave cane yield of 130-136 t/ha. Sugarcane production systems with crop burning are considered highly responsive to potassium fertilization in both the plant cane and ratoon crops (Rossetto *et al*. 2004).

However, the results of this study did not agree with those of others. In South Africa, spectacular cane and sugar yield response to K has been reported where K was not previously applied (Meyer, 2013 pers. comm.). In India Lakholine *et al.* (1979) showed in a 3-year study under Vidarbha conditions in India that there was no response to K applied at 50-100 kg K/ha. Similarly Olalla *et al.* (1986) showed that at 0-300 kg K/ha, there were no differences in cane and sugar yields at Malaga during the first 2 years of K fertilizer use and during the next 2 years when K fertilization was withheld. Sachan *et al.*

(1993) also observed that plant cane crop did not respond to fertilizer K application while the first ratoon crop only did so slightly in a mollisol of Uttar Pradesh, India. Paneque *et al.* (1992) in Brazil reported that neither plant cane nor the first ratoon responded to K but cane yields increased by 23 and 39 t/ha at the end of the second and third ratoons, respectively. Yang and Chen (1991) reported that only 33% of the sites studied in Fiji showed a response to K fertilization.

3.8.4 Sugar yield, juice quality and fibre % cane

Sugar yield per hectare generally increased with K and N application. However, yield due to K application was attributed to improved juice quality (Pol % cane) since K is known to promote sugar synthesis and its translocation to the storage tissue. The improvement in juice quality is thought to be due to an increase in activity of sucrose synthesizing enzymes which also help increase the sucrose yield (Jayashree *et al*., 2008). Application of N resulted in higher cane yields hence the high overall sugar yield per ha recorded. However, a significant drop in juice quality was noted with N application at 138 kg/ha in the absence of K or with K application at 60 kg/ha K_2O, confirming that excess N application is detrimental to sugarcane juice quality. Fibre % cane was variable with slightly lower levels indicated at higher levels of K application.

The results of this study agreed with those of Phonde *et al*. (2005) who observed that adequate K supply ensured higher sugar yields and those of Malavolta (1994); Mahamuni *et al*. (1975) and Khosa (2002) showing that K improved juice quality (Pol) and reduced fibre content. In addition, it agreed with those of Yara (2011) who observed that it is important to have sufficient K available to utilize the assimilated N in the cane to bring about good crop maturity and ensure that reducing sugars are converted to sucrose. However, the results of the study were contrary to those of (Perez and Melgar, 2002; Watanabe *et al.*, 2013; Meyer, 2013 pers. comm.) suggesting that very high levels of K reduced sucrose levels and those by Kawamitsu *et al.* (1997) which showed that K had a highly negative correlation with sucrose contents in the juice of sugarcane in Japan.

3.8.5 Diseases and pests

Infestation by pink sugarcane mealy bugs (*Saccharicoccus sacchari* (Cockerell)) and scale insects (*Eulacapsis tegalensis* Zehnt.) was noted on the crop from the 9th month to maturity. It was thought to be a response to the high sucrose in the stalks due to K application and softer stalks due to N application. The pests are not of economic importance. Studies in S. Africa have shown that infestation of sugarcane by stalk borer (*Eldana sccharina* Walker) are exacerbated by high plant N and water stress (Atkinson and Nuss, 1989). Nitrogen overuse can increase susceptibility to lodging, stem cracking and may encourage diseases and pests such the stem borers. These factors also need to be taken into account when considering the agronomic management of the crop (Atkinson and Nuss, 1989).

3.8.6 Agronomic efficiency (AE)

In both the NE and OG experiments, highest agronomic efficiencies were obtained with K fertilization at 60-120 kg/ha K_2O and N application at 46-92 kg/ha N. The AEs were greater in plots supplied with K along with N. These results agreed with those of studies from Utta Pradesh, India (Singh *et al.*, 2005) which showed that AE was greater in plots with balanced supply of K, S, and Mg along with N and P. The concomitant increase in N use efficiency due to P, K, S and Mg application was in the range of 364 to 557 kg cane/kg nutrient. The increase in efficiency of the individual nutrient was 1,652 to 2,532 kg cane with P_2O_5, 692 to 906 kg cane/kg K_2O, 1,615 to 1,857 kg cane/kg S, and 3,687 to 3,713 kg cane/kg Mg. Similar evidence was gathered on sesame (*Sesamum indicum*) in Mubi Region, Adamawa State, Nigeria indicating that balanced nutrition with N, P and K led to increased dry matter and seed yields (Shehu *et al*., 2010). These results, therefore, are in agreement with those by Gupta and Shukla (1973) who observed that K and N need to be in balance; that while N responses can be small, use of K alongside N ensures better yields of cane.

3.8.7 Economic Evaluation

VCRs followed the same pattern for AEs where the highest were generally recorded with K application at 60 kg/ha K_2O and N at 46 kg/ha. VCRs were higher on the NE compared with OG due to the higher yields recorded. This finding established the need to invest in fertilizer K as muriate of potash with initial rate of 2 bags (60 kg/ha K_2O).

The current fertilizer regime at Mumias costs Ksh 27,428 per ha. With inclusion of K at 60 kg/ha K_2O this cost would escalate by 25.5% to Ksh 34,428 per ha. However, the increased returns per ha would offset the costs and give profit to the growers. Under the circumstances, application of K at 60 kg/ha K_2O would be feasible for a start and a reduction in the bags/ha Urea necessary to balance the costs to the growers.

3.9 Conclusion and Recommendation

The results of this study establish the significance of balanced fertilization with K for higher cane yield, higher sugar yield and higher farmer profit with sugarcane at Mumias in western Kenya. Although year to year weather and location specific soil fertility variability as well as sugarcane variety greatly influence yield and nutrient use efficiency, this can be minimized through fertilizer best management practices. It is recommended that K be included in the fertilization regime at Mumias initially at 60kg/ha K_2O (2 bags of 50 kg muriate of potash). The results suggest that with K fertilization the current N recommendation of 120-150 kg N/ha could be reduced to only 78-92 kg/ha due to better N utilization from the interaction with K.

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CHAPTER FOUR

4.0 EFFECTS OF AGRICULTURAL LIME AND PHOSPHORUS APPLICATION ON SUGARCANE GROWTH, YIELD AND QUALITY

4.1 Abstract

The effects of agricultural lime, phosphorus and their interaction on sugarcane growth, yield and quality were determined in four experiments conducted from 2009 to 2011 within the miller owned nucleus estate and out growers fields of the Mumias sugar zone in western Kenya. The treatments included two levels of agricultural lime at 0 and 3 tons/ha and five rates of phosphorus at 0, 46, 92, 138 and 184 kg/ha P_2O_5 laid out in a randomized complete block design replicated three times. Soil analysis results indicated low levels of pH, total nitrogen, organic carbon, phosphorus, potassium, calcium and magnesium in all sites except those in the nucleus estate where calcium (Ca) and magnesium (Mg) were above threshold. Soils were classified as acrisols with sandy clay and sandy clay loam with high bulk density in all sites. Emergence, tillering, stalk population, inter-node length, cane and sugar yields and Pol % cane increased significantly ($p < 0.05$) with liming and phosphorus application. Although incremental levels of P led to increased tillering, stalk population, cane, sugar yields and juice quality in the un-limed treatment, there was no significant difference ($p < 0.05$) in the components at P levels higher than 92 kg/ha P_2O_5. Sugarcane yields on the nucleus estate at 105.0 t/ha and 122.3 t/ha were higher than those from out growers at 94.6 t/ha and 75.4 t/ha in season 1 and season 2 respectively. Yields recorded in on season 1 crop were higher than those recorded on the season 2. Sugarcane yield response to liming in NE was

11.0 % while it varied from 16.9-24.5 % in OG relative to the control indicating greater response to liming in out growers fields than NE. Agronomic efficiencies (kg sugarcane/kg nutrient) of phosphorus application were greater in plots with supply of agricultural lime along with phosphorus at 46-92 kg P_2O_5. Although higher value cost ratios (VCR) were recorded without liming, net returns were higher in the limed treatment due to improved sugarcane yields. The results of this study suggest that the inclusion of agricultural lime in the fertilizer regime at Mumias is necessary and cost effective on soils with low pH. Where agricultural lime is applied the recommended P dose of 92 kg/ha P_2O_5 could be reduced to 46 kg/ha P_2O_5 with no adverse effects on sugarcane yield.

4.2 Introduction

Sugarcane fertilization in Kenyan plantations over the last 40 years is largely concentrated on nitrogen (N) and phosphorus (P). Sources, amounts and methods of fertilizer application largely remain the same with N source being Urea and P source as diammonium phosphate (DAP). These fertilizers are acidifying and could have contributed to the observed decline in soil pH, a factor linked to declining sugarcane yields in the main production zone of Mumias in western Kenya (Kenya Sugar Research Foundation, 2006). Growing of sugarcane on the same land over the years is a common practice in the MSZ that accounts for 50-60 % of national sugar production. There are no well defined breaks, rotations or fallow periods between the previous crop and re-plant (Wawire *et al*., 2007). These practices coupled with the current fertilizer regimes are thought to have resulted in the observed yield decline from a high of 110 t/ha in 1997 to a low of only 55 t/ha (Kenya Sugar Board, 2012). According to Jaetzold *et al*. (2005), the MSZ has mainly acrisols which are acidic soils with low base status thus indicating low fertility. Acrisols are also rich in aluminium (Al) and iron (Fe) oxide elements that cause nutrient fixation in low pH conditions. Acidification of these soils may perhaps be the main chemical constraint, which demands special crop management practices in sugarcane such as use of agricultural lime and organic manures. The sugarcane production practices in MSZ are known to contribute to low soil fertility which leads to declining yields as evidenced by earlier studies (Bekunda, 2002; Kariaga and Owelle, 1992; Nyongesa, 1992; Odada, 1986; Wawire *et al*., 1987).

Soil acidification is a slow natural process that occurs during pedogenesis and can be either accelerated or slowed down by climatic conditions and farming practices (Tang and Rengel, 2003). High rainfall, use of ammonium based fertilizers and trash harvesting are important factors that contribute to soil acidity (Colleen, 2004; Hartemink, 1998). Since the availability of plant nutrients is affected by the pH of soil, the major plant nutrients N, P and K, as well as Ca and Mg, show a marked reduction in availability in acid conditions (NETAFIM, 2008). Acidification of soil also results in loss of exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, a decrease in effective cation exchange capacity (C.E.C), and an increase in exchangeable Al^{3+} (Graham *et al*., 2002). The principle effects of acidity occur at soil pH $\leq$ 5.5 due to dissolution of Aluminium (Al^{3+}) ions that bond with phosphate ions (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$ and H_3PO_4) limiting P availability and uptake. The onset of Al toxicity results in rapid inhibition of sugarcane root growth due to impediment of both cell division and elongation, leading to reduced volume of soil explored by root system and direct influence of calcium (Ca) and P uptake across cell membrane of damaged roots (Wong and Swift, 2003). Adverse effects of acidification lead to decreased water and nutrient retention capacity in soils and reduced biotic activity (Kinraide, 2003).

Liming can mitigate the effects of P fixation by Al and Fe oxides at low pH thus making the P available to sugarcane plants (NETAFIM, 2008). Singha (2006) reported that liming of sugarcane at 2 tons/ha on a clay loam with pH 4.8 in India significantly increased the cane yields by 5.2 to 16.9% over the un-limed control. Liming slightly improved the quality of juice by increasing the sucrose and decreasing the glucose content of cane juice due to enhanced maturity. Residual effects of liming on the cane yield and quality of juice in ratoon sugarcane crop were also significant and liming improved the available N, P and K status of the soil. Leong (1980) showed that in Malaysia, liming of sugarcane on acid and lateritic latosols increased cane tonnage by about 10 t/ha principally through increases in the production of millable stalks as well as increases in stalk length and internode number.

According to Jaetzold *et al*. (2005), the dominant soil type in the MSZ is orthic Acrisol (60%) followed by Ferralsol, Nitosol, Cambisol and Planosol (40%). Acrisols are acidic soils with low base status; they are strongly leached and are rich in Aluminum (Al) and Iron (Fe) Oxide elements that are responsible for nutrient fixation at low pH thus making the nutrients unavailable to plants. This is an aspect that demands special crop management practices in sugarcane grown on these soils. However, there is no evidence on the effects of liming of sugarcane on acidic acrisols in the MSZ.

The objective of this study was, therefore, to determine the effects of liming, P application and their interaction on sugarcane growth, yield and quality on acrisols in MSZ.

4.3 Materials and methods

4.3.1 Experimental site and plant material

The study was conducted during 2009 through 2011 in the MSZ (0^{o}21'N and 34^{o} 30'E at 1314 m above sea level) on the Mumias sugar company owned Nucleus estate (fields A 28 and E 35) and the out growers fields (Eluche 8 and Khalaba 110). Both sectors have experienced yield decline despite the better management practices on the NE. The zone receives bi-modal rainfall ranging from 1500-2000 mm per annum with long rains peaking in April-May and short rains in September-October each year. The dominant soil type in the zone is orthic Acrisol (60%) followed by Ferralsol, Nitosol, Cambisol and Planosol (40%) (Jaetzold *et al*., 2005).

Predominantly grown sugarcane variety CO 945 was used. The variety was bred in Coimbatore, India from a cross between variety POJ 2878 and variety CO 617 (Jagathesan *et al*.,1990). Its growth habit is erect with rhizomatous tillers. The cane stalks are greenish yellow with a pinkish tinge. The internodes are cylindrical with occasional corky cracks that are the main identifying feature of the variety (Plate 2). Variety CO 945 is a medium maturing sugarcane cultivar harvested between 17 and 20 months (KESREF, 2004).

4.3.2 Soil characterization and rainfall

Prior to planting, soil was sampled at 0-30 cm and 30-60 cm depths and analyzed for textural class, bulk density and chemical properties. Every plot in a replicate was sampled and the soil was bulked to make three composite samples. Soil pH was determined in a soil suspension with a soil: water ratio of 1:1(w/v) using a glass electrode and pH meter S/N K 3386 Mettler Toledo 345. Soil organic matter (C), extractable P, K and total N were determined by the Calorimetric, Mehlich Double Acid, Flame photometry and Kjeldahl procedure (Blamire, 2003), respectively. Exchangeable cations were extracted with neutral 1N NH_4Oac and determined by flame emission for Na and K and by EDTA titration for Ca and Mg (Okalebo *et al*., 2002). Rainfall data was recorded daily at the trial sites and total rainfall calculated for each month.

Soil analysis results from the experimental sites indicated low pH (< 5.5), low total N (< 1.0 %), low P (< 20.0 ppm) and low K (< 0.7 m.e), low Ca (< 4.0 m.e) and Mg (< 2.0 m.e) in OG and low total organic carbon (< 2.0 %) in all sites. The Ca/Mg ratio was low in OG site at Eluche 8 while CEC was low in both OG sites. Soil texture was sandy clay and sandy clay loam with high bulk density (> 1.40 g/cm^3) in all sites in both NE and OG. Rainfall received throughout the crop growth period of 18 months was recorded and was slightly above the long term mean (LTM) (Tables 37 and 38).

Table 37: Soil chemical characteristics at the study sites

Site	*pH (1:1)*	*Total N (%)*	*P Mehlich (ppm)*	*K (m.e)*	*Ca (m.e.)*	*Mg (m.e)*	*Ca/Mg ratio*	*CEC (%)*	*Org.C (%)*
NE A 28	5.1	0.08	18.1	0.30	6.6	3.01	2.19	12.5	1.34
OG Eluche 8	5.3	0.13	12.2	0.50	2.5	1.58	1.58	10.6	2.00
NE E35	4.9	0.07	13.3	0.40	6.1	2.58	2.36	15.8	0.76
OG Khalaba 110	4.8	0.09	17.8	0.10	1.7	0.74	2.30	7.2	1.01
*Recommended**	5.5	> 1.0	> 20	> 0.7	> 4.0	> 2.0	2:1	> 12.0	> 2.0

Source : MSC Agronomy laboratory ; Key : NE –Nucleus Estate, OG –Outgrowers ;SCL –sandy clay loam; CL - clay loam; *for sugarcane (BSES,1994); Org. C- organic carbon; CEC- cation exchange capacity

Table 38: Soil physical characteristics at the study sites

Site	*depth (cm)*	*BD (g/cm^3)*	*M.C (%)*	*Porosity (%)*	*Texture*	*Total rainfall (mm)*	*LTM (mm)*
NE field A 28	0-30	1.58	31.9	38.0	SC	3088.9	2756.4
	30-60	1.50	42.4	45.0			
OG Eluche 8	0-30	1.73	24.2	34.8	SCL	2909.2	2756.4
	30-60	1.75	33.5	33.8			
NE field E 35	0-30	1.66	35.8	37.4	SCL	3246.4	2980.3
	30-60	1.67	29.9	37.0			
OG Khalaba 110	0-30	1.62	14.3	38.9	SC	2949.3	2937.0
	30-60	1.74	15.3	34.2			
*Recommended **		1.10-1.40	$\leq$ 50.0	> 50.0		1800-3000	

Source : KESREF field laboratory ; Key : NE – Nucleus Estate, OG – Outgrowers ; SCL- sandy clay loam; CL- clay loam; BD – bulk density; MC – moisture content; * for sugarcane

4.3.3 Experimental design and treatments

Treatments included two levels of agricultural lime (0, 3 t/ha) and five rates of P (0, 46, 92, 138 and 184 Kg/ha P_2O_5) laid out in a randomized complete block design (RCBD) consisting of a 2 x 5 factorial arrangement with three replications. Gross plot size was 1.5 m x 10 m x 6 rows = 90 m^2 and 1.2 m x 10 m x 6 rows = 72 m^2 in NE and OG respectively, based on the recommended standard practice for spacing. The net plot size for data collection was 1.5 m x 10 m x 4 rows = 60 m^2 and 1.2 m x 10 m x 4 rows = 48 m^2 in NE and OG respectively. A physical count of the number of 3-eye budded setts planted hence the total number of eye buds expected to germinate per plot was done. Emergence (%) was calculated as:

$$\frac{\text{No. of emerged shoots}}{\text{No. of expected shoots}} \times 100$$

Other recommended agronomic practices of weed management, top dressing with N, pest and disease observation were carried out as per the local recommendations (KESREF, 2006). Basal phosphate fertilizer at 92 kg P_2O_5/ha was supplied by DAP while recommended N was top dressed as Urea. The N applied as top dress in the treatments was adjusted based on N provided by DAP at the different rates of P such that all plots receiving the treatment had uniform total of 128 kg/ha N. Other recommended agronomic practices for weed management, top dressing with nitrogen, pest and disease observation were done as per the local recommendations (KESREF, 2006).

4.3.4 Data collection

Data was collected on emergence, tillering, foliar N, P and K content, stalk height, inter-node length and population, diseases and pest attack, cane yield, sugar yield, juice quality and fibre content.

4.3.4.1 Emergence and tillering

A physical count of emerged shoots was done at 30, 45 and 60 days after planting in the data collection plots (net plots) of size 1.5 m x 10 m x 4 rows = 60 m^2 and 1.2 m x 10 m x 4 rows = 48 m^2 in NE and OG respectively. Average emergence was calculated as the highest number of emerged shoots expressed as a percentage (%) of the expected. Tillering was assessed from 3-9 months after planting. A physical count of the total number of shoots in the net plot was done and extrapolated to establish the number of tillers/ha.

4.3.4.2 Foliar sampling and analysis

Nutrient uptake by the plants was monitored monthly from 3-9 months after planting from the four data collection rows. At sampling time, the 3rd leaf below the top visible dew lap (TVD) or spindle was taken. Ten leaves per row were collected making 40 leaves per plot. The centre of gravity of each bundle of leaves was determined by placing it on a specifically constructed table. The bundle was chopped with a sharp knife at the fulcrum and at 20 cm of the remainder towards the tip. Midribs of the sub sample were removed before determining the sample weight. Samples were then dried in the oven model BR 6000 Binder World at 80^{o}C for 24 hours. Dry leaves were ground in an apex cutter and the sample weighed and placed in a clean dry polythene bag ready for analysis. Foliar NPK was analyzed by Kjeldahl, Molybdenum blue and Flame photometry methods respectively (Okalebo *et al*., 2002). Foliar block digester model DK 42/26 Velp Scientifica was used to process the samples that were analyzed in the semi auto nitrogen distillation unit UDK 132 Velp Scientifica. Flame photometer BWB-XP from BWB

Technologies Ltd and Atomic Absorption Spectrophotometer AA-7000, Shimadzu were used for P and K determination.

4.3.4.3 Stalk height, inter-node length and population

Stalk height and inter-node length were recorded on 20 plants in the net plot at harvest. A physical count of all stalks in the net plot was done and extrapolated to establish the stalk population per ha.

