EVALUATION OF FERTILIZER FORMULATIONS ON SOIL CHEMICAL PROPERTIES, GROWTH, YIELD AND QUALITY OF SUGARCANE VARIETY (KEN 83-737) IN KAKAMEGA COUNTY, KENYA.

NAMUNYU JEREMIAH OKELLO (BSC. AGRICULTURE)

A144/OL/20293 /2012

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR AWARD OF THE DEGREE OF MASTER OF SCIENCE (AGRONOMY) IN THE SCHOOL OF AGRICULTURE AND ENTERPRISE DEVELOPMENT OF KENYATTA UNIVERSITY

OCTOBER, 2020

DECLARATION

This thesis is my original work and has not been presented for a degree in Kenyatta University and/or any other university.

Signature: …………………………......… Date: ……………………………..……

Namunyu Jeremiah Okello

A144/OL/20293 /2012

Department of Agricultural Science and Technology,

Kenyatta University.

Supervisors

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors.

Signature: …………………………......… Date: ……………………………..……

Dr. Joseph Onyango Gweyi

Department of Agricultural Science and Technology,

Kenyatta University.

Signature: …………………………......… Date: ……………………………..……

Dr. Benjamin Danga

Department of Agricultural Science and Technology,

Kenyatta University.

DEDICATION

I dedicate this thesis to Almighty God for His grace and hope that kept me alive throughout this study. This is a clear manifestation of God’s doing. Finally, I dedicate this work to my wife and children whom I love and cherish.

ACKNOWLEDGEMENT

First and foremost, I want to thank the Almighty God for where He took me from and where He is leading me to in this life. I would like to express my immense gratitude and appreciation to my supervisors Dr. Joseph Onyango Gweyi and Dr. Benjamin Danga for accepting me to work with them and for all the guidance and support during the whole phase of my study. Working with them was such a constructive experience, a pleasure, and an honour. Their incredible and constructive ideas made this thesis a reality. Lastly, to my mentors, colleagues and friends, for their continued support and encouragement that kept me moving.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATION AND ACRONYMS

ANOVA:	Analysis of Variance
CEC:	Cation Exchange Capacity
DAP:	Di- Ammonium phosphate
FAO:	Food and Agriculture Organizationof the United Nations
KESREF:	Kenya Sugar Research Institute
MOP:	Muriate of Potash
MSC:	Mumias Sugar Company
NPK:	Nitrogen, Phosphorus and Potassium
Pol%:	Polarization measurement

ABSTRACT

Low sugarcane productivity has persisted in Western Kenya where most of the crop is grown. A study conducted by Kenya Sugar Research Institute in January 2011 at, Nyando Sugar Zone indicated that sugarcane yields were varied based on fertilizer type applied to the crop. Average sugarcane yield was 64 tones/ha as opposed to a potential yield of more than 100 tones/ha under rain-fed conditions. Declining soil fertility and lack of critical nutrients in fertilizer formulations applied to the crop were key reasons for the declining yields. The provision of well formulated fertilizers to sugarcane growing areas has been a challenge, yet sugarcane has extremely high demand for elements particularly NPK. There is therefore need to formulate fertilizers with an aim to provide the required nutrients in appropriate quantities. The aim of the present study was to provide formulations of sugarcane fertilizers targeting critical nutrient requirements to improve on the crop response in terms of nutrient uptake, growth, yield and cane quality. The study was conducted in 2013 in Mumias Sugarcane growing zone at Mumias Sugar Nucleus estate situated $0^{0}21^{'}$N and $34^{0}30$E at 1314 meters above sea level. The treatments under experiment were as follows; T_1 (DAP + Urea), T_2 (DAP + MOP + Urea), T_3 (NPKCaMg) and T_4 (No fertilizer – Control). A randomized complete block design (RCBD) was used with 4 treatments each replicated 4 times to give 16 experimental plots, each measuring 10x6 meters (60 m^2). Data was collected on tiller count, growth rate and yield. TCH, P01% cane, foliar potassium, nitrogen and phosphorus were also determined. The soil chemical analyses were carried out before and after cane growth. Data collected was subjected to analysis of variance (ANOVA) using R software version 3.4.0 and treatment means separated using the Tukey`s HSD post hoc test at 5% level of significance. Where there was significant difference, the mean separation was done using LSD. The NPKCaMg (T_3) formulation elicited the highest plant height of 4.2 cm at the time of sampling compared to control which was 1.5cm, the differences were statistically significant. The NPKCaMg (T_3) formulation was superior in Po1% cane (14.1), followed by DAP + Mop (T_2) (13.3) followed by DAP (T_1) (12.0) and control (10.5). The difference between control and DAP were not statistically different. The cane yield followed the % Pol values, only that in this case there were significant differences amongst all treatments. The NPKCaMg (T_3) and DAP + Mop (T_2) treatments led to higher soil pH values ranging between 5.0 to 5.5 while the control and DAP had values less than 5.0. In correlation and regression analysis different fertilizer formulations were observed to affect development and sugarcane yields. Therefore, from these findings farmers at Mumias Sugarcane growing zone should be encouraged to adopt blended fertilizer formulations to improve cane sucrose content, soil chemical properties and overally improve sugarcane yields in the long run.

CHAPTER ONE: INTRODUCTION

1.1 Background to study

Sugarcane (*Saccharum officinarum* L.) is cultivated crop important for sugar and ethanol production. This crop originated from South East Asia and Western India (de Matos *et al.*, 2020). The crop was important in Asia at around 327 B.C, it was later introduced to Africa, in Egypt by around 647 A.D and into Europe in Spain at around 755A.D. Later, the crop was introduced to many tropical and subtropical regions, where it tis commonly cultivated (Blume, 1985; la S and Dlamini, 2012; Bhatt, 2020; de Matos *et al.*, 2020).

Worldwide sugarcane production covers about 20.42 million hactares and the total production is about 1333 million metric tons. Several countries produce sugarcane in the world, the major producers comprise of Brazil, India, China, Thailand, Mexico, Cuba, Columbia, Australia, USA, Phillipines, South Africa, Argentina, Myanmar, and Bangladesh (la S and Dlamini, 2012; Bhatt, 2020). In Africa, the top sugarcane producing countries are South Africa and Egypt. Egypt is one of the oldest African countries known for sugar production (Ali *et al.*, 2020). Other major sugarcane producers in Africa comprise Sudan, Kenya, Kingdom of Morocco, Swaziland and Mauritius (Hassan, 2008).

Total world production of sugar in 2007 was 147.7 million tones and Africa ranked fifth among other continents, however, there has been a sharp decline in cane productivity in Africa compared to other regions such as South America and Asia. It is likey that the causes of the decline in in productivity is due to unreliable precipitation, since sugarcane production in Africa is mainly rainfed, as well as poor soil fertility among other challenges. Soil fertility is very important in Sugarcane production since, the plant has high demands for nutrients for good development and high yields (Bhatt, 2020). The crops require adequate supply of Nitrogen, Phosphorus, Potassium as well as micronutrients such as zin and magnesium. Soil pH should also be in a good range since it has an influence on the available of these elements.

Different elements have different roles, in sugarcane development (de Oliveira *et al*., 2018), but some of the fertilizers used by farmers may comprise one or two macro elements, furthermore, there is less research on the soil properties and soil fertility status which results on poor decision making in terms of soil fertility management. For example, since inception of sugarcane cultivation in MSC cane growing zones in western Kenya, farmers in these zone have utilized various crop nutrition formulations to boost sugar cane yields, these fertilizer formulation have mainly comprised of Urea, TSP, SSP and DAP. The selection of these fertilizer types was guided by the cost of formulation and ability of the individual fertilizers afford them rather than the actual soil fertility status. Furthermore, the above fertilizer formulation lacked potassium, which is also critical for sugarcane nutrition responsible for uptake of other nutrients, enhanced growth rate and yields (Ali *et al.,* 2018).