4.3.4.4 Sugarcane yield, sugar yield, juice quality and fibre content

Cane yield at harvest was determined by weighing all the stalks from the net plots. A tripod stand and calibrated suspension balance Salter model 10X Avery were used. The weight (kg) realized was extrapolated to determine the cane yield in t/ha. Cane quality parameters at harvest were determined from four stalks per net plot. Each stalk was chopped into three equal portions i.e. top, middle and bottom. The sub samples were chopped into smaller pieces and shredded in a Jeffco cutter machine model WD02 Jefress Engineering Pty Ltd. Juice extraction was done in the disintegrator machine model WD02 Jefress Engineering Pty Ltd. A shredded sample of 1000 g was put in the cold digester with 2 litres of water and left to run for 20 minutes. The sample was sieved and 150 ml put in a conical flask. One gram of Lead sub acetate was added for clarification before filtration. From the sieved and digested juice, Brix (total dissoluble solids) was determined directly from the Refractomer Abbemat-WR Anton Paaroptotec GmbH. From the clarified juice, Pol (apparent sucrose) was read on a Polarimeter model AA-5 Optical Activity Ltd. A crushed and sieved cane sample of 100 g was placed in an oven model BR 6000 Binder world at 105^{o}C for 4 hours then re-weighed for moisture determination. From Brix, Pol reading and moisture % calculations, cane juice quality (Pol %), fibre %

and sugar yield per ha were derived according to the South African Sugar Technologists Association (SASTA) formulae (Schoonees-Muir *et. al.*, 2009).

Pol % cane = Brix*[3-(fibre %*0.0125)], where Brix = total dissoluble solids

Fibre % cane = [(100-(Brix*3) + moisture %)/(1-(Brix*0.0125)]

Sugar yield (t/ha) = Pol % cane*cane yield (t/ha)

4.3.4.5 Diseases and pests

Diseases and pests were observed monthly from 3-9 months after planting. Smut if noticed was scored on percentage of tillers infected versus overall tiller population per ha in accordance with the International Society of Sugarcane Technologists (ISSCT) rating (MSIRI, 2000). Observation for pests particularly targeted mealy bugs and scales due to their occurrence in MSZ and likely effect on juice quality (KESREF, 2004). Ten plants per plot (i.e. five plants from the two guard rows) were randomly sampled and two nodes on every plant above the senesced leaves were stripped as documented by Sutherland *et al*. (1996).

4.4 Agronomic efficiency

Agronomic efficiencies (AE) for P application to limed and un-limed plots were evaluated from the yield increase as a result of P fertilization per unit of fertilizer P applied (Snyder *et al.*, 2007; Singh *et al.*, 2008). In case of sugarcane grown for sugar, yield is both fresh cane weight and sugar yield at maturity. AE for sugarcane and sugar yield was arrived at by the formula:

$$AE = \frac{\text{Increase in yield (kg sugarcane or sugar)}}{\text{Fertilizer applied (kg nutrient)}}$$

4.5 Economic evaluation

The costs and sugarcane yield from the limed and un-limed treatments were recorded. Cost-benefit analysis was done using Gross returns (GR), Net returns (NR) and Value cost ratios (VCR) as described by Jennifer Greene and Andrew Stellman (2007) and Shehu *et al*. (2010) where:

Gross return (GR) = sugarcane yield (t/ha) x cost per ton (Ksh)

Net return (NR) = gross return (Ksh) – total variable costs (Ksh)

Value cost ratio (VCR) = value of increased yield / cost of fertilizer used; where > 1 indicates better returns per unit of fertilizer used.

4.6 Data analyses

The data collected on cane growth and yield parameters were subjected to analysis of variance using GenStat Release 13.2 (PC/Windows 7) Copyright 2010, VSN International Limited and means compared by Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance (Steel and Torrie, 1987). Agronomic efficiencies (AE) were calculated as described by Singh *et al*. (2008) and Value Cost Ratios (VCR) computed as described by Jennifer Greene and Andrew Stellman (2007) and Shehu *et al*. (2010).

4.7 Results

4.7.1 Emergence

Sugarcane emergence (%) was affected by the L×P interaction in both seasons of the NE experiment. Generally, higher cane emergence was observed in treatments that received 46 kg/ha P_2O_5 in both un-limed and limed plots in season 1. In season 2, increase in P applied led to increase in sugarcane emergence; however, only higher levels of 138 and184 kg/ha P_2O_5 led to high cane emergence (Table 39).

In the OG experiment, the L×P interaction was not significant in season 2. Application of P had no effect on emergence in un-limed cane in season 1; however, emergence was higher in cane that received 46 and 92 kg/ha P_2O_5. In season 2, liming led to higher sugarcane emergence (Table 40). Generally, emergence was higher in the NE compared with OG in both seasons. Emergence was very low in season 2 in OG due to low rains at the study site after planting.

4.7.2 Tillering

The L × P interaction significantly ($p \leq 0.05$) affected tillering in both locations in both seasons. In season 1 of the NE experiment, tiller numbers generally increased with increase in P at all levels in the un-limed plots. In limed plots, tillering increased only with application of 138 kg/ha and 184 kg/ha P_2O_5. Liming increased tiller numbers across all P levels. In season 2, in un-limed plots, tillering increased with application of 92 kg/ha P_2O_5 but leveled off with further increase in P. In limed plots, P application beyond 138 kg/ha P_2O_5 decreased tillering relative to the control (Table 41).

Table 39: Emergence (%) of NE sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5 (kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	76.1	86.6	73.5	76.3	82.0	*78.9*
	Limed (3 t/ha)	76.6	85.5	74.2	80.4	76.6	*78.7*
	Mean	76.4^{b}	86.0^{a}	73.9^{b}	78.3^{b}	79.3^{ab}	
	$LSD_{0.05}$	(L) = 4.38^{ns}, (P) = 6.92*, (L×P) = 9.79*, CV = 7.2 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	47.33	52.67	54.00	60.33	70.00	*56.87*
	Limed (3 t/ha)	47.00	46.67	47.33	62.67	76.33	*56.00*
	Mean	47.17^{c}	49.67^{c}	50.67^{c}	61.50^{b}	73.17^{a}	
	$LSD_{0.05}$	(L) = 3.78^{ns}, (P) = 5.97*, (L×P) = 8.45*, CV = 7.2 %					

*P < 0.05 ** P < 0.01; *** p < 0.001; ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 40: Emergence (%) of OG sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5 (kg/ha)*					Mean
		0	*46*	*92*	*138*	*184*	
	Un-limed	62.23	63.30	65.17	62.77	68.23	*64.34^{b}*
	Limed (3 t/ha)	64.43	72.20	74.10	71.00	65.97	*69.54^{a}*
	Mean	63.33^{b}	67.75^{a}	69.63^{a}	66.88^{ab}	67.10^{ab}	
	$LSD_{0.05}$	(L) = 2.67***, (P) = 4.23*, (L×P) = 5.98**, CV = 5.2 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	27.67	23.67	22.00	26.33	26.00	*25.13^{b}*
	Limed (3 t/ha)	29.33	26.67	28.00	30.67	27.67	*28.47^{a}*
	Mean	28.50	25.17	25.00	28.50	26.83	
	$LSD_{0.05}$	(L) = 2.58*, (P) = 4.08^{ns} , (L×P) = 5.78^{ns}, CV = 12.6 %					

*P < 0.05 ** P < 0.01; *** p < 0.001; ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

In OG in season 1, tillering increased with P application of 46 kg/ha P_2O_5 and above in un-limed plots; application of 138 kg/ha P_2O_5 had the highest tiller numbers compared to all P rates. In the limed plots, tiller numbers increased with increase in P rate up to 92 kg/ha P_2O_5. Liming increased tiller number across all p rates. In season 2, application of only138 and 184 kg/ha P_2O_5 increased tiller numbers. In limed plots, application of 138 kg/ha P_2O_5 had the highest tiller numbers. Liming also increased tiller numbers at 0, 46 and 92 kg/ha P_2O_5. Generally, tillering was higher in the OG experiment compared with NE in season 1 while the converse was observed in season 2 (Table 42).

4.7.3 Foliar N content

In both seasons of the NE experiment, P application, liming and their interaction had no significant ($p \leq 0.05$) effect on foliar-N content. In season 2, however, L×P interaction significantly affected foliar-N content. In the OG experiment, in season 1, the plots that received 46 kg/ha P_2O_5 and above had a high foliar-N content than the control. However, there were no differences in foliar N among the 46, 92, 138 and 184 kg/ha P_2O_5 P treatments. Similar observations were made in season 2 except that application of 92 kg/ha P_2O_5 and above increased foliar N content relative to the control. Generally, liming led to higher foliar-N content in both seasons and locations (Tables 43 and 44).

Table 41: Tillers/ha ('000) on NE sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5 (kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	40.17	47.33	44.50	57.11	71.28	*52.08^{b}*
	Limed (3 t/ha)	56.67	60.85	60.78	66.56	65.44	*62.06^{a}*
	Mean	48.42^{d}	54.09^{c}	52.64^{c}	61.83^{b}	68.36^{a}	
	$LSD_{0.05}$	(L) = 2.58**, (P) = 4.09**, (L×P) = 5.78***,CV = 5.9 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	117.49	123.09	130.58	127.75	120.22	*123.83^{b}*
	Limed (3 t/ha)	130.08	135.81	126.99	125.80	121.33	*128.30^{a}*
	Mean	123.78^{bc}	129.45^{a}	128.79^{ab}	126.77^{b}	120.78^{c}	
	$LSD_{0.05}$	(L) = 3.58*, (P) = 5.66*, (L×P) = 8.00*, CV = 3.7 %					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 42: Tillers/ha ('000) on OG sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5 (kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	42.56	69.22	63.96	102.93	78.93	*71.52^{b}*
	Limed (3 t/ha)	52.70	106.81	120.59	116.81	83.67	*96.12^{a}*
	Mean	47.63^{e}	88.02^{c}	92.28^{b}	109.87^{a}	81.30^{d}	
	$LSD_{0.05}$	(L) = 3.98***, (P) = 6.30***,(L×P) = 8.91***,CV= 6.2 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	78.6	86.4	94.3	111.6	114.3	*97.0^{b}*
	Limed (3 t/ha)	114.8	105.6	117.0	123.4	108.6	*113.9^{a}*
	Mean	96.7^{b}	96.0^{b}	105.7^{ab}	117.5^{a}	111.5^{a}	
	$LSD_{0.05}$	(L) = 9.69***, (P) = 12.16*, (L×P) = 17.20*, CV = 9.5 %					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 43: Foliar N (%) content of NE sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5 (kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	1.67	1.70	1.65	1.75	1.76	*1.71*
	Limed (3 t/ha)	1.78	1.85	1.87	1.90	1.92	*1.86*
	Mean	1.73	1.78	1.76	1.83	1.84	
	$LSD_{0.05}$	(L) = 0.17^{ns}, (P) = 0.30^{ns}, (L×P) = 0.38^{ns} CV = 12.2 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	1.85	1.73	2.15	2.27	2.26	*2.05*^{a}
	Limed (3 t/ha)	1.96	2.25	2.21	2.43	2.69	*2.41*^{a}
	Mean	1.91^{b}	1.99^{b}	2.18^{ab}	2.35^{ab}	2.48^{a}	
	$LSD_{0.05}$	(L) = 0.29*, (P) = 0.45*, (L×P) = 0.64*, CV = 16.7 %					

*significant ** highly significant; *** very highly significant, ns- not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 44: Foliar N (%) content of OG sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5 (kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	1.35	1.70	1.63	1.64	1.73	*1.61*^{b}
	Limed (3 t/ha)	1.66	1.72	1.68	1.73	1.74	*1.71*^{a}
	Mean	1.51^{e}	1.71^{b}	1.66^{d}	1.69^{c}	1.74^{a}	
	$LSD_{0.05}$	(L) = 0.06*, (P) = 0.10*, (L×P) = 0.14*, CV = 4.8 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	1.70	1.83	1.90	1.82	2.00	*1.85*^{b}
	Limed (3 t/ha)	1.86	1.84	2.06	2.13	2.14	*2.01*^{a}
	Mean	1.78^{d}	1.84^{c}	1.98^{b}	1.98^{b}	2.07^{a}	
	$LSD_{0.05}$	(L) = 0.04*, (P) = 0.07***, (L×P) = 0.10***, CV = 3.0%					

*significant ** highly significant; *** very highly significant, ns- not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

4.7.4 Foliar P content

The L×P interaction did not affect foliar P content except in season 2 of the OG experiment (Tables 45 and 46). In season 2, of the OG experiment, application of P only at 46, 138 and 184 kg/ha P_2O_5 significantly increased foliar P content relative to the control in un-limed plots. In the limed plots, application of P at 46 and 138 kg/ha P_2O_5 increased foliar P content relative to the control. Generally, foliar P content did not differ between NE and OG and the seasons. Notable P deficiency symptoms were observed on the NE crop at field A 28 in the season 1 experiment (Plate 5).

4.7.5 Foliar K content

In both NE and OG, neither liming nor P application had significant ($p \leq 0.05$) effect on foliar K content in season 1. In season 2, foliar K content was high in treatments that received 92 and 184 kg/ha P_2O_5 but was low in the control, 46 and 138 kg/ha P_2O_5 treatments in NE (Table 47).

In OG, foliar K content increased with application of 92 and 138 kg/ha P_2O_5 in un-limed plots. In the limed plots foliar K content increased with P application of up to 138 kg/ha P_2O_5 (Table 48).

Table 45: Foliar P (%) of NE sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5 (kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	0.17	0.19	0.18	0.19	0.19	*0.18*
	Limed (3 t/ha)	0.19	0.19	0.18	0.19	0.18	*0.19*
	Mean	0.18	0.19	0.18	0.19	0.19	
	$LSD_{0.05}$	(L) = 0.01^{ns}, (P) = 0.02^{ns}, (L×P) = 0.03^{ns}, CV = 8.1 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	0.08	0.11	0.10	0.09	0.13	*0.10*
	Limed (3 t/ha)	0.10	0.12	0.10	0.11	0.11	*0.11*
	Mean	0.09	0.11	0.10	0.10	0.12	
	$LSD_{0.05}$	(L) = 0.01^{ns}, (P) = 0.02*, (L×P) = 0.03^{ns}, CV = 8.1 %					

*significant ** highly significant; *** very highly significant, ns - not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 46: Foliar P (%) of OG sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5 (kg/ha*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	0.07	0.09	0.10	0.10	0.09	*0.09^{a}*
	Limed (3 t/ha)	0.09	0.11	0.10	0.11	0.12	*0.11^{a}*
	Mean	0.08^{b}	0.10^{a}	0.10^{a}	0.11^{a}	0.11^{a}	
	$LSD_{0.05}$	(L) = 0.01*, (P) = 0.02*, (L×P) = 0.03^{ns}, CV = 17.8 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	0.06	0.09	0.06	0.08	0.20	*0.10*
	Limed (3 t/ha)	0.08	0.21	0.10	0.20	0.06	*0.13*
	Mean	0.07	0.15	0.08	0.13	0.13	
	$LSD_{0.05}$	(L) = 0.01**, (P) = 0.02** , (L×P) = 0.02**, CV = 12.3 %					

*significant ** highly significant; *** very highly significant, ns - not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 47: Foliar K (%) of NE sugarcane in season 1 and 2

Season 1	Treatment	P_2O_5 (kg/ha)					
		0	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	0.40	0.44	0.39	0.51	0.59	*0.47*
	Limed (3 t/ha)	0.50	0.49	0.53	0.55	0.65	*0.54*
	Mean	0.45	0.47	0.46	0.53	0.53	
	$LSD_{0.05}$	(L) = 0.10 ^{ns}, (P) = 0.15^{ns}, (L×P) = 0.22 ^{ns}, CV = 25.3 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	0.69	0.76	1.25	0.52	1.30	*0.90* ^{b}
	Limed (3 t/ha)	0.74	0.90	1.68	0.84	1.71	*1.17* ^{a}
	Mean	0.72^{c}	0.83^{b}	1.47^{a}	0.68^{c}	1.51^{a}	
	$LSD_{0.05}$	(L) = 0.03**, (P) = 0.05** , (L×P) = 0.07**, CV= 4.3 %					

*significant ** highly significant; *** very highly significant, ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 48: Foliar K (%) of OG sugarcane in season 1 and 2

Season 1	Treatment	P_2O_5 (kg/ha)					Mean
		0	*46*	*92*	*138*	*184*	
	Un-limed	0.78	0.82	0.92	0.75	0.94	*0.84*
	Limed (3 t/ha)	0.94	1.02	0.94	0.83	1.02	*0.95*
	Mean	0.86	0.92	0.91	0.79	0.98	
	$LSD_{0.05}$	(L) = 0.08 ^{ns}, (P) = 0.13 ^{ns}, (L×P) = 0.19 ^{ns} CV = 12.5 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	0.60	0.64	0.75	0.83	0.67	*0.70* ^{a}
	Limed (3 t/ha)	0.65	1.13	1.28	0.95	0.70	*0.94* ^{a}
	Mean	0.62^{d}	0.88^{b}	1.02^{a}	0.89^{b}	0.68^{c}	
	$LSD_{0.05}$	(L) = 0.03***, (P) = 0.05***, (L×P) = 0.07***, CV = 5.0 %					

*significant ** highly significant; *** very highly significant, ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

4.7.6 Stalk height

The L×P interaction significantly ($p \leq 0.05$) affected stalk height in both seasons. In season 1 of the NE experiment, P treated canes had taller stalks relative to the control in the un-limed and limed plots (Table 49). However, there were generally no differences in stalk heights among the 46, 92, 138 and 184 kg/ha P_2O_5 treatments. Liming increased stalk height only in the control plots. In season 2, cane height increased with application of 92 kg/ha P_2O_5 and above in un-limed and limed canes. Liming increased stalk height under all P rates. In OG, the L×P interaction significantly affected stalk height (Table 50). Compared to the control, all P treated canes generally had taller stalks in both un-limed and limed plots of season 1. In season 2, P-treated canes had taller stalks than those in the control plots in the un-limed canes. In the limed plots, application of 92 and 184 kg/ha P_2O_5 increased stalk height; generally, season 1 crop had taller stalks compared with season 2 and the limed plots had taller cane stalks.

4.7.7 Inter-node length

In the NE experiment, cane that received P generally had longer internodes than canes not treated with P in both un-limed and limed plots in season 1. However, inter-node length did not differ among 46, 92, 138 and 184 kg/ha P_2O_5 treatments in the limed and un-limed plots except 46 kg/ha P_2O_5 in the limed plots which had the highest inter-node length. The same pattern was observed in season 2 except that P application did not increase inter=node length in limed plots. Inter-node length was higher in season 2 crop than in season 1 (Table 51). In OG season 1, inter-node length increased significantly with P application relative to the control in the un-limed plots in season 1. However, only application of 138 and 184 kg/ha P_2O_5 increased inter-node length in limed plots. Liming significantly increased inter-node length in all P rates except 46 kg/ha P_2O_5. In season 2, inter-node liming, P rate and L×P interaction had no effect on inter-node length (Table 52). Inter-node length of OG sugarcane was higher in season 1 than in season 2.