Apart from plant nutrient components in the fertilizer, the amount of these nutrients is also important for good development of sugarcane, for example, P deficiency leads to reduced metabolic rate and photosynthesis which then affects cane yield quantity and quality. Although most soils contain a high proportion of total P reserves, most of it remains relatively inert and less than 10 % of the soil P is utilized by the Plant (Mbene *et al.,* 2017). On the other hand, there is also high variability in the soil phosphorus especially in regions with drastic variation in soil characteristic such as the MSC sugarcane growing zone (Muindi *et al.,* 2015; Mbene *et al.,* 2017). It is also known that soluble phosphates added to soil tend to become unavailable to plants in varying degrees, and that ultimately there is a gradual accumulation of these largely unavailable forms in soil (Muindi *et al.,* 2015; Mbene *et al.,* 2017).

Given that variability of soil properties affect nutrient uptake by plants and the existing challenge of poor use of fertilizers in MSC sugarcane growing zone, there is a need for research to evaluate the influence of different fertilizer formulation on growth and yields of sugarcane in these zones. This could help in development of appropriate recommendations for farmers on measures to adopt for efficient management of the native and applied nutrients in the soil for enhanced sugarcane production.

1.2 Statement of the problem

The sugar industry is a source of income for over 260,000 farmers, 11,700 employees, and directly or indirectly supports over 6 million Kenyans (Oyugi, 2016). The Kenya Sugar Research Institute (SRI) has been mandated to research on technological solutions to low sugarcane productivity reported in all sugarcane zones in western Kenya.

Declining cane yields in the sugarcane zones is a major area of concern in Kenya sugar industry (Amolo *et al.,* 2017; Mati and Thomas, 2019). In MSC sugarcane zone, sugarcane yields per unit hectare have continued to decline overtime (MSC, 2012; Mutonyi *et al.,* 2014a). Good sugarcane development and productivity is highly dependent on good soil fertility and well distributed rainfall especially in MSC sugarcane zone, since sugarcane production in this zone is rainfed with limited fertilizer applications. Moreover, soil analysis results in this zone indicate below threshold levels of the critical cane nutrient requirements (Kirungu, 2011; MSC 2012; Amolo *et al.,* 2017).

Adequate and balanced supply of plant nutrients in nutrient deficient soils such as MSC sugarcane zone would enhance growth and yields of cultivated crops, however, this can only be achieved by considering the soil properties, soil nutrient status and plant nutrient requirements while making decisions on fertilizer applications to be done (Gopalasundaram *et al.,* 2012).

Modern agricultural systems largely depend on the fertilizers, this has increased demand for mineral fertilizers which has also resulted in high diversity of mineral fertilizer formulations (organic, synthetic, quick release, slow release, solid liquid or gaseous) (Dave *et al.,* 1999;Trenkel, 2010; Timilsena *et al.,* 2014). Research on crop performance under different fertilizer formulations have been limited in Kenya, therefore, there is scanty information regarding use of these fertilizers in Kenyan settings such as the MSC sugarcane zone. Recent research endeavours, to a great extent are focused in assessing and addressing health and environmental impact of fertilizers. Consequently, various advances are being made on development and selective use of chemical fertilizers (Yue *et al.*, 2016). However, there is a need to better understand crop responses to different fertilizer formulation in unique Kenyan settings. This is even more critical to sugarcane since it is has a high demand for nutrients, particularly K, which is important for the re-translocation of sucrose (Mutonyi *et al.*, 2014b). This gap in the knowledge was the driving force for the current experimental work.

1.3 General objective

To assess the effect of selected fertilizer formulations on the nutrient uptake, growth rate and yields of sugarcane and identify appropriate fertilizer formulation for Mumias sugarcane growing zone.

1.3.1 Specific objectives

i. Assess the growth rate and yield of sugarcane crop by selected fertilizer formulations.

ii. Evaluate effect of different fertilizer formulations on cane quality.

iii. Analyse the effect of different fertilizer formulations on soil chemical changes.

1.4 Hypotheses

i. There are significant differences in growth and yield of sugarcane with different fertilizer formulations.

ii. There are significant variations in cane quality as affected by different fertilizer formulations.

iii. There are significant differences in soil chemical properties as affected by different fertilizer formulations.

1.5 Justification for the study

Whereas there is already reported research findings about sugarcane nutrition requirements, nitrogen and phosphorus suitable forms, there is scanty information on suitable fertilizer formulation that meet all recommended nutrient requirements of cane in the Kenya sugarcane zones and particularly in MSC sugarcane zone.

Declining sugarcane production per unit area in MSC sugarcane zone is worrying. The trend must be reversed for the survival of the sugarcane industry. Therefore, there is need to identify a fertilizer formulation that is all inclusive of the nutrients required by sugarcane crop. One of the major causes of declining cane yields is use of fertilizer formulations that are general and not specific to the needs of sugarcane crop despite the variations in soil types.

Various fertilizer formulations exist in Kenya. Agrochemical industries can formulate fertilizer with various nutrient ratios. There exists an urgent need to provide scientific information that can be used as a reference by manufacturers to come up with fertilizer formulations that would guarantee availability of all fertilizer nutrient elements in the amounts that commensurate with the sugarcane nutrient requirements.

The cost of chemical fertilizers has increased. There is need to improve fertilizer use efficiency by identifying a cost-effective fertilizer formulation that can cause significant increase in cane nutrient uptake, increase in growth rate and increase in yields. This will bring about increase in productivity and increased economic growth. One of the reasons for the extension of COMESA period is the high cost of production factors in sugarcane production in the region. Having cost effective sugarcane production brought about by all-inclusive nutrient dense fertilizer will help the sugar industry in Kenya to become more competitive even with the onset of COMESA.

1.6 Conceptual framework

Fertilizer formulations are critical in soil fertility management process. Fertilizer application rates depend on soil fertility level, crop nutrient need and the percent of nutrients in the specific fertilizer. This study sought to determine the effect of various NPK formulations on sugarcane nutrient uptake, tillering, growth and resultant yield in terms tons of cane per hectare and sugar content (Figure 1.1).

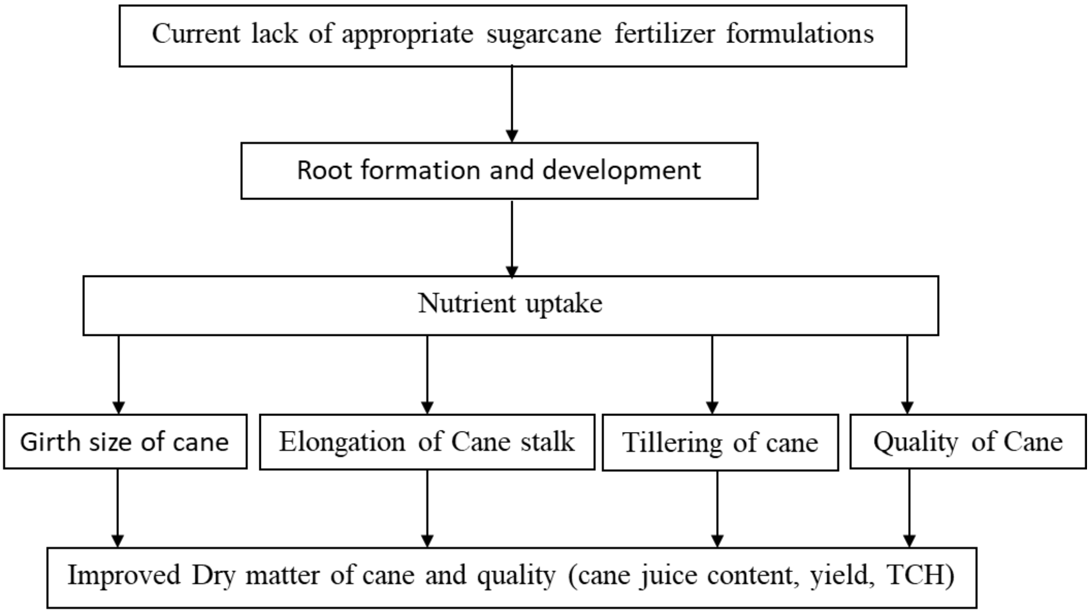


Figure 1.1: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Economic importance of sugarcane

Sugarcane (*Saccharum officinarum* L.) is a perennial grass cultivated in many tropical and subtropical regions of the world for sugar, ethanol, alcohol and other industrial uses (Plaut *et al.,* 2000; Priya *et al.,* 2016; Matos *et al.,* 2020; Shi *et al.,* 2020; Yang *et al.,* 2020). The crop has substantial contributed to industrial growth in many countries (Moraes *et al.,* 2015; de Castro Assumpção *et al.,* 2020). These sugar industries used in processing of sugarcane have contributed to employment opportunities for many people as well as created opportunities for farmers, smallholder farmers who are engaged as sugarcane growers in parts of Kenya (Mati and Thomas, 2019).

2.2 Sugarcane nutrition

Overally, the nutrient requirements of sugarcane especially nitrogen, phosphorus and potassium are high compared to other crops. Each of the major fertilizer elements, Nitrogen N, Phosphorus P and Potassium K, has a role in development, nutrient uptake and resultant sugarcane yield. On average, a hectare of sugarcane needs about 80 to 100 kg of N, 50 kg of P (P_2O_5), and 168 kg of K (K_2O). Each of the fertilizer elements has a role in development, nutrient uptake and resultant sugarcane yield. The combination of these critical nutrient elements should be balanced to enhances internode formation, internode elongation, increase in girth size, nutrient uptake and weight (Tsado *et al.,* 2013; Bhatt, 2020).

Sugar cane has essentially four growth stages; germination phase, tittering phase, grant growth phase and finally maturity and ripening phase (Wiedenfeld et al., 2005; Bonnett, 2013; Glassop *et al.,* 2020) (Figure 2.1). Understanding the growth phases would help in better formulation of fertilizer elements to meet the requirements of each growth phase. Nutrient requirements of sugarcane have significant roles at different crop stages. Nitrogen (N) requirement of sugarcane is high at tillering (30-45 days after planting), hence a need of adequate N during this stage of development (Bachchhav, 2005; Gopalasundaram *et al.,* 2012; Chandiposha *et al.,* 2014) (Figure 2.2).

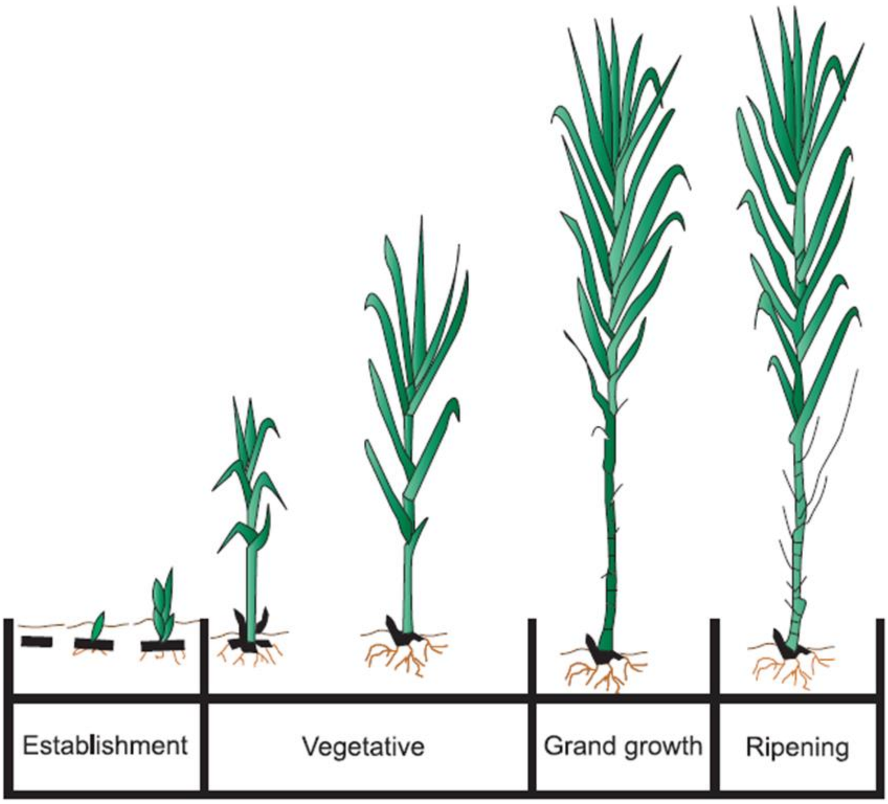


Figure 2.1: Sugarcane growth stages

Source: Wiedenfeld *et al.,* 2005

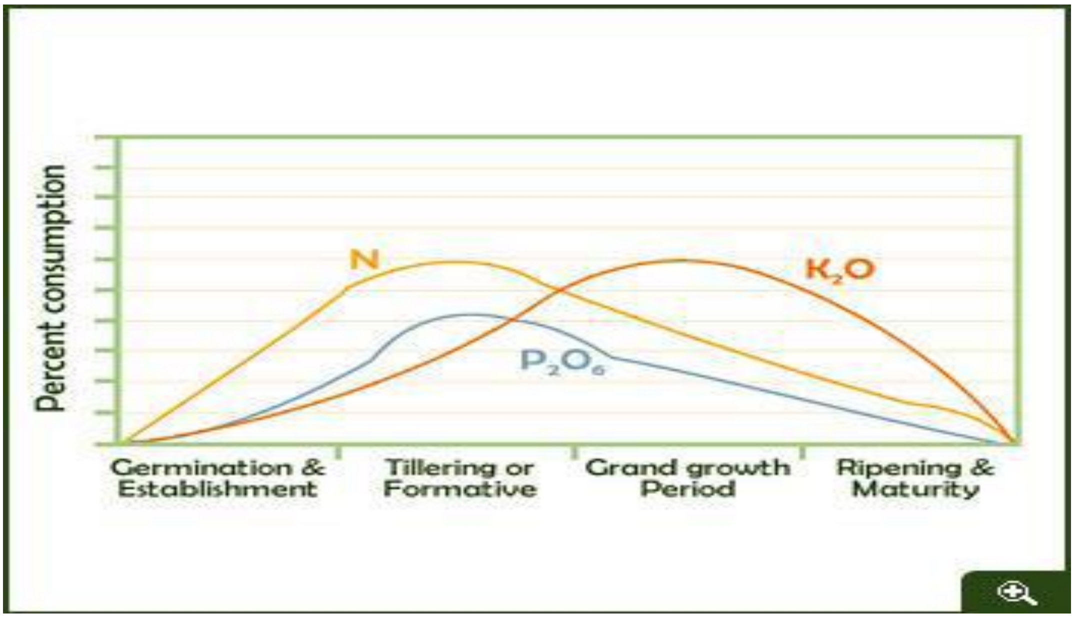


Figure 2.2: Relative requirement of NPK at different crop growth stages of sugarcane (Bachchhav, 2005)

2.3 Need for fertilizer use in sugarcane nutrition

Low soil fertility is a causal factor for declining sugarcane yields in Kenya (Amolo *et al.,* 2017). The low soil fertility has been 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. Soil productivity in the densely populated Western province is low and, on the decline. Deficiencies of N, P and K are widespread in Western province leading to low and declining crop yields (Jaetzold *et al.*, 2005; Amolo *et al.*, 2017) (Figure 2.3).