Table 49: Stalk height (cm) of NE sugarcane in season 1 and 2

		P_2O_5 (kg/ha)					
Season 1	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	93.47	102.73	108.03	111.87	102.17	*103.65*[b]
	Limed (3 t/ha)	105.93	107.93	109.57	112.37	103.57	*107.87*[a]
	Mean	99.70 [a]	105.33 [a]	108.80 [a]	112.12 [a]	102.87 [a]	
	$LSD_{0.05}$	(L) = 2.36*, (P) = 3.73***, (L×P) = 5.27***, CV = 2.9 %					
	Treatment	*0*	*46*	*92*	*138*	*184*	*Mean*
Season 2	*Un-limed*	205.10	226.80	233.37	236.30	247.73	*229.86* [b]
	Limed (3 t/ha)	241.83	246.60	254.73	251.17	256.77	*248.22*[a]
	Mean	223.47[d]	236.70[c]	243.74[ab]	238.73[bc]	252.25[a]	
	$LSD_{0.05}$	(L) = 3.46***, (P) = 5.46***, (L×P) = 7.73***, CV = 1.9 %					

*significant ** highly significant; *** very highly significant, ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 50: Stalk height (cm) of OG sugarcane in season 1 and 2

		P_2O_5(kg/ha)					
Season 1	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	146.6	216.2	152.9	216.0	207.5	*187.8* [a]
	Limed (3 t/ha)	205.7	247.8	238.8	250.2	249.7	*238.4* [a]
	Mean	176.1 [a]	232.0 [a]	195.9 [a]	233.1 [a]	228.6 [a]	
	$LSD_{0.05}$	(L) = 4.80***,(P) = 7.59***,(L×P) = 10.73***,CV = 2.9 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	93.5	105.9	111.4	106.6	111.9	*105.9*[b]
	Limed (3 t/ha)	102.7	108.6	119.0	107.9	117.8	*111.2*[a]
	Mean	98.1[b]	107.3 [a]	115.2[a]	107.3[a]	114.9[a]	
	$LSD_{0.05}$	(L) = 5.12*, (P) = 8.10** , (L×P) = 11.45*, CV= 6.3 %					

*significant ** highly significant; *** very highly significant, ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 51: Inter-node length (cm) of NE sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5(kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	5.57	6.21	6.18	6.51	6.32	*6.16*^{b}
	Limed (3 t/ha)	6.24	7.38	6.61	6.69	6.44	*6.67*^{a}
	Mean	6.05^{c}	6.79^{a}	6.39^{b}	6.60^{a}	6.38^{b}	
	$LSD_{0.05}$	(L) = 0.19***, (P) = 0.30***,(L×P) = 0.43***,CV= 3.8%					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	8.47	9.63	9.37	9.60	9.23	*9.26*^{b}
	Limed (3 t/ha)	9.80	9.97	9.67	9.20	9.63	*9.65*^{a}
	Mean	9.13^{b}	9.80^{a}	9.52^{a}	9.40^{ab}	9.43^{ab}	
	$LSD_{0.05}$	(L) = 0.28**, (P) = 0.43*, (L×P) = 0.62**, CV = 3.8 %					

*significant ** highly significant; *** very highly significant, ns - not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 52: Inter-node length (cm) of OG sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5(kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	6.19	10.63	7.98	10.39	10.24	*9.09*^{b}
	Limed (3 t/ha)	11.16	11.16	11.44	11.78	12.04	*11.52*^{a}
	Mean	8.68^{c}	10.89^{a}	9.71^{b}	11.09^{a}	11.14^{a}	
	$LSD_{0.05}$	(L) = 0.26***,(P) = 0.41***,(L×P)= 0.59***,CV= 3.3%					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	5.57	6.13	6.33	6.30	6.47	*6.16*
	Limed (3 t/ha)	6.13	6.47	6.73	6.53	6.53	*6.48*
	Mean	5.85	6.30	6.53	6.42	6.50	
	$LSD_{0.05}$	(L) = 0.46^{ns}, (P) = 0.73^{ns}, (L×P) = 1.03^{ns}, CV = 9.3 %					

*significant ** highly significant; *** very highly significant, ns - not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

4.7.8 Millable stalks

In NE, stalk population was affected by the L×P interaction in both seasons. In season 1, the P treated canes had higher stalk numbers relative to the control in un-limed treatment. In the limed plots, stalk numbers decreased with P application of 92 kg/ha P_2O_5 and above. Liming increased millable stalks at 46 kg/ha P_2O_5 but decreased this parameter at 138 and 184 kg/ha P_2O_5. In season 2, millable stalk numbers increased with P application of 92 kg/ha P_2O_5 and above relative to the control in the un-limed plots. In the limed plots, millable stalk numbers were not affected by liming and L×P interaction (Table 53). Season 2 crop had higher millable stalk numbers than season 1.

In OG, P application and L×P interaction had no effect on stalk numbers. However, liming increased stalk numbers. In season 2, stalk numbers increased with application of 138 and 184 kg/ha P_2O_5 in the un-limed treatments. Application of P had no effect on stalk numbers in the limed plots (Table 54). Liming increased stalk numbers in plots that received 0, 46 and 92 kg/ha P_2O_5.

4.7.9 Cane yield

In NE, sugarcane cane yields increased significantly ($p \leq 0.05$) with P application relative to the control in un-limed plots in season 1; however, there were no differences among the canes treated with 46-184 kg/ha P_2O_5 (Table 55 and Figures 7-8). Similar observations were made in limed plots except that 46 and 138 kg/ha P_2O_5 treatments did not increase yield relative to the control. In season 2, cane yields generally increased with increase in P to 138 kg/ha P_2O_5 in un-limed plots. In the limed plots, cane yield increased with P application of 46 kg/ha P_2O_5 and above. Generally, liming increased the cane yields.

Table 53: Millable stalks/ha ('000) of NE sugarcane in season 1 and 2

Season	Treatment	P_2O_5(kg/ha)					Mean
Season 1	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	42.97	63.07	51.93	63.50	67.53	*57.80*
	Limed (3 t/ha)	66.93	66.87	51.60	51.87	52.83	*58.33*
	Mean	54.95^{c}	58.25^{b}	51.77^{d}	65.18^{a}	60.18^{b}	
	$LSD_{0.05}$	(L) = 1.44^{ns} (P) = 2.28***,(L×P) = 3.33***,CV= 3.3 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	103.67	108.61	115.22	112.72	116.08	*109.26*^{b}
	Limed (3 t/ha)	114.78	119.83	112.06	111.00	107.06	*112.94*^{a}
	Mean	109.22^{b}	114.22^{a}	113.64^{ab}	111.86^{ab}	106.57^{c}	
	$LSD_{0.05}$	(L) = 3.16*, (P) = 4.99*, (L×P) = 7.06*, CV= 3.7 %					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 54: Millable stalks/ha ('000) of OG sugarcane in season 1 and 2

Season	Treatment	P_2O_5(kg/ha)					Mean
Season 1	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	84.8	93.2	89.2	91.7	90.5	*89.9*^{b}
	Limed (3 t/ha)	94.1	92.7	98.5	91.4	89.6	*93.3*^{a}
	Mean	89.5	92.9	93.8	91.5	90.0	
	$LSD_{0.05}$	(L) = 4.84*, (P) = 7.66^{ns}, (L×P) = 10.83^{ns}, CV= 6.9 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	64.3	70.6	77.1	91.2	93.4	*79.3*^{b}
	Limed (3 t/ha)	93.8	86.3	95.6	90.9	88.8	*93.1*^{a}
	Mean	79.1^{b}	78.5^{b}	86.4^{ab}	91.0^{a}	91.1^{a}	
	$LSD_{0.05}$	(L) = 6.29***, (P) = 9.94*, (L×P) = 14.06**, CV= 9.5 %					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

In OG, P application significantly increased sugarcane yields relative to the control both in the un-limed and limed treatments; however, there was no difference in the yields among the P treatments of 46, 92, 138 and 184 kg/ha P_2O_5 (Table 56 and Figures 9-10). Liming increased sugarcane yields across all P-rates. In season 2, cane yield increased with application of 138 and 184 kg/ha P_2O_5 relative to the control in un-limed plots. In the limed plots, P application had no effect on sugarcane yield. Liming increased sugarcane yield in the 0, 46 and 92 kg/ha P_2O_5 plots. Generally, yields on the NE were higher than those on OG. Season 2 yields were higher than those of season 1.

4.7.10 Juice quality (Pol % cane)

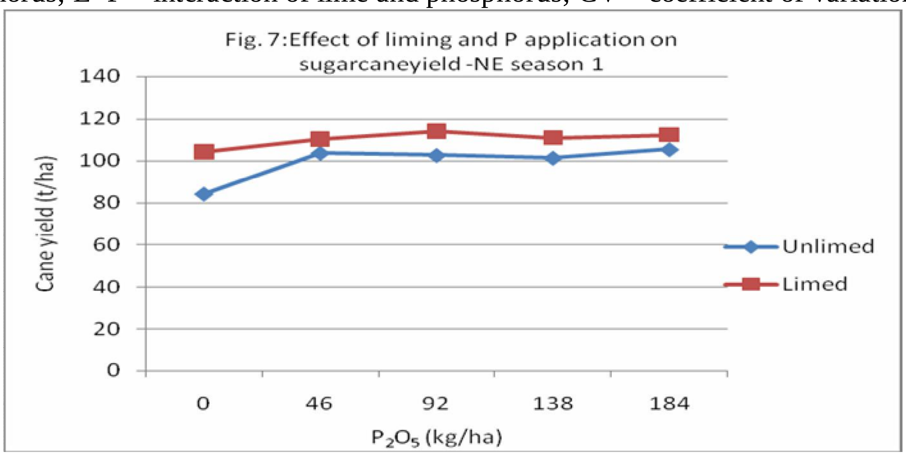
In NE season 1, Pol % cane increased only with P application of 184 kg/ha P_2O_5 in un-limed and limed plots. The control treatment had significantly high Pol % relative to 46 kg/ha P_2O_5. In season 2, liming, P rate and L×P interaction had no significant effect on Pol %. The Pol % cane was higher in the limed compared with un-limed plots (Table 57).

In OG, in season 1, only application of 138 kg/ha P_2O_5 increased Pol % the un-limed plots. In the limed plots, P application had no effect on Pol % cane. In season 2, application of P increased Pol % relative to the control in un-limed plots but not the limed ones (Table 58). In both seasons, liming increased Pol % cane only at 0, 46 and 92 kg/ha P_2O_5.

Table 55: Cane yield (t/ha) of NE sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5(kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	84.10	103.70	102.63	101.33	105.43	*99.44*[a]
	Limed (3 t/ha)	104.33	110.40	114.10	111.07	112.47	*110.47*[a]
	Mean	94.22 [a]	107.05 [a]	108.37 [a]	106.20 [a]	108.95 [a]	
	$LSD_{0.05}$	(L) = 3.03***, (P) = 4.79***, (L×P) = 6.77**,CV = 3.8%					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	93.57	115.67	116.70	128.23	125.77	*115.99*[b]
	Limed (3 t/ha)	110.87	132.77	135.27	131.90	132.70	*128.70*[a]
	Mean	102.22 [d]	124.22[c]	125.98[bc]	130.07[a]	129.23[ab]	
	$LSD_{0.05}$	(L) = 2.24***,(P) = 3.53***,(L×P) = 5.0***, CV= 2.4%					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation



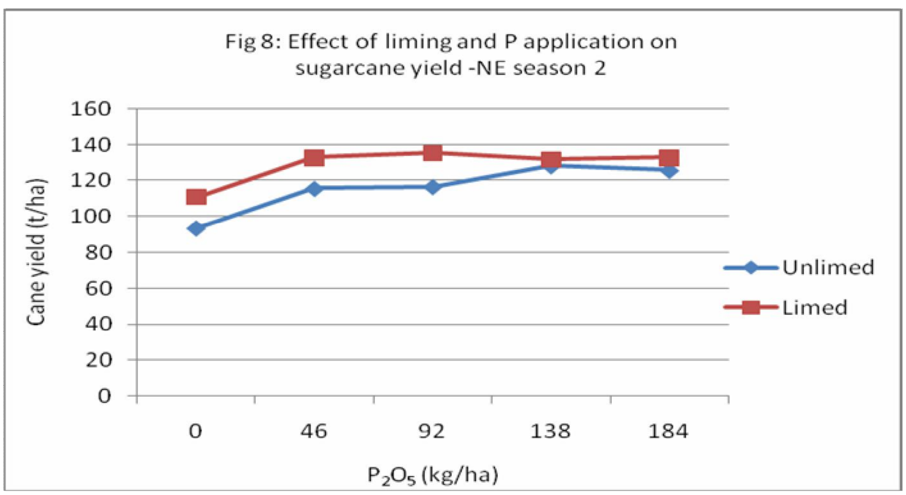
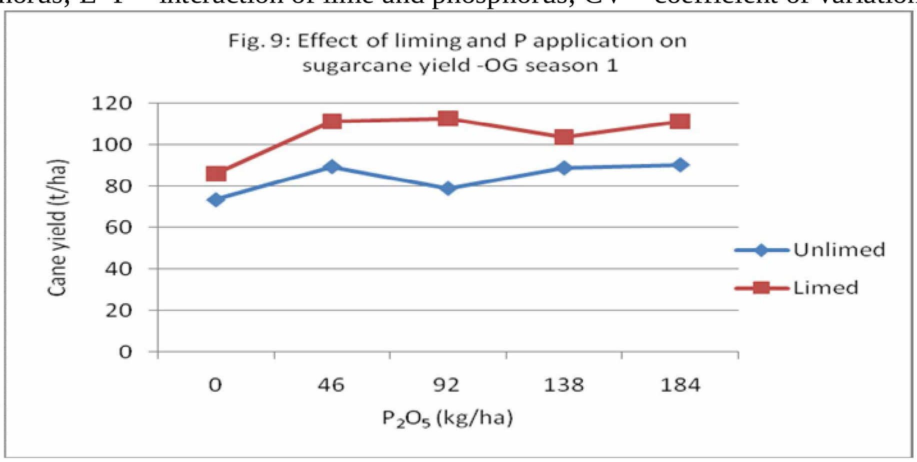


Table 56: Cane yield (t/ha) of OG sugarcane in season 1 and 2

Season 1	*Treatment*	*P_2O_5(kg/ha)*					*Mean*
		0	*46*	*92*	*138*	*184*	
	Un-limed	73.57	89.57	79.00	88.97	90.43	*84.31[b]*
	Limed (3 t/ha)	86.07	111.23	112.73	103.70	111.13	*104.97[a]*
	Mean	79.82[b]	100.40[a]	95.87[a]	96.33[a]	100.78[a]	
	$LSD_{0.05}$	(L) = 3.50***, (P) = 5.53***, (L×P) = 7.83**,CV = 4.8%					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	78.6	86.4	94.3	111.6	114.3	*97.0[b]*
	Limed (3 t/ha)	114.8	105.6	117.0	123.4	108.6	*113.9[a]*
	Mean	96.7[ab]	96.0[ab]	105.7[ab]	117.5[a]	111.5[a]	
	$LSD_{0.05}$	(L) = 7.69*** , (P) = 12.16*, (L×P) = 17.20*,CV = 4.7%					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation



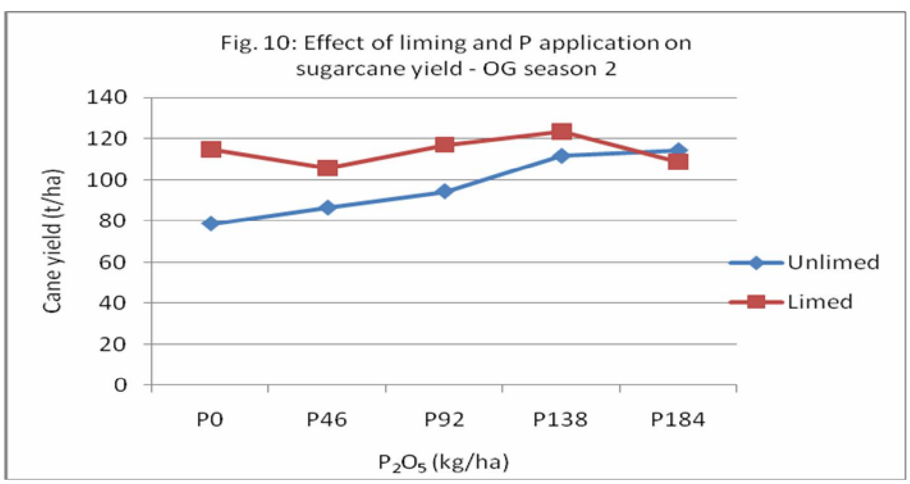


Table 57: Pol % cane of NE sugarcane in season 1 and 2

	Treatment	P_2O_5(kg/ha)					Mean
Season 1		*0*	*46*	*92*	*138*	*184*	
	Un-limed	13.56	13.11	13.34	13.64	13.86	*13.50*^{b}
	Limed (3 t/ha)	13.83	13.53	13.79	14.12	13.59	*13.77*^{a}
	Mean	13.70^{ab}	13.32^{c}	13.56^{bc}	13.88^{a}	13.73^{ab}	
	$LSD_{0.05}$	(L) = 0.12*,(P) = 0.19***, (L×P) = 0.27***, CV = 1.2%					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	12.11	11.85	11.94	11.95	12.25	*12.02*
	Limed (3 t/ha)	12.57	12.43	12.38	11.87	11.90	*12.23*
	Mean	12.34	12.14	12.16	11.91	12.08	
	$LSD_{0.05}$	(L) = 0.02^{ns}, (P) = 0.04^{ns} ,(L×P) = 0.80^{ns},CV = 0.5%					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 58: Pol % cane of OG sugarcane in season 1 and 2

	Treatment	P_2O_5(kg/ha)					Mean
Season 1		*0*	*46*	*92*	*138*	*184*	
	Un-limed	14.14	14.14	14.22	14.69	14.18	*14.27*^{b}
	Limed (3 t/ha)	14.88	14.77	14.94	14.82	14.42	*14.77*^{a}
	Mean	14.51^{b}	14.46^{b}	14.58^{ab}	14.75^{a}	14.30^{c}	
	$LSD_{0.05}$	(L) = 0.11***,(P) = 0.17***, (L×P) = 0.25**, CV = 1.0 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	12.57	13.00	13.01	13.23	13.25	*13.01*^{a}
	Limed (3 t/ha)	13.30	13.18	13.09	13.29	13.30	*13.23*^{a}
	Mean	12.94^{c}	13.09^{b}	13.05^{b}	13.26^{a}	13.28^{a}	
	$LSD_{0.05}$	(L) = 0.03*** (P) = 0.05***,(L×P) = 0.07***,CV = 0.3 %					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

4.7.11 Sugar yield

In both seasons of the NE experiment, sugar yield increased significantly ($p \leq 0.05$) with application of 46 kg P_2O_5/ha and above in un-limed and limed plots (Table 59). Liming increased sugar yield in all P rates except 184 kg P_2O_5/ha in season 1 and 138 and 184 kg P_2O_5/ha in season 2.

In OG, season 1, higher sugar yields were obtained in plots that received P than those that did not under the un-limed and limed treatments; however, there were no differences in sugar yield among the P levels of 46, 92, 138 and 184 kg P_2O_5/ha. Liming significantly increased sugar yield in plots with P rates of 0 and 92 kg P_2O_5/ha. In season 2, sugar yield increased with P application in both the un-limed and limed plots. Generally, liming increased sugar yield (Table 60).

4.7.12 Fibre % cane

The L×P interaction had a significant effect in both seasons of the NE experiment. Application of P did not increase fibre % in un-limed plots but did so relative to the control in limed plots. However, liming had an inconsistent effect on fibre % cane. In season 2, there was a drop in fibre content with P application relative to the control in un-limed plots while the converse was true in the limed plots (Table 61).

In OG, the L×P interaction had no effect on fibre content in season 1. In season 2, fibre content declined significantly with P application at 46 and 138 kg P_2O_5/ha in un-limed and 46-184 kg P_2O_5/ha in the limed plots relative to the control (Table 62).

Table 59: Sugar yield (t/ha) of NE sugarcane in season 1 and 2

	Treatment	P_2O_5 (kg/ha)					Mean
Season 1		*0*	*46*	*92*	*138*	*184*	
	Un-limed	11.39	13.60	13.69	13.83	14.62	*13.42*^{b}
	Limed (3 t/ha)	13.58	15.20	15.73	15.68	15.28	*15.10*^{a}
	Mean	12.49^{b}	14.40^{a}	14.71^{a}	14.75^{a}	14.95^{a}	
	$LSD_{0.05}$	(L) = 0.39***,(P) = 0.61***,(LP) = 0.86*,CV = 3.5%					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	11.33	13.71	13.93	15.32	15.41	*13.94*^{b}
	Limed (3 t/ha)	13.94	16.50	16.75	15.66	15.79	*15.73*^{a}
	Mean	12.63^{c}	15.11^{ab}	15.34^{ab}	15.49^{a}	15.60^{a}	
	$LSD_{0.05}$	(L) = 0.27***,(P) = 0.43***,(L×P) = 0.61***,CV = 2.4 %					

*significant ** highly significant; *** very highly significant, ns- not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 60: Sugar yield (t/ha) of OG sugarcane in season 1 and 2

	Treatment	P_2O_5 (kg/ha)					Mean
Season 1		*0*	*46*	*92*	*138*	*184*	
	Un-limed	10.40	12.67	11.23	13.06	12.82	*12.04*^{b}
	Limed (3 t/ha)	12.82	16.43	16.85	15.37	16.03	*15.50*^{a}
	Mean	11.61^{b}	14.55^{a}	14.04^{a}	14.22^{a}	14.43^{a}	
	$LSD_{0.05}$	(L) = 0.55***,(P) = 0.86***,(LP) =1.22**,CV = 5.2 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	6.43	8.18	8.83	11.32	9.46	*8.84*^{b}
	Limed (3 t/ha)	10.78	9.50	11.40	12.29	10.66	*10.93*^{a}
	Mean	8.60^{d}	8.84^{cd}	10.11^{b}	11.81^{a}	10.06^{bc}	
	$LSD_{0.05}$	(L) = 0.91***,(P) = 1.43***,(L×P) = 2.03*,CV= 12.0 %					

*significant ** highly significant; *** very highly significant, ns- not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 61: Fibre % of NE sugarcane in season 1 and 2

Season 1	Treatment	P_2O_5 (kg/ha)					Mean
		0	*46*	*92*	*138*	*184*	
	Un-limed	17.67	16.86	17.93	17.72	16.80	*17.40*^{a}
	Limed (3 t/ha)	16.96	17.70	17.15	17.36	17.09	*17.25*^{b}
	Mean	17.31^{b}	17.28^{b}	17.54^{a}	17.54^{a}	16.95^{a}	
	$LSD_{0.05}$	(L) = 0.13**, (P) = 0.21***, (LP)= 0.29***, CV = 1.0 %					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	17.15	16.70	16.36	16.36	16.07	*16.53*^{b}
	Limed (3 t/ha)	16.66	17.02	16.83	17.40	17.80	*17.14*^{a}
	Mean	16.91	16.86	16.59	16.88	16.94	
	$LSD_{0.05}$	(L) = 0.43***, (P) = 0.10^{ns}, (L×P) = 0.14***, CV = 2.4 %					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 62: Fibre % of OG sugarcane in season 1 and 2

Season 1	Treatment	P_2O_5 (kg/ha)					Mean
		0	*46*	*92*	*138*	*184*	
	Un-limed	17.23	17.66	17.27	16.81	17.02	*17.20*
	Limed (3 t/ha)	17.37	17.46	17.24	17.35	17.52	*17.39*
	Mean	17.37	17.46	17.24	17.35	17.52	
	$LSD_{0.05}$	(L) = 0.27^{ns}, (P) = 0.43^{ns}, (L×P) = 0.61^{ns}, CV = 2.1%					
Season 2	*Treatment*	*0*	*46*	*92*	*138*	*184*	*Mean*
	Un-limed	17.00	16.18	16.95	16.79	17.17	*16.82*
	Limed (3 t/ha)	17.31	17.01	17.01	16.22	16.33	*16.78*
	Mean	17.15^{a}	16.59^{d}	16.98^{b}	16.50^{d}	16.75^{c}	
	$LSD_{0.05}$	(L) = 0.06^{ns}, (P) = 0.09***, (LP) = 0.13***, CV = 0.4 %					

*significant ** highly significant; *** very highly significant, ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

4.7.13 Diseases and pests

No notable diseases were observed in the trial plots both in NE and OG throughout the growth season; however, P-deficiency was noted on the crop at NE field A 28 in season 1 and pink sugarcane mealy bugs (*Saccharicoccus sacchari* (Cockerell)) were observed on sugarcane stalks from the ninth month after planting to maturity in NE field E 35 (Plate 6).