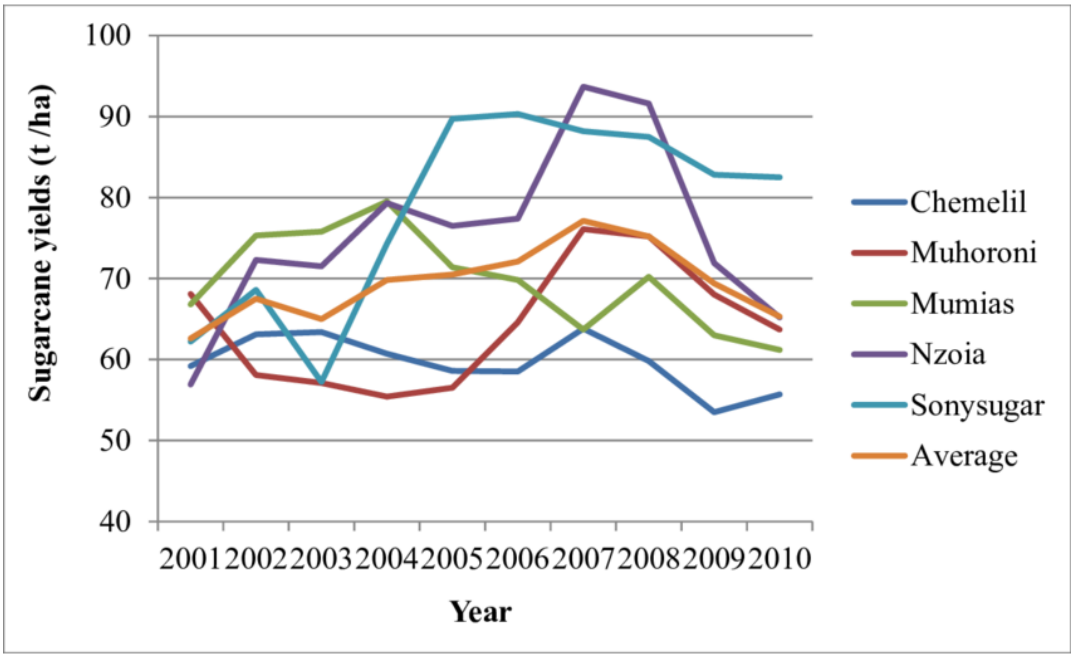


Figure 2.3: Declining sugar yields in sugarcane growing zones in Kenya

Source: Kenya Sugar Board, 2010

K depleted soils are poor in N utilization efficiency even if recommended doses are applied. This is because, K plays has a role in N metabolism,and transport in the plant (Krauss, 2004; Chen *et al.,* 2017). Potassium also plays a key role in sugarcane metabolism and is known to be actively involved in the translocation of sucrose (MSIRI, 2000; Römheld and Kirkby, 2010; Chen *et al.,* 2017). Therefore, balanced application of all the required plant nutrients can help improve cane productivity and enhance sugar recovery.

In S.E Asia, Haerdter and Fairhurst (2003) reported an increase of 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. 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; Chen *et al.,* 2017). Balanced application of N fertilizers in sugarcane fields also enhances the sucrose content in the in canes. However, excess N can lower sucrose content and discolouration of sugar crystals, since good quality sugar requires a balance of N use with K, to maximum sugar conversion (Meyer and Wood, 2001). The response to N rate varies with variety.

2.4 Fertilizers used in crop production

Soil fertility varies from one region to the other and sometimes the amount of Macro and microelements present in the soil may not be sufficient for plant growth and development, hence a need for fertilizer application (Tisdale *et al.,* 1966; Cai *et al.,* 2019). There are both organic (from decomposing organic matter) and inorganic (synthetic), however, the percentage content of nutrients in organic fertilizers (such as manures) is relatively low compared to inorganic fertilizers (Wang *et al.,* 2018).

Organized research into fertilizer technology began in the early seventeenth century. The first, inorganic fertilizer was developed by Glauber which comprising saltpetre, lime, phosphoric acid, nitrogen, and potash (Bora, 2017). However, over time, the chemical needs of plants were discovered, resulting to improved fertilizer compositions. Sir John Lawes was instrumental in development of the modern chemical fertilizer industry, over time there has been development of fertilizer industry which has resulted in diversity of synthetic as well as organic fertilizers.

However, dangers of environmental pollution have increased with increased use of fertilizers in agricultural activities. This has promoted research on the harmful environmental effects of fertilizer use, as well as discovering new, less costly sources of fertilizers (Chen *et al*., 2018; Irfan *et al.*, 2018).

2.5 Fertilizer type, composition and role in cane nutrition

Di-ammonium phosphate DAP $(NH_4)_2HPO_4$) is type of inorganic fertilizer that supplies the plant with N and P. When use in the farm, this fertilizer temporarily increases the soil pH, however, it´s usage of over longer periods results in acidic soils. N is essential in sugarcane metabolism affecting 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 Murate of potash (MOP) on the other hand is an inorganic fertilizer which supplies Potassium K, there are several sources of K (Table 2.1).

Table 2.1: Sources of Potassium (K)

Material	Chemical Symbol	Typical K_2O Analysis
Potassium Chloride/Potash	KCl	60-62%
Potassium Sulfate	K_2SO_4	50-53%
Potassium-Magnesium Sulfate	$K_2SO_4 \cdot 2MgSO_4$	22%
Potassium Nitrate	KNO_3	44-46%
Manure	(not applicable)	0.4-1.0%

Although K is a major nutrient and required by plants in large quantiles some compared to others, sugarcane is among such crops. They have high a demand for K since their K need is slightly higher than other crops (Table 2.2).

Table 2.2: High response crops to K

Fruit crops	Cereals and Grasses	Legumes and Vegetables	Tuber crops
Citrus	Alfalfa	Pumpkins/Squash	Sweet Potatoes
Apples	Clover	Beans (Phaseolus)	Sugar beets
Bananas	Corn Silage	Peppers	
Grapes	Bermudagrass	Tomatoes	
Palm	Sugar Cane	Pears	
Pineapple	Cotton	Tobacco	
Peaches	Rice	Soybeans	
Celery	Sorghum Silage	Vetch	

2.5.1 Role of potassium in Sugarcane nutrition

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 (Ali *et al.,* 2018). Sugarcane is able to mine the soil of its K reserves, therefore, responses to K fertilizers may not observed in plant over a short period since this can de delayed to the second ratoon stage and is likely to result in delayed K amendments especially when soil fertility is monitored using plant tissue analysis (Halpin *et al.,* 2019).

In general sugarcane responds to K fertilizers by an increase in cane yield without any change in sucrose concentration in the cane, while excess K lowers the sucrose recovery from canes, therefore, K fertilizer application should be maintained at adequate levels (Kwong, 2000; Ali *et al.*, 2018). 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 K2O (Kwong, 2000; Ali *et al.*, 2018). 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. Extended K deficiency results in spindle distortion other developmental abnormalities (MSIRI, 2000; Karthika *et al.*, 2018).