4.7.14 Agronomic efficiency of the treatments

Higher AE (increase in yield of sugarcane or sugar/ kg nutrient used) were observed at the lower P levels of 46 and 92 kg/ha P_2O_5 but decreased with increase in P application in both seasons in NE (Tables 65-68). Similar observations were made in the OG experiment where highest AEs for both cane and sugar yield were at the lowest level of P application in un limed and limed plots. Although increase in AEs for both cane and sugar yield was observed at 138 kg/ha P_2O_5 treatment this was lower than the record at 46 kg/ha P_2O_5 (Tables 67-70). Generally, in both NE and OG, AEs were greater in plots that received lime than those that were un limed.

4.7.15 Economic evaluation of the treatments

In NE, VCR decreased with increase in P application to un-limed and limed plots in both seasons (Tables 71 and 72). However, NR was highest in treatments of P at 46 and 92 kg/ha P_2O_5 in both seasons. Generally, NR was higher in the limed treatments than the un-limed.

In OG, VCR decreased with increase in P application to un limed and limed plots in both seasons (Tables 73 and 74). However, NR was highest in treatments of P at 46 kg/ha P_2O_5 in season 1 and 138 kg/ha P_2O_5 in season 2. Generally, NRs were higher in the limed treatments than the un-limed.


Plate 5: Phosphorus deficiency symptoms at Nucleus Estate field A 28 season 1


Plate 6: Incidence of mealy bugs (*Saccharicoccus sacchari* (Cockerel) in NE field E 35

Table 63: Sugarcane yield (t/ha) and AE of L, P rates on NE - season 1

Treatment	*P_2O_5 rate (kg/ha)*	*Y^1 t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
Un-limed	0	84.1^{e}	-	-	-
(0 t/ha)	46	103.7^{cd}	19.6	23.3	426.1
	92	102.6^{d}	18.5	22.0	201.1
	138	101.3^{d}	17.2	20.5	124.6
	184	105.4^{bcd}	21.3	25.4	115.8
Limed	0	104.3^{bcd}	20.2	24.1	-
(3 t/ha)	46	110.4^{abc}	26.3	31.3	571.7
	92	114.1^{a}	30.0	35.7	326.1
	138	111.1^{ab}	27.0	32.1	195.7
	184	112.5^{a}	28.4	33.7	154.3

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's Least significant difference (LSD) procedure at 5 % level of significance.

Table 64: Sugar yield (t/ha) and AE of L, P rates on NE - season 1

Treatment	*P_2O_5 rate (kg/ha)*	*Y^1 t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
Un-limed	0	11.39^{e}	-	-	-
(0 t/ha)	46	13.60^{d}	2.21	19.4	48.0
	92	13.69^{d}	2.30	20.2	25.0
	138	13.83^{cd}	2.44	21.4	17.7
	184	14.62^{bc}	3.23	28.4	17.6
Limed	0	13.58^{d}	2.19	19.2	-
(3 t/ha)	46	15.20^{a}	3.81	33.5	82.8
	92	15.73^{a}	4.34	38.1	47.2
	138	15.68^{a}	4.29	37.7	31.1
	184	15.28^{ab}	3.89	34.2	21.1

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's Least significant difference (LSD) procedure at 5 % level of significance.

Table 65: Sugarcane yield (t/ha) and AE of L, P rates on NE - season 2

Treatment	*P_2O_5 rate (kg/ha)*	*Y^1 t/ha)*	*YI (t/ha)*	*%*	*AE(kg sugarcane/ kg nutrient)*
Un-limed	0	93.6^{e}	-	-	-
(0 t/ha)	46	115.7^{d}	22.1	23.6	480.4
	92	116.7^{d}	23.1	24.7	251.1
	138	128.2^{bc}	34.6	37.0	250.7
	184	125.8^{c}	32.2	34.4	175.0
Limed	0	110.9^{d}	17.3	18.5	-
(3 t/ha)	46	132.8^{ab}	39.2	41.8	852.2
	92	135.3^{a}	41.7	44.5	453.3
	138	131.9^{ab}	38.3	40.9	277.5
	184	132.7^{ab}	39.1	41.8	212.5

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance.

Table 66: Sugar yield (t/ha) and AE of L, P rates on NE - season 2

Treatment	*P_2O_5 rate (kg/ha)*	*Y^1 t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
Un-limed	0	11.33^{d}			
(0 t/ha)	46	13.71^{c}	2.38	21.0	51.7
	92	13.93^{c}	2.60	22.9	28.3
	138	15.32^{b}	3.99	35.2	28.9
	184	15.41^{b}	4.08	36.0	22.2
Limed	0	13.94^{c}	2.61	23.0	-
(3 t/ha)	46	16.50^{a}	5.17	45.6	112.4
	92	16.75^{a}	5.42	47.8	58.9
	138	15.66^{b}	4.33	38.2	31.4
	184	15.79^{b}	4.46	39.4	24.2

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 67: Sugarcane yield (t/ha) and AE of L, P rates in OG - season 1

Treatment	P_2O_5 *rate (kg/ha)*	*Y*[1] *t/ha)*	*YI (t/ha)*	*%*	*AE(kg sugarcane/ kg nutrient*
Un-limed (0 t/ha)	0	73.6[e]	-	-	-
	46	89.6[c]	16.0	21.7	347.8
	92	79.0[de]	5.4	7.3	58.7
	138	89.0[c]	15.4	20.9	111.6
	184	90.4[c]	16.8	22.9	91.3
Limed (3 t/ha)	0	86.1[cd]	12.5	16.9	-
	46	111.2[ab]	37.6	51.1	817.4
	92	112.7[a]	39.1	53.2	425.0
	138	103.7[b]	30.1	40.9	218.1
	184	111.1[ab]	37.5	51.0	203.8

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 68: Sugar yield (t/ha) and AE of L, P rates in OG - season 1

Treatment	P_2O_5 *rate (kg/ha)*	*Y*[1] *t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
Un-limed (0 t/ha)	0	10.40[d]			
	46	12.67[c]	2.27	21.8	49.3
	92	11.23[d]	0.83	8.0	9.0
	138	13.06[c]	2.66	25.6	19.3
	184	12.82[c]	2.42	23.3	13.2
Limed (3 t/ha)	0	12.82[c]	2.42	23.3	
	46	16.43[ab]	6.03	58.0	131.1
	92	16.85[a]	6.45	62.0	70.1
	138	15.37[b]	4.97	47.8	36.0
	184	16.03[ab]	5.63	54.1	30.6

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 69: Sugarcane yield (t/ha) and AE of L, P rates in OG - season 2

Treatment	*P_2O_5 rate (kg/ha)*	*Y^1 t/ha)*	*YI (t/ha)*	*%*	*AE(kg sugarcane/ kg nutrient)*
Un-limed (0 t/ha)	0	78.6	-	-	-
	46	86.4^{d}	7.8	9.9	169.6
	92	94.3^{cd}	15.7	20.0	170.7
	138	111.6^{ab}	33.0	42.0	239.1
	184	114.3^{ab}	35.7	45.4	194.0
Limed (3 t/ha)	0	114.8^{ab}	36.2	46.1	-
	46	105.6^{bc}	27.0	34.4	587.0
	92	117.0^{ab}	38.4	48.9	417.4
	138	123.4^{a}	44.8	57.0	324.6
	184	108.6^{abc}	30.0	38.2	163.0

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 70: Sugar yield (t/ha) and AE of L, P rates in OG - season 2

Treatment	*P_2O_5 rate (kg/ha)*	*Y^1 t/ha)*	*YI (t/ha)*	*%*	*AE (kg sugarcane/ kg nutrient)*
Un-limed (0 t/ha)	0	6.43^{e}			
	46	8.18^{de}	1.75	27.2	38.0
	92	8.83^{cd}	2.40	37.3	26.1
	138	11.32^{ab}	4.89	76.0	35.4
	184	9.46^{bcd}	3.03	47.1	16.5
Limed (3 t/ha)	0	10.78^{abc}	4.35	67.7	
	46	9.50^{bcd}	3.07	47.7	66.7
	92	11.40^{ab}	4.97	77.3	54.0
	138	12.29^{a}	5.86	91.1	42.5
	184	10.66^{abc}	4.23	65.8	23.0

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)
[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 71: Economic evaluation of L, P fertilization on sugarcane - NE season 1

Treatment	*P rate (kg/ha P_2O_5)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
Un-limed	0	315,375.00	10,952.00	160,841.90	14.7
	46	388,875.00	18,746.00	209,476.30	11.2
	92	384,750.00	26,540.00	198,515.40	7.5
	138	379,875.00	34,334.00	186,978.70	5.4
	184	395,250.00	45,128.00	190,988.60	4.5
Limed (3 t/ha)	0	391,125.00	23,357.00	206,592.70	8.8
	46	414,000.00	31,151.00	216,360.60	6.9
	92	427,875.00	38,945.00	219,218.90	5.6
	138	416,625.00	46,739.00	202,787.90	4.3
	184	421,875.00	54,533.00	199,024.50	3.6

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio
Price of DAP= Ksh 3,897 per 50 kg bag, Price of Urea= Ksh 2,960 per 50 kg bag;
Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

Table 72: Economic evaluation of L, P fertilization on sugarcane - NE season 2

Treatment	*P_2O_5 rate (kg/ha)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
Un-limed (0 t/ha)	0	351,000.00	10,952.00	188,192.40	17.2
	46	433,875.00	18,746.00	244,024.30	13.0
	92	437,625.00	26,540.00	239,109.30	9.0
	138	480,750.00	34,334.00	264,423.80	7.7
	184	471,750.00	45,128.00	249,720.20	5.9
Limed (3 t/ha)	0	415,875.00	23,357.00	225,594.10	9.7
	46	498,000.00	31,151.00	280,850.20	9.0
	92	507,375.00	38,945.00	280,253.70	7.2
	138	494,625.00	46,739.00	262,671.10	5.6
	184	497,625.00	54,533.00	257,180.30	4.7

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio
Price of DAP= Ksh 3,897 per 50 kg bag, Price of Urea= Ksh 2,960 per 50 kg bag;
Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

Table 73: Economic evaluation of L, P fertilization on sugarcane - OG season 1

Treatment	*P_2O_5 rate (kg/ha)*	GR (Ksh)	FC (Ksh)	NR (Ksh)	VCR
Un-limed	0	276,000.00	10,952.00	130,612.40	11.9
(0 t/ha)	46	336,000.00	18,746.00	168,882.40	9.0
	92	296,250.00	26,540.00	130,571.00	4.9
	138	333,750.00	34,334.00	151,567.00	4.4
	184	339,000.00	45,128.00	147,803.60	3.5
Limed	0	322,875.00	23,357.00	154,194.90	6.6
(3 t/ha)	46	417,000.00	31,151.00	218,663.80	7.0
	92	422,625.00	38,945.00	215,188.30	5.5
	138	388,875.00	46,739.00	181,483.30	3.9
	184	416,625.00	54,533.00	194,993.90	3.6

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio
Price of DAP= Ksh 3,897 per 50 kg bag, Price of Urea= Ksh 2,960 per 50 kg bag;
Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

Table 74: Economic evaluation of L, P fertilization on sugarcane - OG season 2

Treatment	*P_2O_5 rate (kg/ha)*	GR (Ksh)	FC (Ksh)	NR (Ksh)	VCR
Un-limed	0	294,750.00	10,952.00	145,007.40	13.2
	46	324,000.00	18,746.00	159,669.60	8.5
	92	353,625.00	26,540.00	174,619.70	6.6
	138	418,500.00	34,334.00	216,632.40	6.3
	184	428,625.00	45,128.00	216,611.70	5.1
Limed	0	430,500.00	23,357.00	236,822.20	10.1
(3 t/ha)	46	396,000.00	31,151.00	202,541.40	6.5
	92	438,750.00	38,945.00	227,568.00	5.8
	138	462,750.00	46,739.00	238,199.60	5.1
	184	407,250.00	54,533.00	187,796.40	3.4

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio
Price of DAP= Ksh 3,897 per 50 kg bag, Price of Urea= Ksh 2,960 per 50 kg bag;
Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

4.8 Discussion

4.8.1 Emergence, tillering, stalk number, height and inter-node length

Results obtained from this study indicated that liming and phosphorus application had a positive effect on sugarcane growth and yield parameters. It would be argued that P availability was enhanced by application of higher doses of P or use of agricultural lime.

This result corroborated the findings of other studies which indicate that plant growth benefits from the application of P fertilizers because it increases the rate of P diffusion to roots and promotes root growth into unexploited soil (Blackburn, 1984). Malavolta (1994) and Omollo *et al*. (2002) indicate that the role of phosphorus in sugarcane is to stimulate early root formation and development. Being essential for productive growth, phosphorus firstly works on roots to provide a bigger root mass, but it is equally important in providing stronger stalk development, more tillers and quicker canopy closure. Poor phosphorus supply reduces tillering, intermodal length and root area. While phosphorus is needed in relatively small quantities, studies in Australia have shown that it is a key nutrient required for good root establishment and plant growth (Kelly *et al*., 2005).

Liming is known to mitigate the effects of P fixation by Al and Fe oxides at low pH thus making the P available to sugarcane plants (NETAFIM, 2008). A study by Leong (1980) showed that in Malaysia, liming of sugarcane on acid latosols and lateritic latosols increased cane tonnage principally through increases in the production of millable stalks as well as increases in stalk length and internode number. In the current study liming appeared to unlock the fixed P hence the requirement of only 46 kg/ha P_2O_5 to obtain response in sugarcane growth. It is worth noting that low soil pH is associated with low levels of Calcium and/or Magnesium as well as high soil acidity. As the level of soil acidity increases, Aluminium increases causing the efficiency of nutrient uptake and use by plants to decreases as well.

4.8.2 Cane and sugar yields

Results of this experiment showed that sugarcane yield increased significantly ($p \leq 0.05$) with agricultural lime and P application. Yield increase of up to 15.9 % and 24.1 % on NE and OG respectively was obtained with inclusion of agricultural lime along with the current fertilizer recommendation. With liming, the P requirement could be minimized to only 46-92 kg/ha P_2O_5. Generally, yields on the NE were higher than those on OG and yields in season 2 were higher than those of season 1. The yield increase due to liming was clearly due to increased tillering, millable stalk numbers, increased stalk height and intermodal length. Liming appears to have improved the available N, P and K status of the soil hence the utilization of the nutrients for plant growth. A study by Leong (1980) showed that in Malaysia, liming of sugarcane on acid latosols and lateritic latosols increased cane tonnage by about 10 t/ha principally through increases in the production of millable stalks as well as increases in stalk length and internode number. Singha (2006) also reports that agricultural lime applied on a clay loam soil with pH 4.8 significantly increased sugarcane yield by 5.2 to 16.9% over the control. Residual effect of liming on the cane yield in ratoon sugarcane crop were significant. Cane yields were higher on NE probably due to historical management practices that included the use of organic manure (filter press mud) on the fields.

Yields were higher in season 2 due to the slightly above normal rains recorded in the growth period of the crop compared to that of season 1. According to Mutanda (1990), MSZ sugarcane yields for plant crops are largely related to climatic factors especially rainfall. Environmental processes (rainfall, radiation, temperatures) enhance biomass accumulation and improve the cane and sugar yields.

Sugar yields increased with P application to un-limed plots but largely remained the same in the limed plots at all levels of P. Sugar yields per ha from the limed treatments were higher than those from the un limed treatment due to the higher cane yields recorded. Most of the time the application of P, while increasing yield and tons sucrose per hectare, did not affect Pol % cane significantly. Therefore, the increase in sugar yield per ha was largely due to the higher sugarcane yields realized. The results of this study contrasted with those from Malaysia (Leong, 1980) indicating that liming at 2.5 t/ha caused a drop in the sucrose percentage, thereby lowering the cane commercial sugar.

4.8.3 Juice quality and fibre content

In this study, application of lime slightly improved the quality of juice by increasing the Pol % cane. Although P application increased the Pol % cane, there was no difference in Pol % among the P treatments. Generally, Pol % cane was higher in season 1 compared with season 2 because the latter received higher rainfall in the crop growth period. Liming and P application had no effect on the fibre content. The result of this study agreed with that of Singha (2006) suggesting that application of lime increased the quality of juice by increasing the sucrose and decreasing the glucose content of cane juice caused by enhanced maturity. It was also in agreement with findings from Malaysia (Leong, 1980) where liming of sugarcane on acid latosols had no effect on the fibre content. However, a study in S. Africa (Meyer, 1976) contradicts this finding by reporting that in one trial on a high N mineralizing soil, lime treatments significantly depressed sucrose % cane from an average of 13.4 % in the control to 12.4 % in the lime treatment. The decline was accompanied by a general increase in foliar-N values in excess of 2.5 %.

4.8.4 Diseases and pests

There was no disease expression during the growth period but pink sugarcane mealy bugs (*Saccharicoccus sacchari* (Cockerell) (Hemiptera: Pseudococcidae) were observed at the nodal region on cane stalks from the 9th month to maturity. This was thought to be a response to the sucrose in the stalks at the onset of the maturation phase of the crop. The pink mealy bug is a minor pest of sugarcane in Kenya and did not pose any risk to the crop (Nzioki and Jamoza, 2006). Studies in Australia (Graham and Michael, 2005) indicate that pink mealy bug is a major pest infesting ratoons more than plant crop cane. The bugs infest above ground storage tissue as it develops feeding on the phloem and producing exudates at the nodal regions. Severe infestation could lead to lowered juice quality.

4.8.5 Agronomic efficiency (AE)

In both NE and OG experiments, agronomic efficiency of P application on sugarcane and sugar yield decreased with increase in P. The AE was greater in plots supplied with agricultural lime along with N and P possibly due to release of soil nutrients for plant growth. The results of this experiment agree with those of Abreha Kidanemariam *et al*. (2013) who found out that yield and yield attributes of wheat showed significant response to the main effects of lime and fertilizer applications. Fertilizer x lime interaction effect was significantly different in grain yield, total biomass and N and P uptake. The highest agronomic efficiency and apparent recovery efficiency were recorded in the soils treated with limes along with recommended P and NP fertilizers. In North Carolina, USA Colleen (2004) concluded that agricultural lime increased fertilizer use efficiency and saved money. He concluded that money spent on fertilizer is not well invested unless soil pH is properly adjusted first through liming.

4.8.6 Economic Evaluation

Although lower value cost rations (VCRs) were realized with liming, there were higher net returns (NR) per ha with liming and P application at 46-92 kg/ha P_2O_5 due to higher sugarcane yields realized in the limed treatment. Application of P beyond the recommended 92 kg/ha P_2O_5 cost 29-70 % more without liming and 17-105 % with liming. It would, therefore, be cost effective to lime and reduce the current recommendation of P. The lower returns on the Nucleus were associated with the high input costs related with mode of land preparation by mould board ploughs and weed management by chemicals. This calls for prudent management of the costs to realize the potential high profits due to the higher yields recorded on the Nucleus Estate compared with out growers. From these results, liming would be more beneficial to out growers than the nucleus estate if adopted.

4.9 Conclusion and Recommendation

The results of this study established that liming increased the sugarcane growth and yield parameters. Fertilization with phosphate also increased the growth and yield parameters of cane. When agricultural lime is used, the rate of P fertilizer used could be reduced without compromising the cane yield and juice quality. It is recommended that agricultural lime be included in the fertilization regime at Mumias where soil analysis results show acidic conditions. The current recommendation of 92 kg/ha P_2O_5 should be retained along with liming while P application at 46 kg/ha P_2O_5 along with liming could be adopted on high P response soils.