Under potassium depletion, utilization of N by the plants is also impaired hence an increase in crop development impact (Krauss, 2004). Therefore, it is important to have sufficient potassium available to utilize the assimilated nitrogen in the cane to to unsure that during maturation the 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 K2O) (Rossetto *et al*., 2004). On crop quality, Phonde *et al*. (2005) observed that adequate potassium supply ensured a higher sugar yield.

K leads to improved Pol quality and reduced fibre content (Malavolta, 1994; Mahamuni *et al*., 1975; Khosa, 2002). Juice purity is also improved; however, extremely high levels of potassium reduces sucrose levels (Perez and Melgar, 2000; Meyer, 2013). 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 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, luxurious uptake of K affect the crystallization of sugar leading to poor recovery of raw and refined sugar as well as higher sugar losses in molasses. On the other hand, excess K increases the ash content in sugarcane juice (Singh *et al*., 2008).

2.6 NPK. composition and role in sugarcane nutrition

NPK is a compound fertilizer containing some or all the Macroelement required by the plant, these comprise of Nitrogen (N), Phosphorus (P) and Potassium (K). Apart from provision of all the major plant nutrients, NPK fertilizers may also serve improve chemical, physical and biological properties of the soil.

2.6.1 Effect of NPK on sugarcane yield and quality

Balanced sugarcane nutrition results in better crop growth rate. In S.E Asia, Haerdter and Fairhurst (2003) reported a 16% N recovery when traditional N and P were 28 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.

Use of NPK fertilizers, many enhanced easy balancing of Macroelements, especially were the general soil fertility is low this will also avoid the detrimental effects of an excess of one of these elements. Since it is known that excess K has a highly negative correlation with sucrose content in juice of sugarcane (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. On the other hand, 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 (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.

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 (Malavolta, 1994).

Potassium plays a key role in sugarcane production, there is need to optimize K supply, uptake and utilization by the sugarcane crop to achieve desired yield and sugar accumulation. Excessive K uptake from soil may depress sucrose recovery (Malavolta, 1994) (Figure 2.4).

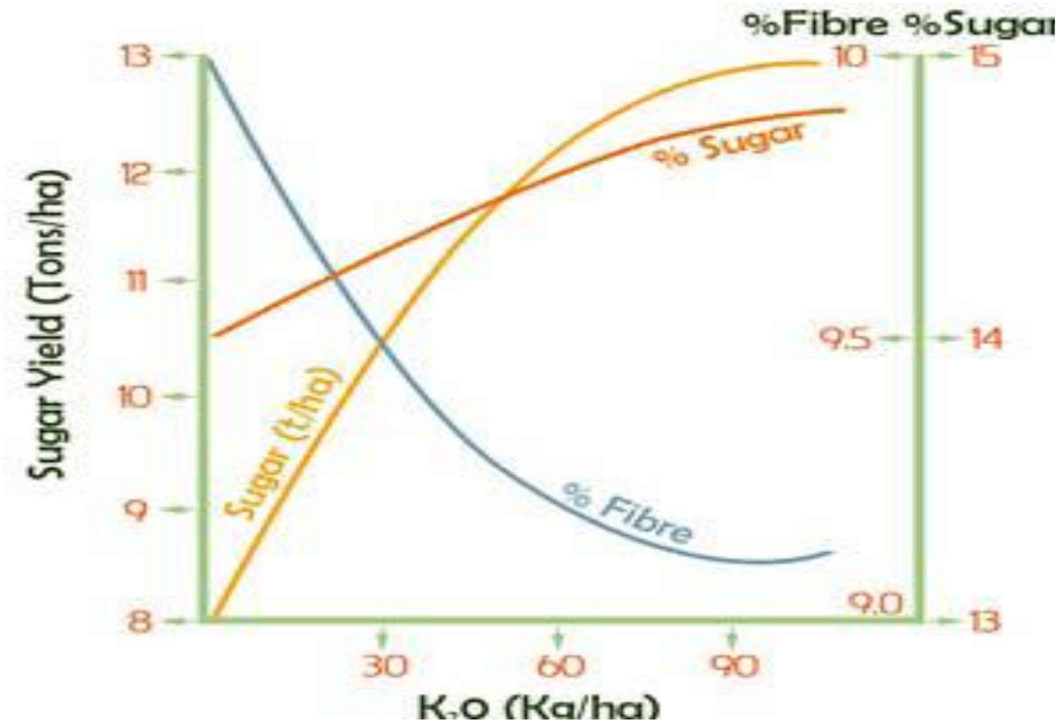


Figure 2.4: Effect of K supply on sucrose yield, sucrose and fibre content (Malavolta, 1994)

2.7 Nutrient uptake and fertilizer formulations

Potassium salts in nutrient culture have an acidifying effect on nutrient solution and are capable of dropping pH as low as 3.2. This acidifying effect, which is known for nutrient solutions has been found to improve iron nutrition in calcareous soils which cause iron deficiencies. Evidence point to an alteration in the cation anion uptake balance by encouraging greater uptake of potassium and subsequent efflux of protons from the roots into the immediate root environment. Minerals affect the dynamics of potassium in soils by ion adsorption at their surfaces as well as by release of lattice potassium (Yadav and Sidhu, 2016).

Transport in soil is an important link in the processes involved in supplying potassium to the roots. The most important transport mechanism for potassium is diffusion. Grimme (2012), claims that transport by diffusion can be rate limiting if either the potassium concentration in the soil solution or soil water content or both are too low. He further argues that in a dry soil transport it is impeded because the cross-sectional area for diffusion is reduced. This effect can be counteracted by a higher K concentration in the soil solution.

A field with a given K status availability may vary greatly during a growing season. It may drop below the optimum level for limited period even if the K status is apparently high enough because K diffusion may have become limiting. Where K becomes deficient, efficiency of applied N fertilizer declines but as it is a slow and gradual decline, it often remains unnoticed resulting in financial losses to farmer, the company and national economy.

A study conducted by Quemener (1986), on states of potassium in the soil and consequences for plant nutrition concludes that, keeping the K level in the soil solution more or less high whilst the roots are drawing potassium from it is of great importance for the feeding of the plant. It was noted that buffer capacity varies considerably between soils, and with richness in potassium for a given soil. Addiscott (1970) had shown that the buffer capacity is a function of the ratio, exchangeable K/cation exchange capacity. Anything that can affect this ratio will thus react upon the buffer capacity.

2.8 Sugarcane production at MSC sugarcane zone and potential of fertilizer inputs on yields

The MSC sugarcane zone average cane yields of 50 tonnes per hectare and sugar recovery (9.46%) is much lower than the other sugarcane growing countries of the world. Isherwood, (2006) estimated that less than two percent of the farmers apply potash whereas 92 percent apply nitrogen and 83 percent apply phosphate. Therefore, it is imperative to supplement required plant nutrients at proper time, in proper amounts and balanced proportions to harvest the maximum potential of the existing sugarcane varieties. The present study was therefore planned to evaluate the effect of NPK applications on the nutrient uptake, growth rate, yield and quality of sugarcane and also to determine optimum NPK level for getting maximum economic returns from the same genotype under agro-climatic conditions of MSC sugarcane zone.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Area

The study site was in Mumias Sugarcane growing zone, headquartered at Mumias Sugar Company. The specific site is in MSC nucleus estate situated 0^0 21' N and 34^0 30 E at 1314 meters, mean maximum and minimum temperature of 29.9°c and 14.4°C respectively, mean daily temperature of 22.1°C, evaporation of 1665 mm per year with radiation of 23.7 mjm^{-2} per day. The scheme receives on the average 2000 mms of rainfall. The rainfall regime is bimodal with long rains occurring between February to July and short rains between September and November. The scheme comprises of a Nucleus estate of about 3,600 hectares and the out-grower farms of about 59,000 hectares with 104,000 small holder farmers spread out in four counties of Kakamega, Bungoma, Busia and Siaya. Based on FAO system of soil classification, the major soils are Ferrasols and Acrisols in western province and Cambisols, Planosols, Vertisols and Phaoezems in Nyanza province (Jaetzold *et al,* 2005).