CHAPTER FIVE

5. EFFECTS OF AGRICULTURAL LIME, ORGANIC MANURE AND SELECTED FERTILIZERS ON SUGARCANE GROWTH, YIELD AND QUALITY

5.1 Abstract

Effects of agricultural lime, organic manure and selected fertilizers on sugarcane growth, yield and quality were determined in four trials carried out on the miller owned Nucleus Estate (NE) and Out growers (OG) fields of Mumias Sugar Zone in western Kenya. Predominantly grown sugarcane variety CO 945 was used in all experiments that were laid out in a randomized complete block design with three replications. The treatments comprised control (no manure, no fertilizer), compost (18 t/ha), compost (18 t/ha)+100 kg/ha diammonium phosphate (DAP) + 100 kg/ha Urea, agricultural lime (3 t/ha) + 200 kg/ha DAP + 200 kg/ha Urea, agricultural lime (3 t/ha) + 100 kg/ha DAP + 100 kg/ha Urea, Mavuno (350 kg/ha) + 200 kg/ha Urea and Single Super Phosphate (450 kg/ha + 200 kg/ha Urea. Soil analysis results generally indicated low levels of pH, total nitrogen, phosphorus, potassium, calcium, magnesium, organic carbon and cation exchange capacity (C.E.C) in all sites. The soils were classified as acrisols with sandy clay, clay loam and sandy clay loam texture and high bulk density in all sites. Emergence, tillering, stalk number, height, inter-node length, cane and sugar yields differed significantly ($p \leq 0.05$) among the treatments in all locations. Highest cane and sugar yields were recorded in treatments where agricultural lime and compost were included. Sugarcane juice quality was highest in the SSP+Urea treatment ranging from 13.58 - 14.43 % Pol and lowest in the compost treatment ranging from 11.43- 13.37 % Pol. Smut incidence was notable in

the compost and control treatments. Agronomic efficiency was highest in treatments where compost and agricultural lime were included, ranging from 90.3 to 253.9 kg sugarcane/kg nutrient in NE experiments and 194.6 to 481.5 kg sugarcane/kg nutrient in OG experiment. Highest net returns and value cost ratios were also recorded in treatments with compost and agricultural lime. Based on these results the inclusion of agricultural lime and organic manures in the cane production systems at Mumias is recommended.

5.2 Introduction

Sugarcane yield decline has plagued the sugar industry in Kenya over the last two decades. In the Mumias sugar zone (MSZ) that accounts for 50-60% of national production, average sugarcane yields declined by about 36% from a high of 110 t/ha in 1996 to a low of 69 t/ha in 2006. The yields declined further to only 51 t/ha in the year 2013 (Kenya Sugar Board, 2013). This trend has caused great concern to farmers, millers, economists and many others who support the sugar industry as it has forced the factory to crush immature cane or to haul cane over long distances at great cost to meet the daily mill requirement of 8,000 tons.

The sugarcane production practices in MSZ are thought to have led to serious deterioration of the soil physical and chemical quality parameters which appears to be the main contributory factor to the sharp yield decline over the years (KESREF, 2006). Growing of sugarcane on the same land is a common practice with no well defined breaks, rotations or fallow periods between the previous crop and re-plant. The loss of nutrients through erosion and crop harvests is inadequately addressed, with little or no replenishment through organic and inorganic sources (Gachene *et al*., 2000). Amounts and methods of fertilizer application largely remain the same with N-source being Urea and P-source diammonium phosphate (DAP). These fertilizers are acidifying and could have contributed to the observed decline in soil pH over the years (Wawire *et al*., 2007). Intensive mechanized tillage and infield cane loading and haulage operations in wet soil using heavy field equipment is done leading to soil compaction and stool damage. Severe soil compaction leads to high soil bulk density, low porosity, decreased water infiltration rate, water logging, poor root penetration and decreased crop yields (Muturi, 2010).

Studies from the Australian sugar industry indicate that yield decline has been associated with soil degradation caused by the long-term monoculture of sugarcane. The results show that old sugarcane land was degraded in chemical (Bramley *et al.*, 1996; Skjemstad *et al.*, 1995), physical (Ford and Bristow, 1995) and biological (Holt and Mayer, 1998; Pankhurst *et al.*, 1996; Magarey *et al.*, 1997) properties, with old land being more acid, having lower levels of organic carbon, lower cation exchange capacity, more exchangeable Al, lower levels of Cu and Zn, more plant parasitic nematodes, more root pathogens, less microbial biomass, greater soil strength (more compacted) and lower water infiltration rate and storage capacity. In India, (Yadav *et al.* , 2009) have shown that in acid soils, deficiency of Ca and Mg is usually encountered, hence application of limestone at 1-3 t/ha to the plant crop in the acid soils of Thiruvella, Kerala improved the yield and juice quality of subsequent ratoons. Soon and Arshad (2005) found a significant increase in crop yield and soil labile N pools due to liming with zero tillage compared to liming with conventional tillage. Other findings (Edwards and Lofty, 1982; Schjonning and Christensen, 1994) show that long-term addition of organic matter improves crop yield, water holding capacity, porosity, and water stable aggregation and decreases bulk density and surface crusting. Soil organic matter being an indicator of biological activity in the soil, provides substrate for the micro-organisms responsible for converting un-available plant and animal nutrients into forms that can be assimilated by plants (MSIRI, 2000).

Agricultural lime increases the pH of acidic soil and provides a source of Ca for plants and permits improved water penetration for acidic soils. Liming also mitigates the effects of P fixation by Al and Fe oxides at low pH thus making the P available to sugarcane plants (NETAFIM, 2008). In South Africa, high pH values, low Al, Na and high levels of P are reported to be associated with high sugarcane yielding points (Antwerpen *et al.*, 2007). In North Carolina, USA (Colleen, 2004) reports that agricultural lime increased fertilizer use efficiency, concluding that money spent on fertilizer is not well invested unless soil pH is properly adjusted first. Elsewhere, Abreha Kidanemariam *et al*. (2013) found out that yield and yield attributes of wheat showed significant response to the main effects of lime and fertilizer applications. Fertilizer × lime interaction effect was significantly different in grain yield, total biomass and N and P uptake. The highest agronomic efficiency and apparent recovery efficiency were also recorded in the soils treated with limes along with recommended P and NP fertilizers.

It is argued that changes to the sugarcane production system that will address soil acidity, conserve organic matter, break the monoculture, control traffic and minimize tillage are the most appropriate ways to combat the yield decline. Although some sugarcane growers have adopted the above practices, very little work has been done in MSZ to determine the effects of these practices on sugarcane growth, yield and juice quality. In addition there are no studies done to determine the cost effectiveness and profitability of adopting these practices. The objectives of this study, therefore, were (i) to evaluate the impact of selected fertilizers, organic manure and agricultural lime applications on sugarcane growth, yield and quality and ii) to determine the agronomic efficiency and cost-effectiveness of various management options.

5.3 Materials and Methods

5.3.1 Experimental site

The study was conducted from 2009 to 2011 in the Mumias sugar zone (0^{o}21'N and 34^{o} 30'E at 1314 m above sea level) on the company owned Nucleus estate (NE) and the out growers (OG) fields. The MSZ receives bi-modal rainfall ranging from 1500-2000 mm per annum with long rains peaking in April-May and short rains in September-October each year. The dominant soil type in the zone is orthic Acrisol (60%) followed by Ferralsol, Nitosol, Cambisol and Planosol (40%) (Jaetzold *et al*., 2005).

Prior to planting, soil was sampled at 0-30 cm and 30-60 cm depth for determination of textural class, bulk density and chemical properties at the MSC Agronomy field laboratory. Soil pH was determined in a soil suspension with a soil: water ratio of 1:1(w/v) using a glass electrode and pH meter S/N K 3386 Mettler Toledo 345. Soil organic matter (C), extractable P, K and total N were determined by the Calorimetric, Mehlich Double Acid, Flame photometry and Kjeldahl procedure (Blamire, 2003), respectively. Exchangeable cations were extracted with neutral 1N NH_4Oac and determined by flame emission for Na and K and by EDTA titration for Ca and Mg (Okalebo *et al*., 2002). Rainfall data was recorded daily at the trial sites and the total calculated for each month.

Soils from the NE and OG test sites at 0-30 cm and 30-60 cm were low in pH (4.7-5.4, strong to medium acid), low in total N (< 1.0%), P (< 20 ppm) except at Musanda 22 and

Khalaba 49 in OG, K (< 0.7 m.e.), organic carbon (< 2.0%), Ca (< 2.0 m.e), Mg (< 4.0 m.e) and CEC (< 12.0%) (Table 75). They were classified as acrisols with sandy clay, clay loam and sandy clay loam texture and high bulk density (> 1.4 g/cm^3) (Table 76).

Table 75: soil chemical characteristics at the study sites

Site	*pH (1:1)*	*Total N (%)*	*P Mehlich (ppm)*	*K (m.e)*	*Ca (m.e.)*	*Mg (m.e)*	*Ca/Mg ratio*	*CEC (%)*	*Org.C (%)*
NE field D 51	5.0	0.10	8.8	0.20	5.5	2.27	2.42	11.3	0.45
OG Musanda 22	4.7	0.12	25.5	0.30	1.0	1.07	0.90	10.1	1.28
NE field A 1	5.4	0.10	19.8	0.40	3.5	1.83	1.91	10.4	1.05
OG Khalaba 49	5.2	0.12	27.9	0.30	2.1	1.01	2.08	8.5	1.39
*Recommended**	5.5	> 1.0	> 20	> 0.7	> 4.0	> 2.0	2:1	> 12.0	> 2.0

Source : MSC Agronomy laboratory ; Key : NE –Nucleus Estate, OG –Out growers ;SCL –sandy clay loam; CL - clay loam; *for sugarcane (BSES,1994); Org. C- organic carbon; CEC- cation exchange capacity

Table 76: Soil physical characteristics at the study sites

Site	*depth (cm)*	*BD (g/cm^3)*	*M.C (%)*	*Porosity (%)*	*Texture*	*Total rainfall (mm)*	*LTM (mm)*
NE field D 51	0-30	1.65	32.96	37.90	SCL	2909.2	2756.4
	30-60	1.85	24.64	30.30			
OG Musanda 22	0-30	1.46	35.55	44.50	SCL	2347.7	2535.6
	30-60	1.48	45.32	44.20			
NE field A 1	0-30	1.66	27.74	36.10	SC	3147.1	2920.5
	30-60	1.72	36.40	33.80			
OG Khalaba 49	0-30	1.46	12.97	44.90	SC	2949.3	2937.0
	30-60	1.69	16.64	36.40			
Recommended for sugarcane*		1.10-1.40	$\leq$ 50.0	> 50.0		1800-2500	

Source : KESREF field laboratory ; Key : NE – Nucleus Estate, OG – Out growers ; SCL- sandy clay loam; CL- clay loam; BD – bulk density; MC – moisture content

5.3.2 Plant material

Predominantly grown sugarcane variety CO 945 was used. The variety was bred in Coimbatore, India from a cross between variety POJ 2878 and variety CO 617 (Jagathesan *et al*.,1990). Its growth habit is erect with rhizomatous tillers. The cane stalks are greenish yellow with a pinkish tinge. The internodes are cylindrical with occasional corky cracks that are the main identifying feature of the variety. Variety CO 945 is a medium maturing sugarcane cultivar harvested between 17 and 20 months (KESREF, 2004).

5.3.3 Experimental design and treatments

The treatments were laid out in a randomized complete block design (RCBD) with three replications. They comprised, control (no manure, no fertilizer), compost (18 t/ha), compost (18 t/ha)+100 kg/ha diammonium phosphate (DAP) + 100 kg/ha Urea, agricultural lime (3 t/ha) + 200 kg/ha DAP + 200 kg/ha Urea, agricultural lime (3 t/ha) + 100 kg/ha DAP + 100 kg/ha Urea, Mavuno (350 kg/ha) + 200 kg/ha Urea and Single Super Phosphate (450 kg/ha + 200 kg/ha Urea. The chemical composition was SSP (20 % P), DAP (18 % N:46 % P_2O_5:0 K_2O), Urea (46 % N) and Mavuno (10:26:10 8% Ca, 4% Mg, 4% S) as N, P and K source; organic compost (2.00 % N, 0.02 P % and 0.84 K %) and agricultural lime (Calcium hydroxide $Ca(OH)_2$ >36% and Calcium Oxide (CaO), >24% small quantities of Calcium Carbonate ($CaCo_3$), Magnesia (Mg) and trace elements).

Gross plot size was 1.5 m x 10 m x 6 rows of sugarcane = 90 m^2 and 1.2 m x 10 m x 6 rows of sugarcane = 72 m^2 in NE and OG respectively, based on the recommended standard practice for spacing. The net plot size for data collection was 1.5 m x 10 m x 4 rows = 60 m^2 and 1.2 m x 10 m x 4 rows = 48 m^2 in NE and OG respectively. Three eye-budded sugarcane setts were laid end to end in the furrows. A physical count of the number of 3-eye budded setts planted hence the total number of eye buds expected to germinate per plot was done. Other recommended agronomic practices of weed management, top dressing with N, pest and disease observation were carried out as per the local recommendations (KESREF, 2006).

5.4 Data collection and analysis

5.4.1 Emergence and tillering

A physical count of emerged shoots was done at 30, 45 and 60 days after planting in the net plots. Average emergence was calculated as the highest number of emerged shoots expressed as a percentage (%) of the expected. Tillering was assessed from 3-9 months after planting. A physical count of the total number of shoots in the net plot was done and extrapolated to establish the number of tillers/ha.

5.4.2 Foliar sampling and analysis

Nutrient uptake by the plants was monitored monthly from 3-9 months after planting from the four net rows. Each time the 3^{rd} leaf below the top visible dew lap (TVD) or spindle was sampled. Ten leaves per row were collected making 40 leaves per plot. The centre of gravity of each bundle of leaves was determined by placing on a specifically constructed table. The bundle was chopped with a sharp knife at the fulcrum and at the 20 cm measured length of the remainder towards the tip. Midribs of the sub sample were removed before weighing and recording the sample. Samples were then oven dried at $80^{o}C$ for 24 hours. Dry leaves were ground in an apex cutter. The sample was weighed and placed in a clean dry polythene bag ready for analysis. Foliar N, P and K were analyzed by Kjeldahl, Molybdenum blue and Flame photometry methods (Okalebo *et al.*,

2002) respectively. Foliar block digester model DK 42/26 Velp Scientifica was used to process the samples that were analyzed in the semi auto N distillation unit UDK 132 Velp Scientifica. Flame photometer BWB-XP from BWB Technologies Ltd and Atomic Absorption Spectrophotometer model no. AA-7000, Shimadzu were used for P and K determination.

5.4.3 Stalk height, inter-node length and population

Stalk height and number of internodes per stalk were recorded on 20 plants in the net plot at harvest. This record was also used to establish the inter-node length. A physical count of all stalks in the net plot was done and extrapolated to establish the stalk population per ha. The randomly selected plants were 2 m from the edge of either side of the plot to avoid the border effect.

5.4.4 Cane yield, sugar yield, juice quality and fibre content

Cane yield at harvest was determined by weighing all stalks from the net plots. A tripod stand and calibrated suspension balance S/N: C1080JC/574-1267 Avery were used. The weight (kg) realized was extrapolated to determine the cane yield in t/ha. Cane quality parameters at harvest were determined from 4 stalks per net plot. Each stalk was chopped into 3 equal portions i.e. top, middle and bottom. The sub samples were chopped into smaller pieces and shredded in a Jeffco cutter machine model WD02 Jefress Engineering Pty Ltd. Juice extraction was done in the disintegrator machine model WD02 Jefress Engineering Pty Ltd. A shredded sample of 1000 g was put in the cold digester with 2 liters of water and left to run for 20 minutes. The sample was sieved and 150 ml put in a conical flask. One gram of Lead sub acetate was added to the sample for clarification before filtration. From the sieved and digested juice, Brix (total dissoluble solids) was determined directly from the Refractomer Abbemat-WR Anton Paaroptotec GmbH. From the clarified juice, Pol (apparent sucrose) was read on a Polarimeter model AA-5 Optical Activity Ltd. A crushed and sieved cane sample of 100 g was placed in an oven model BR 6000 Binder world at 105^{o}C for 4 hours then re-weighed for moisture determination. From Brix, Pol reading and moisture % calculations, cane juice quality (Pol % cane), fibre % cane and sugar yield per ha were derived by the South African Sugar Technologists Association (SASTA) formulae (Schoones-Muir *et. al.*, 2009):

Pol % cane = Brix*[3-(fibre %*0.0125)], where Brix = total dissoluble solids

Fibre % cane = [(100-(Brix*3) + moisture %)/(1-(Brix*0.0125)]

Sugar yield (t/ha) = Pol % cane*cane yield (t/ha)

5.5 Diseases and pests

Diseases and pests were observed monthly from 3-9 months after planting. Smut was scored on percentage of tillers infected versus overall tiller population per ha in accordance with the International Society of Sugarcane Technologists (ISSCT) rating (MSIRI, 2000). Observation for pests particularly targeted mealy bugs and scales due to their occurrence in MSZ and likely effect on juice quality (KESREF, 2004). Ten plants per plot (i.e. five plants from the two guard rows) were randomly sampled and two nodes on every plant above the senesced leaves were stripped as documented by Sutherland *et al*. (1996).

5.6 Agronomic Efficiency

Agronomic efficiencies (AE) for fertilizer, manure and agricultural lime application were evaluated. The AE is the yield increase as a result of fertilizer or manure application per unit weight of fertilizer applied (Singh *et al*., 2008). In case of sugarcane grown for sugar, yield is both fresh cane weight and sucrose content at maturity. Agronomic efficiency was determined by the formula: AE = Increase in yield (kg sugarcane or sugar)/Nutrient applied (kg nutrient)

5.7 Economic evaluation

The costs and sugarcane yield from the various management options were recorded. Cost-benefit analysis was done using Gross returns (GR), Net returns (NR) and Value Cost Ratios (VCR) as described by Jennifer Greene and Andrew Stellman (2007) and Shehu *et al*. (2010), where:

Gross Return = sugarcane yield (t/ha) x cost per ton (Ksh)

Net Return = gross return (Ksh) – total variable costs (Ksh)

Value Cost Ratio = value of increased yield (Ksh) / cost of fertilizer used (Ksh)

5.8 Data analyses

The data collected on cane growth and yield parameters were subjected to analysis of variance using GenStat Release 13.2 (PC/Windows 7) Copyright 2010, VSN International Limited and means compared by Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance (Steel and Torrie, 1987). Agronomic efficiencies (AE) were calculated as described by Singh *et al*. (2008) and Value Cost Ratios (VCR) computed as described by Jennifer Greene and Andrew Stellman (2007) and Shehu *et al*. (2010).

5.9 Results

5.9.1 Emergence

In the NE experiment sugarcane emergence was significantly ($p \leq 0.05$) affected by the treatments in both seasons (Table 77). In season 1, emergence was higher in the Lime + ½ dose DAP + ½ dose Urea than DAP + Urea, Mavuno + Urea and the control. In season 2, emergence was highest in the compost + ½ dose DAP + ½ dose Urea followed by Lime + ½ dose DAP + ½ dose Urea and lowest in the SSP + Urea treatment. In OG, sugarcane emergence did not differ significantly ($p \leq 0.05$) among the treatments in season 1. Generally, in season 2 the highest emergence was recorded in the Compost + ½ dose DAP + ½ dose Urea and Lime + ½ dose DAP + ½ dose Urea followed by Compost. Lowest emergence was recorded in the SSP + Urea and Mavuno + Urea treatments. Overall, emergence was higher in OG than in NE. The season 1 crop had higher emergence than that of season 2.

5.9.2 Tillering

In NE highly significant differences ($p \leq 0.05$) in tillering were recorded among the treatments in both seasons (Table 78). In season 1, the highest tillering was recorded with Mavuno + Urea, followed by Compost + ½ dose DAP + ½ dose Urea and Lime + DAP + Urea. It was lowest in the control treatment. All the soil amendment treatments had higher tiller number than the control. Similar observations were made in season 2.

In OG, emergence differed significantly ($p \leq 0.05$) among the treatments in both seasons. In season 1, highest tillering was recorded for Lime + DAP + Urea and Lime + ½ dose DAP + ½ dose treatments. All treatments had higher tiller number than the control.

However, tillering was generally low at the study site due to poor crop establishment. In season 2, highest tillering was observed in Lime + DAP + Urea followed by Compost + ½ DAP + ½ Urea and SSP + Urea. Lowest tillering was recorded in the control treatment in both seasons. Generally, tillering was higher in NE compared with OG but was not different among the seasons.

5.9.3 Foliar N (%) content

In the NE season 1 experiment, foliar N content was not significantly ($p \leq 0.05$) affected by the treatments (Table 79). In season 2, the fertilizer treatments significantly affected foliar N; the compost + ½ dose DAP + ½ dose urea, full dose DAP + full dose Urea and SSP + Urea had higher foliar N content than most of the other treatments. The lowest foliar N content was in the Lime + ½ dose DAP + ½ dose Urea treatments.

In the OG experiment, foliar N was significantly ($p \leq 0.05$) affected by the treatments in both seasons (Table 81). In season 1, all treatments had similar foliar N content except Mavuno + Urea treatment that had lowest value. In season 2, foliar N was generally higher in the Lime + full dose DAP + full dose Urea, Lime + ½ dose DAP + ½ dose Urea and compost treatments than Mavuno + Urea. Foliar N content was not significantly different between the locations and seasons.

Table 77: Sugarcane emergence (%) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	45.43^{c}	36.33^{d}	48.80	37.00^{c}
Compost	52.30^{ab}	42.67^{c}	49.00	48.33^{ab}
Compost + ½ DAP + ½ Urea	47.97^{abc}	57.33^{a}	48.00	51.00^{a}
DAP + Urea	46.67^{bc}	41.00^{cd}	46.80	37.00^{c}
Lime + DAP + Urea	48.00^{abc}	36.00^{d}	48.00	51.00^{a}
Lime + ½ DAP + ½ Urea	53.30^{a}	51.33^{b}	46.60	46.67^{b}
Mavuno + Urea	46.57^{bc}	37.00^{d}	46.60	31.00^{d}
SSP + Urea	46.93^{abc}	30.33^{e}	46.90	30.00^{d}
Mean	48.40	41.50	47.60	46.33
$LSD_{0.05}$	6.45*	5.48**	8.90^{ns}	3.16**
CV %	7.6	7.5	10.7	6.1

Table 78: Sugarcane tillers/ha ('000) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	120.80^{e}	121.75^{d}	56.10^{c}	104.22^{c}
Compost	136.70^{de}	135.56^{ab}	73.70^{b}	122.92^{ab}
Compost + ½ DAP + ½ Urea	206.90^{ab}	136.45^{a}	79.90^{b}	126.18^{a}
DAP + Urea	176.90^{c}	131.50^{abc}	78.10^{b}	109.11^{c}
Lime + DAP + Urea	189.60^{bc}	132.19^{abc}	99.60^{a}	126.49^{a}
Lime + ½ DAP + ½ Urea	150.30^{d}	131.64^{abc}	95.40^{a}	119.89^{b}
Mavuno + Urea	210.00^{a}	129.65^{c}	84.00^{b}	121.43^{ab}
SSP + Urea	138.70^{de}	130.88^{bc}	78.50^{b}	126.11^{a}
Mean	166.20	131.20	80.70	119.54
$LSD_{0.05}$	19.53***	5.07***	10.34***	5.77***
CV %	6.7	2.2	7.3	3.9

Table 79: Foliar N (%) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	1.42	2.18^{bc}	2.08^{ab}	1.81^{d}
Compost	1.50	2.25^{ab}	2.18^{a}	2.41^{abc}
Compost + ½ DAP + ½ Urea	1.57	2.64^{a}	2.10^{ab}	2.08^{b}
DAP + Urea	1.45	2.31^{ab}	2.18^{a}	1.92^{d}
Lime + DAP + Urea	1.48	2.18^{bc}	2.21^{a}	2.50^{a}
Lime + ½ DAP + ½ Urea	1.59	1.82^{c}	2.11^{ab}	2.48^{ab}
Mavuno + Urea	1.59	2.07^{bc}	1.99^{b}	2.10^{cd}
SSP + Urea	1.46	2.30^{ab}	2.08^{ab}	2.12^{bcd}
Mean	1.51	2.22	2.12	2.18
$LSD_{0.05}$	0.17^{ns}	0.39*	0.16*	0.36*
CV %	6.5	10.0	4.2	14.1

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; Means with the same superscript within a column are not significantly different at $p \leq 0.05$

5.9.4 Foliar P (%) content

In season 1, foliar P content was not significantly different ($p \leq 0.05$) among the treatments in both NE and OG. In season 2, foliar P content differed significantly only in the OG experiment. Lime + ½ dose DAP + ½ dose Urea treatment had higher foliar P content than all the treatments except compost alone while the control treatment generally had the lowest foliar P content (Table 80). Foliar P content was not significantly different among the locations and seasons.

5.9.5 Foliar K (%) content

In the NE experiment, foliar K content was significantly ($p \leq 0.05$) affected by the treatments in both seasons (Table 81). In season 1, K content was higher in the DAP + Urea, Compost + ½ dose DAP + ½ dose Urea and Compost treatments but lower in the Mavuno + Urea, lime + ½ dose DAP + ½ dose Urea and control treatments. In season 2, foliar K was higher in the compost, compost + ½ dose DAP + ½ dose Urea and Lime + ½ dose DAP + ½ dose than all the other treatments. DAP + Urea and control treatments had significantly lower p content than all the other treatments.

In OG, foliar K content differed significantly ($p \leq 0.05$) in both seasons (Table 81). In season 1, K content was similar in all treatments except that compost and lime + DAP + Urea had higher K content than the control and SSP + Urea treatments. In season 2, foliar K content was higher in the compost and lime + DAP + Urea treatments than the control and all other treatments. Generally, foliar K did not differ between locations and seasons.

Table 80: foliar P (%) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	0.18	0.18	0.18	0.09^{d}
Compost	0.22	0.20	0.19	0.19^{ab}
Compost + ½ DAP + ½ Urea	0.22	0.21	0.18	0.12^{c}
DAP + Urea	0.20	0.19	0.18	0.10^{cd}
Lime + DAP + Urea	0.19	0.16	0.17	0.21^{a}
Lime + ½ DAP + ½ Urea	0.19	0.16	0.18	0.17^{b}
Mavuno + Urea	0.18	0.18	0.17	0.12^{c}
SSP + Urea	0.20	0.19	0.17	0.12^{c}
Mean	0.20	0.18	0.18	0.14
$LSD_{0.05}$	0.04^{ns}	0.03^{ns}	0.03^{ns}	0.02*
CV %	12.0	8.4	9.8	8.8

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns- not significant at ($p<0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

Table 81: Foliar K (%) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	1.03^{d}	0.50^{e}	0.48^{b}	1.32^{b}
Compost	1.23^{abc}	1.03^{a}	0.82^{a}	1.84^{a}
Compost + ½ DAP + ½ Urea	1.27^{ab}	0.99^{a}	0.58^{ab}	1.23^{b}
DAP + Urea	1.28^{a}	0.43^{f}	0.48^{ab}	1.20^{b}
Lime + DAP + Urea	1.13^{cd}	0.88^{b}	0.84^{a}	1.79^{a}
Lime + ½ DAP + ½ Urea	1.09^{d}	0.98^{a}	0.68^{ab}	1.35^{b}
Mavuno + Urea	1.10^{d}	0.77^{c}	0.53^{ab}	1.20^{b}
SSP + Urea	1.15^{bcd}	0.60^{d}	0.46^{b}	1.21^{b}
Mean	1.16	0.77	0.61	1.39
$LSD_{0.05}$	0.12*	0.05*	0.31*	0.18*
CV %	5.9	3.6	28.9	13.7

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns- not significant at ($p<0.05$) using Fischer's least significant Difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

5.9.6 Stalk height

In the NE experiment, there were significant differences ($p \leq 0.05$) in stalk height among the treatments in both seasons (Table 82). In season 1, except for control and Mavuno + Urea which had the shortest stalks, stalk height was similar among the other treatments. In season 2, the highest stalk height was observed in the Lime + DAP + Urea treatment. The shortest stalks were observed in the SSP + Urea treatment. In OG, poorly grown and stunted stalks were observed in season 1 due to infestation by witch weed (*Striga species*.) in all treatments. However, stalks were taller in the DAP + Urea, compost and compost + ½ dose DAP + ½ Urea treatments and shorter in the Mavuno + Urea and control treatments. In season 2, tallest stalks were recorded in the Lime + ½ dose DAP + ½ dose Urea and shortest in the control treatment (Table 82). Overall, NE cane stalks were taller than those of OG. In NE season 1 canes were taller than season 2 while the contrast occurred for OG where season 1 crop was shorter than that of season 2.

Table 82: Stalk height (cm) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	242.5^{b}	152.0^{c}	81.3^{d}	140.1^{e}
Compost	254.3^{a}	162.0^{b}	95.4^{a}	171.2^{c}
Compost + ½ DAP + ½ Urea	256.8^{a}	160.6^{b}	94.4^{a}	153.5^{d}
DAP + Urea	255.9^{a}	164.6^{b}	95.7^{a}	152.7^{d}
Lime + DAP + Urea	252.7^{a}	176.5^{a}	92.5^{ab}	171.6^{c}
Lime + ½ DAP + ½ Urea	250.5^{ab}	155.9^{c}	92.0^{ab}	189.6^{a}
Mavuno + Urea	241.4^{b}	164.0^{b}	85.0^{cd}	181.3^{b}
SSP + Urea	254.2^{a}	141.4^{d}	88.2^{bc}	170.9^{c}
Mean	251.0	159.6	90.6	166.4
$LSD_{0.05}$	9.57*	4.3***	4.9*	2.0***
CV %	2.2	1.5	3.1	1.0

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns- not significant at ($p<0.05$) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

5.9.7 Inter-node length

In the NE experiment, the treatments had a significant ($p \leq 0.05$) effect on inter-node length in both seasons (Table 83). Longest internodes were recorded in the compost + ½ dose DAP + ½ dose Urea and DAP + Urea treatments while the shortest were in the compost treatment in season 1. In season 2, lime + ½ dose DAP + ½ dose Urea, DAP + Urea and compost recorded the longest internodes while control treatment recorded the shortest. Generally, longer internodes were recorded in the compost and limed treatments.

In OG, shortest internodes were recorded in season 1 experiment following *Striga* infestation at the study site; inter-node length did not differ significantly ($p \leq 0.05$) among the treatments. In season 2, the longest internodes were recorded in compost treatment and the shortest in the control (Table 83). Overall, there was better growth on NE compared with OG.

5.9.8 Stalk population (‘000)

In NE, stalk population differed significantly ($p \leq 0.05$) among the treatments in both seasons (Table 84). In season 1, higher stalks/ha were recorded in the lime + ½ dose DAP + ½ dose Urea, compost + ½ dose DAP + ½ dose Urea and compost treatments. The control and SSP + Urea treatments had fewer stalks. In season 2, the highest stalks/ha were recorded in compost + ½ dose DAP + ½ dose Urea followed by compost. The control treatment recorded lowest stalk population in both seasons.

In OG season 1, lime + DAP + Urea and lime + ½ DAP + ½ Urea had higher stalk population than all the other treatments. In season 2, stalk population was lowest in the DAP + Urea and control treatments. Generally, stalk population was higher on NE compared with OG but was comparable among the seasons (Table 84).

Table 83: inter-node length (cm) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	10.80^{c}	8.43^{d}	4.40	5.30^{g}
Compost	10.99^{bc}	9.50^{a}	4.52	8.40^{a}
Compost + ½ DAP + ½ Urea	12.32^{a}	8.70^{cd}	4.24	6.70^{d}
DAP + Urea	11.97^{a}	9.60^{a}	4.44	6.20^{e}
Lime + DAP + Urea	11.18^{bc}	9.13^{b}	4.37	7.30^{c}
Lime + ½ DAP + ½ Urea	11.37^{b}	9.73^{a}	4.32	7.20^{c}
Mavuno + Urea	11.21^{bc}	9.13^{b}	4.48	7.50^{b}
SSP + Urea	11.37^{b}	9.03^{bc}	4.27	5.60^{f}
Mean	11.40	9.16	4.38	6.78
$LSD_{0.05}$	0.56***	0.37***	0.31^{ns}	0.17***
CV %	0.7	2.3	4.0	1.8

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns- not significant at ($p<0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

Table 84: Stalk population/ha ('000) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	87.7^{d}	98.4^{d}	85.6^{b}	87.7^{c}
Compost	112.2^{ab}	109.6^{ab}	90.3^{b}	103.5^{a}
Compost + ½ DAP + ½ Urea	118.0^{a}	110.3^{a}	89.5^{b}	106.2^{a}
DAP + Urea	108.0^{b}	106.3^{abc}	91.7^{b}	91.9^{c}
Lime + DAP + Urea	109.2^{b}	106.9^{abc}	104.5^{a}	106.5^{a}
Lime + ½ DAP + ½ Urea	121.2^{a}	106.4^{abc}	104.4^{a}	100.9^{b}
Mavuno + Urea	108.3^{b}	104.8^{c}	88.1^{b}	102.2^{ab}
SSP + Urea	89.2^{d}	105.8^{bc}	89.4^{b}	106.2^{a}
Mean	106.7	106.1	92.9	100.6
$LSD_{0.05}$	9.56***	4.10***	7.24**	4.83***
CV %	5.1	2.2	4.4	4.0

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns- not significant at ($p<0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

5.9.9 Cane yield (t/ha)

In NE, there were significant ($p \leq 0.05$) differences among treatments in cane yield in both seasons (Table 85). In season 1, highest yield was observed in the Lime + ½ dose DAP + ½ dose Urea treatment while the lowest was observed in the control. Generally, Mavuno + Urea had lower cane yield than all treatments except the control. In season 2, high and similar yields were observed in compost, DAP + Urea and compost + ½ dose DAP + ½ dose Urea treatments; the lowest yields were similarly observed in the control.

In OG season 1, high yields were observed in compost, compost + ½ dose DAP + ½ dose Urea, lime + DAP + Urea and lime + ½ dose DAP + ½ dose Urea. Control and SSP + Urea treatments had the lowest cane yields/ha. In season 2, the highest cane yield was observed in lime + DAP + Urea followed by compost + ½ dose DAP + ½ dose Urea; it was lowest in the control followed by SSP + Urea treatments(Table 85). Overall, cane yield was higher in NE compared with OG and higher in season 1 than in season 2.

5.9.10 Sugarcane juice quality (Pol %)

In the NE experiment, Pol % cane was significantly ($p \leq 0.05$) different among the treatments in both seasons (Table 86). In season 1, higher juice quality was recorded in SSP + Urea treatment than control, compost alone, compost + ½ dose DAP + ½ dose Urea and Mavuno + Urea. In season 2, Pol % cane was higher in the control, SSP + Urea and lime + ½ dose DAP + ½ dose Urea treatments than in all other treatments. The DAP + Urea treatment had the lowest Pol % cane.

In OG, Pol % was lower in the compost and Mavuno + Urea treatments than all other treatments in season 1. In season 2, highest Pol % was recorded in SSP + Urea treatment while compost had the lowest Pol % (Table 86). Overall, Pol % cane was higher in NE compared with OG and in season 1 compared with season 2.

Table 85: Sugarcane yield (t/ha) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	116.1^{e}	84.6^{d}	89.5^{d}	57.3^{e}
Compost	128.3^{bc}	109.6^{a}	134.9^{a}	67.0^{c}
Compost + ½ DAP + ½ Urea	124.1^{cd}	106.1^{a}	133.7^{a}	76.8^{b}
DAP + Urea	132.4^{b}	108.9^{a}	115.9^{c}	59.4^{e}
Lime + DAP + Urea	128.6^{bc}	102.1^{b}	127.7^{ab}	84.4^{a}
Lime + ½ DAP + ½ Urea	137.3^{a}	102.5^{b}	133.8^{a}	75.2^{b}
Mavuno + Urea	123.5^{d}	98.6^{c}	123.5^{bc}	67.7^{c}
SSP + Urea	127.7^{bcd}	102.2^{b}	114.4^{c}	62.7^{d}
Mean	127.3	101.8	121.7	68.8
$LSD_{0.05}$	4.74***	3.1***	8.3***	2.93
CV %	2.1	1.7	3.9	2.9

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns- not significant at ($p<0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

Table 86: Sugarcane juice quality (Pol % cane) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	13.73^{cd}	13.60^{a}	14.21^{a}	13.25^{c}
Compost	13.37^{d}	13.03^{c}	13.26^{c}	11.43^{g}
Compost + ½ DAP + ½ Urea	13.61^{cd}	13.03^{c}	14.41^{a}	12.26^{f}
DAP + Urea	14.27^{ab}	12.39^{e}	14.38^{a}	12.94^{d}
Lime + DAP + Urea	14.26^{ab}	12.78^{d}	14.30^{a}	12.25^{f}
Lime + ½ DAP + ½ Urea	14.05^{abc}	13.56^{a}	14.35^{a}	13.42^{b}
Mavuno + Urea	13.81^{bcd}	13.26^{b}	13.74^{b}	12.66^{e}
SSP + Urea	14.38^{a}	13.58^{a}	14.43^{a}	13.60^{a}
Mean	13.94	13.15	14.16	12.72
$LSD_{0.05}$	0.48**	0.10	0.33**	0.08**
CV %	2.0	0.4	1.3	0.5

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; ns- not significant at ($p<0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

5.9.11 Sugar yield (t/ha)

In the NE experiment, **s**ugar yield differed significantly ($p < 0.05$) among treatments in both seasons 1 and 2 (Table 87). In season 1, sugar yield was highest in the treatment with lime + ½ dose DAP + ½ dose Urea followed by DAP + Urea and SSP + Urea. Lowest sugar yield was recorded in Mavuno + Urea and Compost + ½ dose DAP + ½ dose Urea treatments. In season 2, sugar yield was highest in Compost treatment followed by Lime + ½ DAP + ½ Urea and SSP + Urea. Sugar yield was lowest in the control treatment.

In OG season 1, sugar yield was higher in the compost, compost + ½ dose DAP + ½ dose Urea, lime + DAP + Urea and lime + ½ dose DAP + ½ dose Urea treatments; lowest yield was in the control treatment. In season 2, sugar yield was higher in the lime + DAP + Urea, lime + ½ dose DAP + ½ dose Urea and compost + ½ dose DAP + ½ dose Urea treatments. Lower sugar yield was observed in the control, compost and DAP + Urea treatments (Table 87). Overall, sugar yield was higher in season 1 compared with season 2 and in NE compared with OG.

5.9.12 Fibre % cane

In the NE experiment, fibre % cane was significantly ($p \leq 0.05$) different among the treatments in both seasons. In season 1, higher fibre content was recorded in the SSP + Urea, Mavuno + Urea and DAP + Urea treatments (Table 88). Lowest fibre level was recorded in the compost + ½ dose DAP + ½ dose Urea treatment. In season 2, higher fibre % cane was recorded in the lime + ½ dose DAP + ½ dose Urea, control and lime + DAP + Urea treatments. Low fibre was recorded in the compost and Mavuno + Urea treatments.

In OG season 1, higher fibre content was recorded with DAP + Urea and compost + ½ dose DAP + ½ dose Urea treatments. Lower fibre content was in the Mavuno + Urea, SSP + Urea, compost and control treatments. In season 2, fibre % cane was highest in the control treatment but lowest in compost and lime + ½ dose DAP + ½ dose Urea (Table 88). Overall, fibre % cane was same at NE and OG and lower in season 1 than season 2.

Table 87: Sugar yield (t/ha) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	17.77^{cd}	11.51^{e}	12.72^{d}	7.60^{d}
Compost	17.15^{de}	14.28^{a}	19.35^{a}	7.70^{d}
Compost + ½ DAP + ½ Urea	17.06^{e}	13.83^{bc}	19.26^{a}	9.40^{b}
DAP + Urea	18.90^{ab}	13.49^{c}	16.66^{c}	7.70^{d}
Lime + DAP + Urea	18.34^{bc}	13.05^{d}	18.27^{ab}	10.30^{a}
Lime + ½ DAP + ½ Urea	19.57^{a}	13.90^{ab}	18.01^{ab}	10.10^{a}
Mavuno + Urea	17.06^{e}	13.07^{d}	16.96^{bc}	8.60^{c}
SSP + Urea	18.36^{bc}	13.88^{abc}	16.51^{c}	8.50^{c}
Mean	18.03	13.38	17.22	8.70
$LSD_{0.05}$	0.68^{**}	0.40**	1.34**	0.37**
CV %	2.2	1.7	4.5	2.8

* p<0.05; ** p<0.01; *** p<0.001; ns- not significant at (p<0.05) using Fischer's least significant difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

Table 88: Fibre % cane in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	16.80^{bc}	17.42^{a}	16.57^{cd}	17.64^{a}
Compost	16.66^{c}	17.03^{c}	16.55^{cd}	17.01^{e}
Compost + ½ DAP + ½ Urea	16.07^{d}	17.23^{b}	17.53^{a}	17.10^{d}
DAP + Urea	16.99^{ab}	17.24^{b}	17.64^{a}	17.46^{b}
Lime + DAP + Urea	16.68^{c}	17.41^{a}	16.72^{bc}	17.07^{de}
Lime + ½ DAP + ½ Urea	16.91^{b}	17.46^{a}	17.01^{b}	17.01^{e}
Mavuno + Urea	17.01^{ab}	17.02^{c}	16.28^{d}	17.22^{c}
SSP + Urea	17.20^{a}	17.28^{b}	16.42^{cd}	17.03^{de}
Mean	16.79	17.26	16.84	17.19
$LSD_{0.05}$	0.21*	0.13*	0.41*	0.08***
CV %	0.7	0.4	1.4	0.4

* p<0.05; ** p<0.01; *** p<0.001; ns- not significant at (p<0.05) using Fischer's least significant difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

5.9.13 Diseases and pests

Smut incidences were observed in the organic compost and control treatments in both seasons in the NE and OG experiments. In season 1, higher expression of smut was in the control and compost than in all the other treatments in NE while in OG infestation was observed in the compost, compost + ½ dose DAP + ½ dose Urea and control treatments. In season 2, smut incidence was highest in the compost followed by compost + ½ dose DAP + ½ dose Urea and the control treatments in the NE experiment. In OG, smut was highest in the compost treatment followed by the control. The rest of the treatments did not differ significantly in smut attack. Infestation by pink sugarcane mealy bugs (*Saccharicoccus sacchari* (Cockerell)) and scale insects (*Eulacapsis tegalensis* Zehnt.) was observed in Musanda 22 and NE field A1 in season 1 and season 2 respectively (Table 89 and Plates 7 - 10).