The dominant soil type in Mumias Sugar Scheme is Acrisols (60%) followed by Ferrasols, Nitosol, Cambisols, and Planosols (40%) (MSC, 2012). The experiment was located on the principal soil type of Acrisols and Ferrasols. The major varieties planted in MSC sugar zone are Co945, KEN 83-737, Co421, EAK 73-335 and Co61.

Figure 3.1: Sugarcane growing zones in Kenya are as indicated on the map

3.2 Study design and layout

The experiment was set up in a Randomized complete block design with 4 treatments each replicated 4 times to give 16 experimental plots, each measuring 10 x 6 meters (60 m^2). Each plot had 4 rows of cane spaced at 1.2 m. The total experiment area including guard rows was 529.20 m^2. Different fertilizer formulations used for treatment F1, F2 and F3 were sourced from different agrochemical companies, four treatment combinations that was used at planting and topdressing are outlined below (Table 3.1):

Table 3.1: Treatment components

Treatment	Planting fertilizer formulations		Topdressing fertilizer formulations		Source
F1	DAP 4bags per ha	18:46:0	Urea 4bags per hectare	46:0:0	MSC standard
F2	DAP + MOP (3bags + 1bag) per ha	18:46:0+ 0:0:60	Urea + MOP (3bags + 2bags) Per ha	46:0:0 + 0:0:60	MEA
F3	NPKCaMg 5bags per ha	12:30:7: 7:2	NPKCaMg	26:0:20: 3:1	ArthRiver Mining
F4	No fertilizer	No formulation	No Fertilizer	No formulation	None

Note: 1bag is equivalent to 50 kgs

Table 3.4: Trial layout

R4	R3	R2	R1
F3	F2	F4	F5
F1	F5	F2	F3
F4	F3	F5	F1
F2	F1	F3	F4
F5	F4	F1	F2

3.3 Experimental layout and data collection

Cane sets were planted in a Randomized complete block design (RCBD). The main treatments were four fertilizer formulations with one cane variety. The treatments were replicated four times, giving a total of 16 plots.

3.4 Agronomic practices

3.4.1 Field preparation and management

A seedbed was prepared by use of a disc plough at a depth of 25 cm. At about one month later, harrowing was undertaken at a depth of 20 to 22 cm. This operation breaks the clods in order to make the land even. Furrowing operation then followed immediately after harrowing of the field. This entailed opening furrows for placement of seed setts at 15-30 cm depth. The spacing between the furrows was 1.2 m.

3.4.2 Choice of sugarcane variety

Sugarcane variety KEN 83-737 of 2002 release series was used as the test crop. This is an early maturing sugarcane variety that matures in 16 months. It is agro-ecologically suited to western Kenya and MSC cane zone in particular, (Kenya gazette notice (Jamoza 2005; Jamoza *et al.*, 2013; Shikanda *et al.*, 2017).

3.4.3 Planting and crop management

The seed cane stalks of the variety were cut into sets of 3 eye buds and laid in the furrows at a depth of 15 cm. The sets were placed at 30% overlap to attain a seed rate of 8 tons per hectare. The treatments were then applied in the furrows as per the design. The planted sets were covered with 5 cm depth of soil to mark the end of planting. The research trial management entailed weed control by use of both manual and chemical weeding uniformly applied across all the treatments, disease and pest control was done based on occurrence and economic injury level.

3.4.4 Data collection procedure

Plant growth parameters for measurement were subjected to quantitative measurement and data collected included.

i. Cane germination / emergency count
ii. Tiller count done at 30, 45 and 60 day
iii. Plant height / growth measurement was done at 3, 5, and 7 months using a tape measure
iv. Cane sucrose accumulation determined at harvest
v. Projected yield in terms of TCH and Pol% cane was based on cane yield parameters

3.5 Sampling strategy

3.5.1 Soil sampling and analysis

Topsoil samples (0-15 cm depth) were obtained from the experimental site at the start of the experiment just before planting and at the end of the experiments following harvesting. Core samples were collected randomly and mixed inside a plastic bucket and used for obtaining the composite sample. The soil samples were air-dried, crushed and sieved through a 2 mm sieve. The samples were analysed in the laboratory for physical and chemical properties.

The target soil nutrients parameters were Phosphorus, Potassium, Calcium, magnesium, and Cation exchange capacity. Composite soil samples were obtained at soil depth of 25 cm from each of the experimental plots before applying treatments and at the end of experiment. The soil samples were clearly labelled according to the treatments and replications.

3.5.2 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 insect pests was done following methods described by Thomas *et al.* (2018), this was done for pests such as Pink sugarcane mealy bugs (*Saccharicoccus sacchari* (Cockerel) and scale insects (*Eulacapsis tegalensis* Zehnt.) due to their occurrence in the zone and the likely negative effect on juice quality.

3.5.3 Soil analysis procedure

i. Extraction of soil cations using ammonium acetate

Ammonium acetate was used due to its ammonium ion being higher in the reactivity series, and hence capable of displacing cations in the reactivity series.

Materials: 250 ml beakers, 300 ml measuring cylinder, 250 ml conical flask, 1000ml measuring cylinder, Plastic funnels, Rubber corks, Percolation tubes, Percolation rack, 2000 ml volumetric flask, pH meter, weighing balance.

Procedure: Weighed 10 Gms of the well dried and ground soil sample in a 250 ml beaker. Added 60 mls Acid washed sand and mixed the soil and sand thoroughly. Percolation rack was set by fixing percolation tubes on the rack and funnels on the percolation tubes. Added cotton wool at the lower end of the tubes and fixed bored rubber corks after cotton wool, poured sand through the funnel to a depth of 2 cm on top of the cotton wool, transferred the soil and sand mixture through funnel on to the 2 cm layer of sand, added sand to cover the sample content in the tube. Using the ammonium acetate solution as the extractant, poured 250 mls of 0.5N ammonium acetate solution via the funnel to the sample. Collected the filtrate in a 250 ml conical flask, added 150 mls 70% isopropyl alcohol to the sample to wash off the excess unreacted ammonium acetate solution after collecting the filtrate, added the 250 mls of 0.05N hydrochloric acid through the funnel to extract the ammonium ions used to displace the cations. Preserved the two percolate solutions for cations determination and cation exchange capacity (CEC) determination. Ensured that a lab check and a blank sample are included in the series of samples run.

Cations determination: This was determined from the first percolate by reading directly on BWB-1 Performance plus Flame Photometer for group one elements and Magnesium was determined by AA7000 atomic absorption spectrophotometer.

ii. Soil cation exchange capacity determination

Materials: Distillation unit, conical flask, beakers.

Reagents; Sodium hydroxide, methyl red bromocresol green mixed indicator, distilled water, boric acid.

Procedure: 20 mls of the second percolate solution was pipette and transfer into the test tube of the semi-automatic distillation unit. The distillation unit which is programmed to deliver specified amount of reagent to the sample was switched on and the steam distillation commenced for 3 minutes while the distillate was collected in the conical flask with 10 mls 2% boric acid and methyl red bromocresol green mixed indicator. The distillate was transferred to the titration rack for titration against 0.00714N sulphuric acid solution and titre recorded on reaching the end point.

iii. Soil phosphate determination

The Troug's extractant of 0.02N sulphuric acid and Molybdenum blue method were used for Mumias soils. When phosphate was reacted with molybdenum a phosphomolybdenum complex was formed in the oxidation state giving a colourless solution. A reducing agent, stannous chloride was used to alter the oxidation state of the solution to blue coloured complex. The blue coloration was directly proportional to the concentration of the phosphate.

Materials: 200 plastic containers, 50 ml pipette, shaker, funnels, Whitman filter paper No.91, UV Spectrophotometer.

Reagents: 0.02N Sulphuric acid, molybdic acid, stannous chloride (tin chloride)

Procedure: Weighed 4.0 gms of a soil sample into a 300 ml plastic container, added 200 mls of 0.02N sulphuric acid and transferred to a shaker for 30 minutes, filtered the sample using Whatman filter paper No. 91, pipette 50 mls of the filtrate, added 2.00 mls of acid molybdate solution and shaken. Added 1.0mls of stannous chloride solution for coloration, the coloured sample solution was read on the UV Spectrophotometer, P ppm = p reading x 50.

iv. Soil CEC analysis method

The apparatus used were distillation unit, conical flask and beakers. The reagents were sodium hydroxide, methyl red bromocresol, green mixed indicator, distilled water and boric acid.

The procedure was as follows; pipette 20 mls of the second percolate solution and transferred into the test tube of the semi-automatic distillation unit. The distillation unit which is programmed to deliver specified amount of reagent to the sample was switched on and the steam distillation commences for 3 minutes while the distillate was collected in the conical flask with 10 mls 2% boric acid and methyl red bromocresol green mixed indicator. The distillate was transferred to the titration rack for titration against 0.00714N sulphuric acid solution and titra recorded on reaching the endpoint.

3.5.4 Cane analysis procedure

Juice quality determination

Materials: Jeffco/cane crusher, Wet disintegrator WD02, Balance, Measuring cylinder 1.0-liter, Oven, Trays, Buckets, Funnels, 250 ml conical flask, Whatman filter paper No.91, Refractometer and Polarimeter.

Procedure: sampled sugar cane stalks as per the treatments then chopped into small chips, crushed it by a Jeffco cutter into bagasse state and weighed accurately 1.0 kilogrammes of the crushed bagasse and transferred it in the digester bowl, added 2.0 litres of distilled water and raised the bowl then ran the machine for 20 minutes. Collected the juice by sieving the digested sample on the sieve provided and determined the Brix and Polarimeter readings by using Refractometry and Polarimeter machines respectively.

Calculation:

Pol% cane = 3.0 – (0.0125 x fibre %) x Pol % extract)

$$Purity = \frac{pol\%\ extract\ x\ 100}{Brix}$$

Used the smith table to determine pol% Extract which is equal to

$$\frac{\textit{Apparent density of sugar X pol reading}}{1.0} = \frac{0.26\ \textit{X pol reading}}{1.0}$$

Cane fibre % determination

Procedure: 100 gms of the cane bagasse was weighed in a container and dried in the oven for 4 hours at 105 degrees centigrade. Weight of the container = a gms, weight of the container + 100 gms wet sample bagasse = b gms, weight of container + weight of dry sample bagasse = c gm, weight of the moisture = (b-c) hence moisture % since it’s out of 100 gm bagasse.

3.6 Data collection

3.6.1 Germination assessments

The assessment was done at 30, 45 and 60 days to ascertain the amount of cane seedlings emerged.

3.6.2 Tiller counting

This was done at 3, 5 and 7 months, the instrument used was a tally Counter. All lines were counted and recorded based on the layout as guided by the MSC – Agronomy cultural operations work instruction (form 6).

3.6.3 Foliar assessment

3.6.3.1 Sugarcane foliar sampling

Foliar samples were obtained from fully opened leaves emerging from the Top Visible Dewlap (TVD) or 3rd leaf below the TVD at 3, 4, 5, 6 and 7 months after planting. Leaf samples were collected randomly in the morning, placed in polythene bags and later subdivided into laminae and mid ribs before drying. The leaf fractions were oven dried for 24 hours at 80^{o} C to constant weight and analysed for NPK.

3.6.3.2 Method of Foliar NPK and CEC analysis

Apparatus used were, 200 ml test tube, analytical balance to four decimal place i.e 0.0001 gm, block digester with a scrapper, 100ml volumetric flasks, 5 ml pipette, 20 ml pipette.

The reagents included distilled water, hydrogen peroxide, concentrated sulphuric acid, catalyst (selenium dioxide and sodium sulphate). Procedure of analysis involved; 0.25 gms of foliar sample was accurately weighed on the analytical balance and transferred in 200 ml test tube, 3.0 mls of the sulphuric acid was added and allowed to stand for at least 30 minutes, 2.0 mls of the Hydrogen peroxide was added drop by drop after which 1.0 gms of the catalyst (selenium dioxide and sodium sulphate) was added. The sample was transferred in a programmed block digester and properly covered with the scrapper assembly for fume extraction. The wet washing continued for 60 minutes after which the sample were allowed to cool.

The cooled digest was transferred to 100 ml volumetric flasks and made to the mark by distilled water. The digest was used to analyse potassium, phosphorous and nitrogen. Nitrogen in the sample was determined using the CEC method with a semi-automatic distillation unit. N% = (T – Blank) x 0.392.

3.6.3.3 Method of Potassium analysis in foliar

The apparatus used were Pipette 5.0 mls of the aliquot into 100 ml volumetric flask and brought to the mark with distilled water. Determination was by method of flame photometry in parts per million (ppm). The calculation was as follows; K % = (R – BLANK) X 0.8 Where R is the direct reading from the flame photometer in ppm.

3.6.3.4 Method of Phosphorus analysis in Foliar

The procedure was as follows; Pipette 20 mls of the digest aliquot into 100 ml volumetric flask. 5 mls of Scheel one and 5mls of Scheel two were added and left to stand for 30 minutes followed by 10 mls of Scheels three. Distilled water was added to the mark and read the sample for phosphate on UV-Spectrophotometer. Calculation was as follows; P% =(R - Blank) x 0.2, P_2O_5 % = (R –Blank) x 0.2 x 2.29.

3.6.3.5 Method for cane juice quality (Pol %) analysis

The apparatus were Jeffco /cane crusher, wet disintegrator WD02, balance, measuring cylinder 1.0 litre, oven, trays, Buckets, funnels, 250 ml conical flask, Whatman filter paper No.91, refractometer and polarimeter. The procedure for the analysis was as follows; sugarcane stalks sampled from the trial treatments were chopped into small chips, crushed by a Jeffco cutter into bagasse state, weighed accurately 1.0 kilogrammes of the crushed bagasse and transferred into the digester bowl, 2.0 litres of distilled water added and raised the bowl, the machine was run for 20 minutes then stopped to collect the juice by sieving the digested sample on the sieve provided. Brix and Polarimeter readings were determined by using Refractometry and Polarimeter machines respectively. The calculation was as follows; Pol% cane = 3.0 – (0.0125 x fibre %) x Pol % extract), Purity = pol% extract x 100. For Brix we used the smith table to determine pol% extract which is equal to apparent density of sugar x pol reading = 0.26 x pol reading.