Table 89: Smut infestation (%) in season 1 and 2

Treatment	Nucleus Estate		Out growers	
	Season 1	Season 2	Season 1	Season 2
Control	0.83^{a}	0.30^{c}	1.33^{a}	0.85^{b}
Compost	0.77^{a}	2.00^{a}	1.83^{a}	1.45^{a}
Compost + ½ DAP + ½ Urea	0.40^{b}	1.57^{b}	1.37^{a}	0.11^{c}
DAP + Urea	0.00^{c}	0.00^{d}	0.00^{b}	0.00^{c}
Lime + DAP + Urea	0.00^{c}	0.00^{d}	0.00^{b}	0.00^{c}
Lime + ½ DAP + ½ Urea	0.00^{c}	0.00^{d}	0.00^{b}	0.00^{c}
Mavuno + Urea	0.03^{c}	0.00^{d}	0.00^{b}	0.00^{c}
SSP + Urea	0.00^{c}	0.00^{d}	0.00^{b}	0.00^{c}
Mean	0.25	0.48	0.57	0.30
$LSD_{0.05}$	0.19^{***}	0.24***	0.57***	0.21***
CV %	42.6	27.7	57.7	46.0

* p<0.05; ** p<0.01; *** p<0.001; ns- not significant at (p<0.05) using Fischer's least significant difference (LSD) procedure at 5 % level; means with the same superscript within a column are not significantly different at $p \leq 0.05$

Plate 7: Incipient shoot of smut (*Ustilago scitaminea* H & P. Sydow)
Out growers Khalaba field 49 (season 2)

Plate 8: Full blown shoot of smut (*Ustilago scitaminea* H & P. Sydow)
Out growers Musanda field 22 (season 1)

Plate 9: Incidence of mealy bugs (*Saccharicoccus sacchari* (Cockerell)) in Musanda field 22 (season 1)

Plate 10: Incidence of scale insect (*Eulacapsis tegalensis* Zehnt.) in Nucleus Estate A1 (season 2)

5.9.14 Agronomic efficiency (AE) of the treatments on sugarcane yield

Agronomic efficiency ranged from 33.9 to 230.4 and 64.2 to 253.9 in the NE experiment in seasons 1 and 2 respectively. In season 1, highest AE on cane was recorded on lime + ½ dose DAP + ½ dose Urea followed by compost and DAP + Urea. The lowest AE was observed with Mavuno. In season 2, highest AE was observed for compost followed by compost + ½ dose DAP + ½ dose Urea and lime + ½ dose DAP + ½ dose Urea. Lowest AE was recorded on Mavuno + Urea (Tables 90-91).

In OG, higher AE was indicated in treatments with lime and compost in seasons 1 and 2, ranging from 136.8 to 481.5 and 29.7 to 212.0 respectively. In season 1, AE was highest for lime + ½ dose DAP + ½ dose Urea followed by compost + ½ dose DAP + ½ dose Urea and compost. Lowest AE was recorded in the SSP + Urea treatment. In season 2, AE was highest in the compost + ½ dose DAP + ½ dose Urea 50 followed by Lime + ½ dose DAP + ½ dose Urea and Lime + DAP + Urea. Lowest AE was recorded in the DAP + Urea treatment (Table 92-93).

5.9.15 Agronomic efficiency (AE) of the treatments on sugar yield

For sugar yield, AE ranged from -7.7 to 19.6 and 7.2 to 26.0 in seasons 1 and 2 of the NE experiment respectively. In season 1, highest AE was recorded in the lime + ½ dose DAP + ½ dose Urea but was negative in Mavuno + Urea, compost and compost + ½ dose DAP + ½ dose Urea treatments. In season 2, AE was highest in the lime + ½ dose DAP + ½ dose Urea followed by compost + ½ dose DAP + ½ dose Urea and compost treatments. AE was lowest in the Mavuno + Urea treatment (Table 94-95).

For sugar yield in OG, AE ranged from 19.4 to 71.1 and was highest in the compost + ½ dose DAP + ½ dose Urea followed by lime + ½ dose DAP + ½ dose Urea and compost treatments in season 1 but lowest in the Mavuno + Urea treatment. In season 2, AE was highest in lime + ½ dose DAP + ½ dose Urea followed by compost + ½ dose DAP + ½ dose Urea and lime + DAP + Urea. It was lowest in the Mavuno + Urea treatment (Tables 96 and 97).

Table 90: Agron. efficiency (AE) of N, P, lime and compost on cane yield - NE season 1

Treatment	*N rate (kg/ha)*	*P_2O_5 rate (kg/ha)*	*Y^1 t/ha)*	*YI (t/ha)*	*%*	*AE*
Control	-	-	116.1^{e}	-	-	-
Compost	108	8.4	128.3^{bc}	12.2	10.5	90.3
Compost + ½ DAP + ½ Urea	46	46	124.1^{cd}	8.0	6.9	87.0
DAP + Urea	92	92	132.4^{b}	16.3	14.0	88.6
Lime + DAP + Urea	92	92	128.6^{bc}	12.5	10.8	67.9
Lime + ½ DAP + ½ Urea	46	46	137.3^{a}	21.2	18.3	230.4
Mavuno + Urea	127	91	123.5^{d}	7.4	6.4	33.9
SSP + Urea	90	92	127.7^{bcd}	11.6	10.0	63.7

Y= Yield, YI= Yield increase over control, AE = agronomic efficiency (kg sugarcane/kg nutrient); [1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 91: Agron. efficiency (AE) of N, P, lime and compost on cane yield - NE season 2

Treatment	*N rate (kg/ha)*	*P_2O_5 rate (kg/ha)*	*Y^1 (t/ha)*	*YI (t/ha)*	*%*	*AE*
Control	-	-	84.6^{d}	-	-	-
Compost	108	8.4	109.6^{a}	25.0	29.6	253.9
Compost + ½ DAP + ½ Urea	46	46	106.1^{a}	21.5	25.4	233.7
DAP + Urea	92	92	108.9^{a}	24.3	28.7	132.1
Lime + DAP + Urea	92	92	102.1^{b}	17.5	20.7	95.1
Lime + ½ DAP + ½ Urea	46	46	102.5^{b}	17.9	21.2	194.6
Mavuno + Urea	127	91	98.6^{c}	14.0	16.5	64.2
SSP + Urea	90	92	102.2^{b}	17.6	20.8	96.7

Y= Yield, YI= Yield increase over control, AE = agronomic efficiency (kg sugarcane/kg nutrient); [1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 92: Agron. efficiency (AE) of N, P, lime and compost on cane yield - OG season 1

Treatment	*N rate (kg/ha)*	*P_2O_5 rate (kg/ha)*	*Y^1 (t/ha)*	*YI (t/ha)*	*%*	*AE*
Control	-	-	89.5^{d}	-	-	-
Compost	108	8.4	134.9^{a}	45.4	50.7	435.8
Compost + ½ DAP + ½ Urea	46	46	133.7^{a}	44.2	49.4	480.4
DAP + Urea	92	92	115.9^{c}	26.4	29.5	143.5
Lime + DAP + Urea	92	92	127.7^{ab}	38.2	42.7	207.5
Lime + ½ DAP + ½ Urea	46	46	133.8^{a}	44.3	49.5	481.5
Mavuno + Urea	127	91	123.5^{bc}	34.0	38.0	156.0
SSP + Urea	90	92	114.4^{c}	24.9	27.8	136.8

Y= Yield, YI= Yield increase over control, AE = agronomic efficiency (kg sugarcane/kg nutrient); [1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer’s Least Significant Difference (LSD) procedure at 5 % level of significance.

Table 93: Agron. efficiency (AE) of N, P, lime and compost on cane yield - OG season 2

Treatment	*N rate (kg/ha)*	*P_2O_5 rate (kg/ha)*	*Y^1 (t/ha)*	*YI (t/ha)*	*%*	*AE*
Control	-	-	57.3^{e}	-	-	-
Compost	108	8.4	67.0^{c}	9.7	16.9	145.4
Compost + ½ DAP + ½ Urea	46	46	76.8^{b}	19.5	34.0	212.0
DAP + Urea	92	92	59.4^{e}	2.1	3.7	11.4
Lime + DAP + Urea	92	92	84.4^{a}	27.1	47.3	147.3
Lime + ½ DAP + ½ Urea	46	46	75.2^{b}	17.9	31.2	194.6
Mavuno + Urea	127	91	67.7^{c}	10.4	18.2	47.7
SSP + Urea	90	92	62.7^{d}	5.4	9.4	29.7

Y= Yield, YI= Yield increase over control, AE = agronomic efficiency (kg sugarcane/kg nutrient); [1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer’s least significant difference (LSD) procedure at 5 % level of significance.

Table 94: Agron. efficiency (AE) of N, P, lime and compost on cane yield - NE season 1

Treatment	*N rate (kg/ha)*	*P_2O_5 rate (kg/ha)*	*Y^1 t/ha)*	*YI (t/ha)*	*%*	*AE*
Control	-	-	17.77^{cd}	-	-	-
Compost	108	8.4	17.15^{de}	-0.62	-3.5	-5.3
Compost + ½ DAP + ½ Urea	46	46	17.06^{e}	-0.71	-4.0	-7.7
DAP + Urea	92	92	18.90^{ab}	1.13	6.4	6.1
Lime + DAP + Urea	92	92	18.34^{bc}	0.57	3.2	3.1
Lime + ½ DAP + ½ Urea	46	46	19.57^{a}	1.80	10.1	19.6
Mavuno + Urea	127	91	17.06^{e}	-0.71	-4.0	-3.3
SSP + Urea	90	92	18.36^{bc}	0.59	3.3	3.2

Y= Yield, YI= Yield increase over control, AE = agronomic efficiency (kg sugarcane/kg nutrient); [1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 95: Agron. efficiency (AE) of N, P, lime and compost on sugar yield - NE season 2

Treatment	*N rate (kg/ha)*	*P_2O_5 rate (kg/ha)*	*Y^1 (t/ha)*	*YI (t/ha)*	*%*	*AE*
Control	-	-	11.51^{e}	-	-	-
Compost	108	8.4	14.28^{a}	2.77	24.1	23.8
Compost + ½ DAP + ½ Urea	46	46	13.83^{bc}	2.32	20.2	25.2
DAP + Urea	92	92	13.49^{c}	1.98	17.2	10.8
Lime + DAP + Urea	92	92	13.05^{d}	1.54	13.4	8.4
Lime + ½ DAP + ½ Urea	46	46	13.90^{ab}	2.39	20.8	26.0
Mavuno + Urea	127	91	13.07^{d}	1.56	13.6	7.2
SSP + Urea	90	92	13.88^{abc}	2.37	20.6	13.0

Y= Yield, YI= Yield increase over control, AE = agronomic efficiency (kg sugarcane/kg nutrient); [1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 96: Agron. efficiency (AE) of N, P, lime and compost on sugar yield - OG season 1

Treatment	*N rate (kg/ha)*	*P_2O_5 rate (kg/ha)*	*Y^1 (t/ha)*	*YI (t/ha)*	*%*	*AE*
Control	-	-	12.72^{d}	-	-	-
Compost	108	8.4	19.35^{a}	6.63	52.1	57.0
Compost + ½ DAP + ½ Urea	46	46	19.26^{a}	6.54	51.4	71.1
DAP + Urea	92	92	16.66^{c}	3.94	31.0	21.4
Lime + DAP + Urea	92	92	18.27^{ab}	5.55	43.6	30.2
Lime + ½ DAP + ½ Urea	46	46	18.01^{ab}	5.29	41.6	57.5
Mavuno + Urea	127	91	16.96^{bc}	4.24	33.3	19.4
SSP + Urea	90	92	16.51^{c}	3.79	29.8	20.8

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)

[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

Table 97: Agronomic efficiency (AE) of N, P, lime and compost on sugar yield - OG season 2

Treatment	*N rate (kg/ha)*	*P_2O_5 rate (kg/ha)*	*Y^1 (t/ha)*	*YI (t/ha)*	*%*	*AE*
Control	-	-	7.60^{d}	-	-	-
Compost	108	8.4	7.70^{d}	0.10	1.3	0.9
Compost + ½ DAP + ½ Urea	46	46	9.40^{b}	1.80	23.7	19.6
DAP + Urea	92	92	7.70^{d}	0.10	1.3	0.5
Lime + DAP + Urea	92	92	10.30^{a}	2.70	35.5	14.7
Lime + ½ DAP + ½ Urea	46	46	10.10^{a}	2.50	32.9	27.2
Mavuno + Urea	127	91	8.60^{c}	1.00	13.2	4.6
SSP + Urea	90	92	8.50^{c}	0.90	11.8	4.9

Y= Yield, YI= Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient)

[1]Means with the same superscript within the column are not significantly different ($p < 0.05$) using Fischer's least significant difference (LSD) procedure at 5 % level of significance.

5.9.16 Economic evaluation of the treatments

From table 100, highest VCR in NE was indicated for the lime + ½ dose DAP + ½ dose Urea followed by DAP + Urea and compost treatments in season 1. Net returns followed the same pattern. In season 2, VCR was highest in the compost, followed by DAP + Urea and lime + ½ dose DAP + ½ dose Urea treatments. The lowest net return was with the Mavuno + Urea treatment (Table 99).

From tables 100 and 101, although the highest VCRs in OG season 1 were indicated for the lime + ½ dose DAP + ½ dose Urea followed by compost and DAP + Urea, net returns did not follow the same pattern, being highest in the compost, lime + ½ dose DAP + ½ dose Urea and compost + ½ dose DAP + ½ dose Urea treatments. In season 2, VCRs were generally low due to low yields recorded. However, the highest VCR was in the lime + ½ dose DAP + ½ dose Urea treatment followed by compost and lime + DAP +Urea treatments. Net returns did not follow the same pattern being highest in the lime + DAP +Urea followed by lime + ½ dose DAP + ½ dose Urea and compost + ½ dose DAP + ½ dose Urea treatments.

Table 98: Economic evaluation of liming and OM fertilization on sugarcane - NE season 1

Treatment	*Yield (t/ha)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
Control	116.1^{e}	435,375.00	0.00	279,497.30	-
Compost	128.3^{bc}	481,125.00	27,000.00	289,237.90	10.7
Compost + ½ DAP + ½ Urea	124.1^{cd}	465,375.00	40,714.00	262,869.30	6.5
DAP + Urea	132.4^{b}	496,500.00	27,428.00	301,163.20	11.0
Lime + DAP + Urea	128.6^{bc}	482,250.00	39,833.00	277,308.80	7.0
Lime + ½ DAP + ½ Urea	137.3^{a}	514,85.00	26,119.00	317,235.90	12.1
Mavuno + Urea	123.5^{d}	463,125.00	34,940.00	266,835.50	7.6
SSP + Urea	127.7^{bcd}	478,875.00	38,390.00	276,040.10	7.2

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio

Price of DAP = Ksh 3,897; SSP = Ksh 2,950; Urea = Ksh 2,960; Mavuno = Ksh 3,300 per 50 kg bag; Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

Table 99: Economic evaluation of liming and OM on sugarcane - NE season 2

Treatment	*Yield (t/ha)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
Control	84.6^{d}	317,250.00	0.00	184,569.80	-
Compost	109.6^{a}	411,000.00	27,000.00	232,894.80	8.6
Compost + ½ DAP + ½ Urea	106.1^{a}	397,875.00	40,714.00	208,635.30	5.1
DAP + Urea	108.9^{a}	408,375.00	27,428.00	230,357.70	8.4
Lime + DAP + Urea	102.1^{b}	382,875.00	39,833.00	197,464.30	5.0
Lime + ½ DAP + ½ Urea	102.5^{b}	384,375.00	26,119.00	212,383.50	8.1
Mavuno + Urea	98.6^{c}	369,750.00	34,940.00	191,811.80	5.5
SSP + Urea	102.2^{b}	383,250.00	38,390.00	199,208.60	5.2

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio

Price of DAP = Ksh 3,897; SSP = Ksh 2,950; Urea = Ksh 2,960; Mavuno = Ksh 3,300 per 50 kg bag; Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

Table 100: Economic evaluation of liming and OM on cane yield - OG season 1

Treatment	*Yield (t/ha)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
Control	89.5[d]	335,625.00	0.00	187,340.50	-
Compost	134.9[a]	505,875.00	27,000.00	291,047.10	10.8
Compost + ½ DAP + ½ Urea	133.7[a]	501,375.00	40,714.00	273,878.30	6.7
DAP + Urea	115.9[c]	434,625.00	27,428.00	235,918.10	8.6
Lime + DAP + Urea	127.7[ab]	478,875.00	39,833.00	257,485.30	6.5
Lime + ½ DAP + ½ Urea	133.8[a]	501,750.00	26,119.00	288,761.20	11.1
Mavuno + Urea	123.5[bc]	463,125.00	34,940.00	250,286.50	7.2
SSP + Urea	114.4[c]	429,000.00	38,390.00	220,637.60	5.7

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio

Price of DAP = Ksh 3,897; SSP = Ksh 2950; Urea = Ksh 2,960; Mavuno = Ksh 3.300 per 50 kg bag; Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

Table 101: Economic evaluation of liming and OM on cane yield - OG season 2

Treatment	*Yield (t/ha)*	*GR (Ksh)*	*FC (Ksh)*	*NR (Ksh)*	*VCR*
Control	57.3[e]	214,875.00	0.00	94,636.70	-
Compost	67.0[c]	251,250.00	27,000.00	95,563.00	3.5
Compost + ½ DAP + ½ Urea	76.8[b]	288,000.00	40,714.00	110,063.20	2.7
DAP + Urea	59.4[e]	222,750.00	27,428.00	73,254.60	2.7
Lime + DAP + Urea	84.4[a]	316,500.00	39,833.00	132,824.00	3.3
Lime + ½ DAP + ½ Urea	75.2[b]	282,000.00	26,119.00	120,051.80	4.6
Mavuno + Urea	67.7[c]	253,875.00	34,940.00	89,638.30	2.6
SSP + Urea	62.7[d]	235,125.00	38,390.00	71,793.30	1.9

GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio

Price of DAP = Ksh 3,897; SSP = Ksh 2,950; Urea = Ksh 2,960; Mavuno = Ksh 3.300 per 50 kg bag; Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

5.10 Discussion

5.10.1 Soil characterization and rainfall data

The findings of this study were consistent with reports by Jaetzold *et al.* (2005) indicating that deficiencies of N, P and K are wide spread in Western province leading to low and declining crop yields. The soil physical and chemical characteristics were indicative of low soil fertility which is a causal factor for declining sugarcane yields in Kenya as established by various studies (Odada, 1986; Wawire *et al.*, 1987; Nyongesa, 1992; Kariaga and Owelle, 1992). The low soil fertility could be attributed to low inherent soil fertility and loss of nutrients through erosion and crop harvests with little or no nutrient replenishment through organic and in-organic sources (Gachene *et al.*, 2000).The findings were also consistent with those of studies from the Australian sugar industry which show that yield decline has been clearly associated with soil degradation caused by the long-term monoculture of sugarcane. The results showed that old sugarcane land was degraded in chemical (Bramley *et al.*, 1996; Skjemstad *et al.*, 1995), physical (Ford and Bristow, 1995 a, b) and biological (Holt and Mayer, 1998; Pankhurst *et al.*, 1996; Magarey *et al.*, 1997) properties, with old land being more acid, having lower levels of organic carbon, lower camion exchange capacity, more exchangeable Al, lower levels of Cu and Zn, more plant parasitic nematodes, more root pathogens, less microbial biomass, greater soil strength (more compacted) and lower water infiltration rate and storage capacity. It is possible that the lower yields observed in the control treatment were as a result of continuous monoculture in MSZ.

5.10.2 Emergence, tillering, stalk number, height and inter-node length

Results obtained in this study showed that sugarcane emergence, tillering and the stalk parameters were consistently influenced by treatments where agricultural lime and compost were included. This was attributed to the likely increase in labile P through improved release and availability for plant uptake and the moisture retention by compost favouring emergence. This finding was consistent with that of studies by Blackburn (1984), Malavolta (1994) and Omollo *et al*. (2011) which indicated that the role of P in sugarcane is to stimulate early root formation and development. Being essential for productive growth, P firstly works on roots to provide a bigger root mass, but it is equally important in providing stronger stalk development, more tillers and quicker canopy closure. Phosphorus deficiency, therefore, leads to reduced tillering, intermodal length and root area. The results also agreed with the observation that liming is known to improve soil physical, chemical and biological activities resulting in better growth of crops (Davies and Payne, 1988; Haynes and Naidu, 1998).

5.10.3 Sugarcane yield, sugar yield and juice quality

The study clearly demonstrated that the inclusion of agricultural lime, organic compost and selected inorganic fertilizers improved sugarcane and sugar yield, with potential benefits of reduced dosage of N and P to 50% of the local recommendation. Sugarcane juice quality improved with liming but the converse was true with compost manure. The high sugar yield recorded with compost was, therefore, a result of the increased sugarcane yield as opposed to improved juice quality. Results of this study agreed with those in India by Yadav *et al*. (2009) which have shown that in acid soils, deficiency of Ca and Mg is usually encountered, hence application of limestone at 1-3 t/ha to the plant crop in acid soils of Thiruvella, Kerala improved the yield and juice quality of subsequent ratoons. It also agreed with those of Soon and Arshad (2005) who found a significant increase in crop yield and soil labile N pools due to liming with zero tillage compared to liming with conventional tillage. The findings also agreed with other reports which have shown that long-term addition of organic matter improves crop yield, water holding capacity, porosity, and water stable aggregation and decreases bulk density and surface crusting (Edwards and Lofty, 1982; Schjonning and Christensen, 1994). It was also proved that soil organic matter is an essential component with key multifunctional roles in soil quality and related to many physical and biological properties of soil. The large organic matter returns with fertilizer addition can stimulate soil biological activity (Smith *et al*., 2000).

Results of this study were also in agreement with the observation that the utilization of organic manures and other soil ameliorants is known to be one way to replenish soil fertility. Soil organic matter being an indicator of biological activity in the soil, provides substrate for soil micro-organisms (MSIRI, 2000). The micro-organisms are responsible for converting un-available plant and animal nutrients into forms that can be assimilated by plants. Yadav *et al*. (2009) have observed that the old practice of applying large quantities of bulky organic manures like farm yard manure (FYM), green manure and organic waste material to sugarcane keeps on replenishing the soil with adequate quantities of micronutrients and the utilization of organic manures and other soil ameliorants like agricultural lime is known to be one way to replenish soil fertility. Agricultural lime increases the pH of acidic soil and provides a source of Ca for plants and permits improved water penetration for acidic soils. Liming also mitigates the effects of P fixation by Al and Fe oxides at low pH thus making the P available to sugarcane plants (NETAFIM, 2008). In South Africa, high pH values, low Al, Na and high levels of

P are reported to be associated with high sugarcane yielding points (Antwerpen *et al.*, 2007). This was evident in the current study as there was increased yield and quality in lime treated canes.

5.10.4 Agronomic efficiency

Higher agronomic efficiencies were indicated in the treatments where N and P were applied along with agricultural lime and compost manure. This showed better availability and utilization of nutrients when the soil ameliorants were applied. This finding agreed with studies in North Carolina, USA (Colleen, 2004) which showed that agricultural lime increased fertilizer use efficiency and saved money. The study concluded that money spent on fertilizer is not well invested unless soil pH is properly adjusted first. Elsewhere, Abreha Kidanemariam *et al*. (2013) found out that yield and yield attributes of wheat showed significant response to the main effects of lime and fertilizer applications. Fertilizer x lime interaction effect was significantly different in grain yield, total biomass and N and P uptake. The highest agronomic efficiency and apparent recovery efficiency were also recorded in the soils treated with limes along with recommended P and NP fertilizers. The utilization of organic manures and other soil ameliorants like agricultural lime is known to be one way to replenish soil fertility. One of the products of soil organic matter decomposition is humus which is an important chemical property in cation exchange capacity. The organic matter also improves soil structure and water holding capacity (MSIRI, 2000).

5.10.5 Economic evaluation

Consistently high VCRs and net returns were indicated in the treatments where N, P was applied along with agricultural lime or compost manure. The apparently high input cost relative to the standard practice was mitigated by improved sugarcane yields hence higher gross and net returns. The treatment with agricultural lime and 50% dose of DAP and Urea had a marginally lower cost of fertilization yet it consistently recorded the highest cane and sugar yields hence being the most feasible recommendation economically.

5.10.6 Conclusion and recommendation

The results of this study established the significance of agricultural liming and utilization of organic manures along with recommended NP fertilizers for better sugarcane growth, higher cane and sugar yields, higher agronomic efficiency and higher farmer profitability in MSZ. It is recommended that agricultural lime and organic manures be included in the fertilization regime at Mumias especially in places where soil analysis results show low organic carbon fraction. The current recommendation of 92 kg/ha P_2O_5 could be retained along with liming while P application at 46 kg/ha P_2O_5 along with agricultural lime could be adopted on high P response soils.

CHAPTER SIX

6.0 GENERAL DISCUSSION

Sugarcane production systems in Kenya have been in existence over the last 60 years in monoculture of sugarcane. This aspect is strongly linked to the yield decline experienced in the last two decades and is associated with soil degradation as evidenced by the soil physical and chemical characteristics in the study sites. This finding agrees with other studies showing that worldwide sugarcane production systems have experienced yield decline associated with soil degradation caused by the long-term monoculture of sugarcane (Magarey *et al*., 1997).

Results from experiment 1 (K x N) established the significance of balanced fertilization with K for higher cane yield, higher sugar yield, higher agronomic efficiency and higher farmer profit with sugarcane at Mumias in western Kenya. A review of the literature shows that inputs of N and K must be balanced to optimize sugarcane production. For high yield (and good juice quality), K fertilizers are required in amounts equal to or greater than N (and P). In most sugarcane producing countries of the world, NPK ratios of 2:1:3 or 2:1:2 or 3:1:5 are commonly used (Wood, 1990). While N strongly stimulates growth, expansion of the crop canopy and interception of solar radiation (MSIRI, 2000) to primarily produce more millable cane, a large amount of K is needed as an osmotic solute to maintain the necessary cell turgor to drive this N-stimulated growth (Perez and Melgar, 1998). Fields with poor yields normally tend to have high N and critically low K levels resulting in high reducing sugars and low sucrose (Cavalot, 1990). This statement serves to stress upon the necessity of having adequate K available to utilize unassimilated N in the cane in order to bring about a stage of maturity where the reducing sugars are converted to sucrose.

It is, therefore, recommended that K be included in the fertilization regime at Mumias initially at 60kg/ha K_2O (2 bags of 50 kg muriate of potash). There were strong indications that with K fertilization the current N recommendation of 120-150 kg N/ha could be reduced to only 78-92 kg/ha due to better N utilization from the interaction with K.

The results from experiment 2 (L x P) established that liming along with P fertilization increased the sugarcane growth and yield parameters. It was also evident that where agricultural lime was applied the rate of P application could be substantially reduced. This was consistent with literature reviews indicating that lime increases the pH of acidic soils under which the major plant nutrients N, P, K as well as Ca and Mg show a marked reduction. Low soil pH is associated with low levels of Calcium and/or Magnesium as well as high soil acidity. As the level of soil acidity increases, Al increases and could become toxic to plants. The efficiency of nutrient uptake and use decreases as well (Graham *et al.*, 2002). Liming mitigates the effects of P fixation by Al and Fe oxides at low pH thus making the P available to sugarcane plants (NETAFIM, 2008).

It is recommended that agricultural lime be included in the fertilization regime at Mumias where soil analysis results show acidic conditions. When agricultural lime is used, the rate of P fertilizer used could be reduced without compromising the cane yield and juice quality. The current recommendation of 92 kg/ha P_2O_5 should be retained along with liming while P application at half the rate of current recommendation (46 kg/ha P_2O_5) along with liming could be adopted on high P response soils.

Results of experiment 3 established the significance of agricultural liming and utilization of organic manures along with recommended NP fertilizers for better sugarcane growth, higher cane and sugar yields, higher agronomic efficiency and higher farmer profitability in MSZ. It is recommended that agricultural lime and organic manures be included in the fertilization regime at Mumias especially in places where soil analysis results show low organic carbon fraction. The current recommendation of 92 kg/ha P_2O_5 could be retained along with liming while P application at 46 kg/ha P_2O_5 along with agricultural lime could be adopted on high P response soils.

CHAPTER SEVEN

7.0 CONCLUSIONS & RECOMMENDATIONS

Results of the three experiments conducted from 2009-2011 in this study clearly demonstrated that the long-term sugarcane monoculture coupled current sugarcane production practices in Mumias sugar zone of western Kenya have led to serious deterioration of the soil physical and chemical quality parameters. This was thought to be the main cause of the observed decline in sugarcane yields over the years. The following recommendations have been made:

(i) balanced fertilization with K for higher cane yield, higher sugar yield and higher farmer profit with sugarcane at Mumias in western Kenya should be done. It is recommended that K be included in the fertilization regime at Mumias initially at 60 kg/ha K_2O (2 bags of 50 kg muriate of potash). From the agronomic efficiency and economic evaluation, there were strong indications that with K fertilization the current N recommendation of 120-150 kg N/ha could be reduced to only 78-92 kg/ha due to better N utilization from the interaction with K.

(ii) amendment of acidic soils (pH < 5.0) with agricultural lime should be done in MSZ to improve the sugarcane growth and yield parameters thorough better nutrient uptake. The current recommendation of 92 kg/ha P_2O_5 should be retained along with liming while P application at 46 kg/ha P_2O_5 along with liming could be adopted on high P response soils.

(iii) liming and utilization of organic manures along with recommended NP fertilizers should be enhanced or better sugarcane growth, higher cane and sugar yields, higher agronomic efficiency and higher farmer profitability in MSZ. It is recommended that agricultural lime and organic manures be included in the fertilization regime at Mumias especially in places where soil analysis results show low organic carbon fraction.

Further research into factors contributing to the yield decline in MSZ should include: the performance of early maturing sugarcane varieties compared with established early, mid and late maturing varieties, the occurrence and prevalence of ratoon stunting disease, the impact of minimum tillage practices on soil fertility and sugarcane yields, impact of green manures and trash blanketing on improvement of soil and conservation practices among smallholder farmers, introducing crop rotation in sugarcane, avoidance of heavy machinery in the field when wet and adoption of dual row planting with controlled traffic among others.

CHAPTER EIGHT

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Appendix 1

Table 1: Overall soil reaction and nutrient status of Mumias soils

Year	N	pH (H_2O)	P ppm (Troug)	K (m.e.)	CEC (m.e.)
2012/13	4842	5.4	9.8	0.5	10.7
2011/12	1252	5.5	8.6	0.6	12.3
2010/11	1549	5.5	6.2	0.7	10.3
2009/10	1552	5.5	6.6	0.7	10.6
2008/09	2401	5.4	7.6	0.6	11.0
Mean	2319	5.5	7.8	0.6	11.0

Source: Mumias Agronomy Annual Reports (2001-2013)

Table 2: Foliar nutrient content and interpretation

Nutrient	Age (m)	Crop class					
		Plants			Ratoons		
		Low	Adequate	High	Low	Adequate	High
N %	3-5	< 1.55	1.55-1.88	> 1.80	< 1.50	1.50-1.72	> 1.72
	6-8	< 1.60	1.60-1.85	> 1.85	< 1.32	1.32-1.57	> 1.85
	9-12	1.45	1.45-1.65	> 1.65	< 1.25	1.25-1.45	> 1.65
P %	3-5	*	*	*	< 0.19	0.19-0.23	*
	6-8	*	*	*	< 0.17	0.17-0.22	*
	9-12	*	*	*	< 0.15	0.15-0.19	*
K %	3-5	< 1.15	1.15-1.22	> 1.22	< 1.15	1.15-1.20	*
	6-8	< 1.19	1.19-1.26	> 1.26	< 1.30	1.30-1.38	*
	9-12	*	*	*	< 1.23	1.23-1.30	*

Source: Mumias Agronomy Laboratory.

Table 3: Soil reaction and nutrient interpretation

Parameter	Level	Interpretation
pH (H_2O)	< 5.0	Strongly Acid
	5.0 - 5.5	Medium Acid
	5.6 - 6.0	Slightly Acid
	6.1 - 7.0	Very Slightly Acid
P ppm (Troug)	< 10.0 10.0 - 16.0 16.1 - 20.0 > 20.0	V. low Low Moderate Adequate
K (m.e.)	< 0.4 0.4 – 0.5 0.6 – 0.7 > 0.7	V. low Low Moderate Adequate
Ca (m.e)	< 2.0 2.0 - 3.0 3.1 - 4.0 > 4.0	V. low Low Moderate Adequate
Mg (m.e)	< 1.0 1.0 – 1.5 1.6 - 2.0 > 2.0	V. low Low Moderate Adequate
Ca/Mg ratio	< 1.0 1.0 – 2.0 2.1 - 3.0 > 3.0	V. low Low Moderate Adequate
CEC (m.e.)	< 6.0	V. low
	6.1 - 9.0	Low
	9.1 - 12.0	Moderate
	> 12.0	Adequate

Source: BSES, Australia 1994; Okalebo et. al., 2002

Appendix 2: ANOVA Tables

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N × K Experiment (season 2)

Source of variation	d.f	Experiment 1 (N×K) NE Field E 35				
		Emergence (%)	Tillers/ha ('000)	N (%)	P (%)	K (%)
Rep stratum	2	197.52	164.59	0.005590	0.000065	0.000752
Rep×Units×Stratum						
K	3	334.58***	500.68***	0.145728***	0.003113*	0.497533***
N	3	241.19**	254.31***	0.259372***	0.000541*	0.393261***
K×N	9	211.26***	238.01***	0.129281***	0.000406*	0.400672***
Residual	30	49.14	26.80	0.004118	0.000401	0.003748
Total	47					

Source of variation	d.f	Experiment 1 (N×K) NE Field E 35						
		S.H (cm)	I.L (cm)	MS/ha ('000)	Cane yield (t/ha)	Pol % cane	Sugar yield (t/ha)	Fibre % cane
Rep stratum	2	55.6	0.1852	103.18	2.831	0.000727	0.03785	0.0365
Rep×Units stratum								
K	3	746.9*	0.7174*	313.87 ***	366.704 ***	2.120989 ***	20.32814 ***	0.0519 ***
N	3	941.6**	0.50402 ns	159.43 ***	685.880 ***	3.334706 ***	2.26669 ***	0.1505 ***
K×N	9	393.2*	0.2761*	149.21 ***	213.284 ***	0.096520 ***	3.48780 ***	0.0941 ***
Residual	30	208.3	0.2959	16.80	3.827	0.005315	0.07288	0.0081
Total	47							

Source of variation	d.f	Experiment 1 (N×K) Khalaba 49				
		Emergence (%)	Tillers/ha ('000)	N (%)	P (%)	K (%)
Rep stratum	2	61.396	-	0.00179	0.0000021	0.005258
Rep×Units×Stratum						
K	3	186.299*	-	0.19401***	0.0012722***	0.085469***
N	3	150.743***	-	0.41812***	0.0014389***	0.056763***
K×N	9	3.928*	-	0.05494***	0.0005778***	0.018172***
Residual	30	9.240	-	0.00698	0.0001376	0.001823
Total	47					

Source of variation	d.f	Experiment 1 (N×K) Khalaba 49						
		S.H (cm)	I.L (cm)	MS/ha (‘000)	Cane yield (t/ha)	Pol % cane	Sugar yield (t/ha)	Fibre % cane
Rep stratum	2	0.00	0.00000	0.22	27.421	0.0567	0.4632	0.005352
Rep×Units stratum								
K	3	423.64*	0.39687 ns	719.70***	844.924***	6.91221***	31.1517***	0.484911**
N	3	908.45*	2.52687*	124.91***	958.593***	1.77708***	11.1960***	0.039091***
K×N	9	84.80*	0.64354*	148.52***	74.504***	0.16918***	1.50180***	0.092613***
Residual	30	0.00	0.00000	14.33	9.820	0.02505	0.16180	0.004834
Total	47							

N × K Experiment (season 1)

Source of variation	d.f	Experiment 1 (N×K) NE Field D 51 & OG Musanda 22					
		Emergence (%)	MS/ha (‘000)	Cane yield (t/ha)	Pol % cane	Sugar yield (t/ha)	Fibre % cane
Rep stratum	2	15.10	3.28	110.93	0.0198	2.683	0.02672
Site stratum	1	1.76	13122.73	5814.15	0.2501	106.445	3.42393
Site×Rep stratum	2	4.88	17.73	38.72	0.1017	1.222	0.02953
Site×Rep×Units stratum							
K	3	30.84*	240.38 ns	2466.91***	2.3768***	73.447***	0.25671 ns
N	3	478.14***	200.93*	621.96***	0.4296***	11.481***	0.11818 ns
K×N	9	70.56*	111.65*	322.70***	0.1254*	7.959***	0.08332*
Residual	75	13.23	49.29	66.00	0.1267	1.584	0.04852
Total	95						

L×P Experiment (season 2)

Source of variation	d.f	Experiment 2 (L×P) Khalaba 110				
		Emergence (%)	Tillers/ha (‘000)	N (%)	P (%)	K (%)
Rep stratum	2	19.30	96.10	0.005493	0.000363	0.002303
Rep×Units×Stratum						
L	1	83.33*	1630.82 ***	0.006750 *	0.009363 **	0.607763 ***
P	4	17.53 ns	218.66*	0.086608 ***	0.007570 **	0.112145 ***
L×P	4	5.17 ns	52.98*	0.061308 ***	0.017397 **	0.143772 ***
Residual	18	11.34	23.96	0.003267	0.000197	0.001614
Total	29					

Source of variation	d.f	Experiment 2 (L×P) Khalaba 110						
		S.H (cm)	I.L (cm)	MS/ha (‘000)	Cane yield (t/ha)	Pol % cane	Sugar yield (t/ha)	Fibre % cane
Rep stratum	2	215.46	0.1270	162.38	53.27	0.001143	0.86	0.01057
Rep×Units×Stratum								
L	1	1.08 *	0.1080 ns	1421.78 ***	2199.92 ***	0.365203 ***	32.531 ***	0.01365 *
P	4	146.99 **	0.8753 ns	347.76 *	482.75 *	0.125692 ***	9.763 ***	0.43558 ***
L×P	4	42.87 *	0.2297 ns	236.96 **	228.51 *	0.128628 ***	2.988 *	0.67442 ***
Residual	18	44.59	0.3614	67.17	79.47	0.001791	1.398	0.00564
Total	29							

L×P Experiment (season 1)

Source of variation	d.f	Experiment 2 NE Field A 28 & OG Eluche 8				
		Emergence (%)	MS/ha (‘000)	Cane yield (t/ha)	Pol % cane	Sugar yield (t/ha)
Site stratum	1	2108.71	16830.40	1596.50	13.97803	3.6229
Rep stratum	2	132.69	25.06	11.44	0.00013	0.2685
Site×Rep stratum	2	147.02	72.24	1.19	0.01073	0.0424
Site×Rep×Units stratum						
L	1	220.03 ns	108.54 ns	3608.40***	1.52323*	96.3111***
P	4	57.67*	79.29 ns	585.18***	0.39325***	13.6853***
L×P	4	33.44*	232.39 ns	71.89**	0.18754***	1.8986*
Residual	45	28.30	38.76	39.79	0.06665	0.8698
Total	59					

Organic manure and lime Experiment (season 2)

Source of variation	d.f	Experiment 3 NE Field A1 & OG Khalaba 49						
		Emergence (%)	S.H (cm)	MS/ha ('000)	Cane yield (t/ha)	Pol % cane	Sugar yield (t/ha)	Fibre % cane
Rep stratum	2	2.083	0.513	66.53	7.989	0.001254	0.12744	0.010252
Rep×Units×Stratum								
Site	1	280.333	544.727	357.39	13064.700	2.213070	258.29628	0.055352
Treatment	7	188.905 **	477.451 ***	151.00 ***	293.017 ***	1.548869 **	3.58803 **	0.145557 *
Site×Treatment	7	170.143	643.533	38.22	155.945	0.591915	2.3246	0.105871
Residual	30	7.194	2.779	16.71	6.180	0.005021	0.09826	0.005290
Total	47							

Organic manure and lime Experiment (season 1)

Source of variation	d.f	Experiment 3 NE Field 51 & OG Musanda 22						
		Emergence (%)	S.H (cm)	MS/ha ('000)	Cane yield (t/ha)	Pol % cane	Sugar yield (t/ha)	Fibre % cane
Rep stratum	2	28.59	28.59	5.72	38.31	0.11661	0.8214	0.2753
Rep×Units×Stratum								
Site	1	8.09	8.09	2278.39	373.53	0.60301	7.8435	0.0310
Treatment	7	14.10*	14.10*	448.09**	590.88***	0.39585**	7.3961**	0.3176*
Site×Treatment	7	13.13	13.13	161.54		0.38519	8.7465	0.1799
Residual	30	19.34	19.34	22.06	57.16	0.05894	0.3614	0.1887
Total	47							