3.7 Statistical analysis and graphics

Data collected was subjected to analysis of variance (ANOVA) using R software version 3.4.0 (R Core Team, 2013). A one-way analysis of variance (ANOVA) was used to determine whether the various NPK treatment combinations have statistically significant impact on cane tillering, uptake, elongation and resultant yield. Statistical significance was determined at the 0.05% level of significance using the Tukey's HSD post hoc test. The data was further subjected to spearman's correlation and regression analysis to check the relationships in growth and yield parameters. The results were presented in tables and graphs generated in both excel and R software.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Initial soil properties

At the start of the experiment there was no drastic differences in the soil properties at the study site, the soil types were clay loam, with a clay % ranging from 38 to 41, silt % was 12.0 to 12.4, sand % was 17.9 to 18.4. The range of soil pH was 5.4 to 5.5. CEC levels ranged from 12.0 cmol(+)/kg^{-1} to 12.4 cmol(+)/kg^{-1}. The soil bulk density was 1.6 gcm-3, while the level of soil organic carbon ranged from 1480 mg kg^{-1} to 1488 mg kg^{-1} (Table 4.1).

Table 4.1: Initial characteristics of the experimental soils

SOIL PROPERTIES	**F1**	**F2**	**F3**	**F4**
Clay (%)	39	41	38.2	38.8
Silt (%)	12.2	12.2	12.4	12
Sand (%)	18	18.4	18.1	17.9
Textural class	Clay loam	Clay loam	Clay loam	Clay loam
pH (1:2.5)	5.5	5.4	5.5	5.5
CEC (cmol (p+) kg^{-1}	12.4	12.2	12	12.4
Bulky density (gcm-3)	1.6	1.6	1.6	1.6
Organic carbon (mg kg^{-1})	1480	1485	1488	1482

4.2 Effect of fertilizer formulations on growth and yield of sugarcane

4.2.1 Growth

The different fertilizer formulation differed significantly ($P \leq 0.05$) for sugarcane growth (stalk height and stalk girth). The highest 4.2 m growth was recorded in treatment F3 (NPKCaMg) followed by treatments F2 (DAP + MOP) + (Urea + MOP), with 2.9 m and then F1 (DAP+Urea) 2.5 m (Figure 4.1). Lowest height of 1.5 m was recorded in treatment F4 (Control). On stalk girth the highest 13.1 cm was recorded in F3 (NPKCaM followed by 10.1 cm in F2 (DAP + MOP) + (Urea + MOP), then 7.2 cm F1 (DAP+Urea), and lastly 5.5 cm F4 (control) (Figure 4.1).

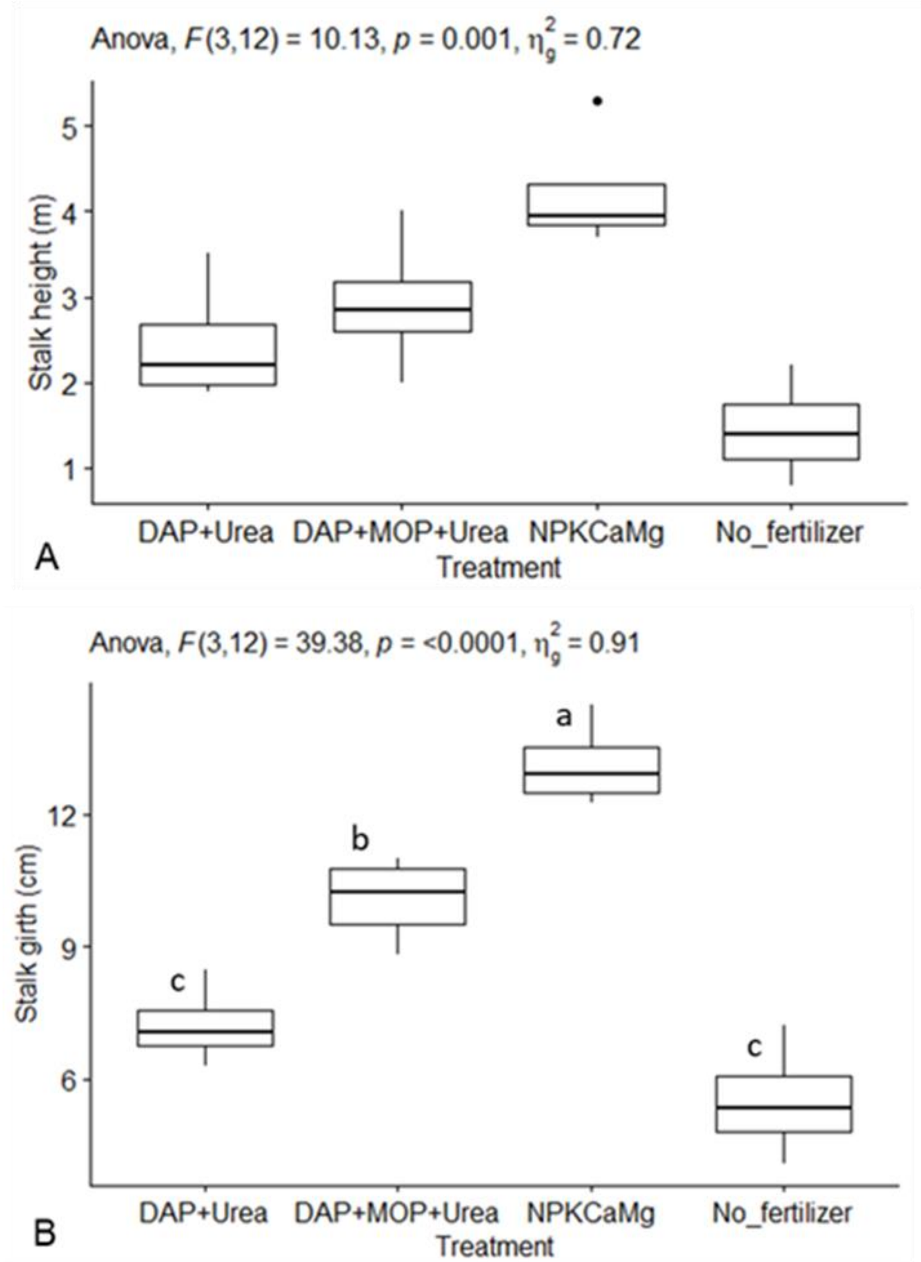


Figure 4.1: Effect of fertilizer formulations on stalk height and girth

From these results, it is speculative that the significantly high stalk height and girth obtained in NPKCaMg was a result of balanced availability of nutrients, which enhanced the crop growth (Figure 4.1). This result corroborates with those of

Soomro *et al.* (2014) who observed maximum cane thickness and cane height ha^{-1} under a balanced NPK application at the recommended levels.

The F3 treatment could have enhanced the sugarcane growth due to the presence of macro element K. This agrees with the findings as reported by Flores *et al.* (2020), that potassium (K) has positive effect on sugarcane stalk development. Potassium has a positive effect on uptake of phosphorus and nitrogen and consequently the growth rate by ensuring appropriate balance of nutrients. K plays a key role in increased photosynthesis in the plant, root development and in enhancing uptake of other plant nutrients (Rawat *et al.*, 2016), this directly and positively impact on plant growth, plant height and cane girth are the major contributing factors for high cane yield (Khan *et al.*, 2012).

4.2.2 Yield (tillers)

Significant ($P \leq 0.05$) differences were recorded in number of tillers among all the treatments and the highest tiller numbers were observed in treatment F3 (NPKCaMg) + (NPKCaMg) followed by F2 (DAP + MOP) + (Urea + MOP), then F1 (DAP) + (Urea), respectively, while the poorly performed treatment was F4 (NO Fertilizer) Control (Figure 4.2).

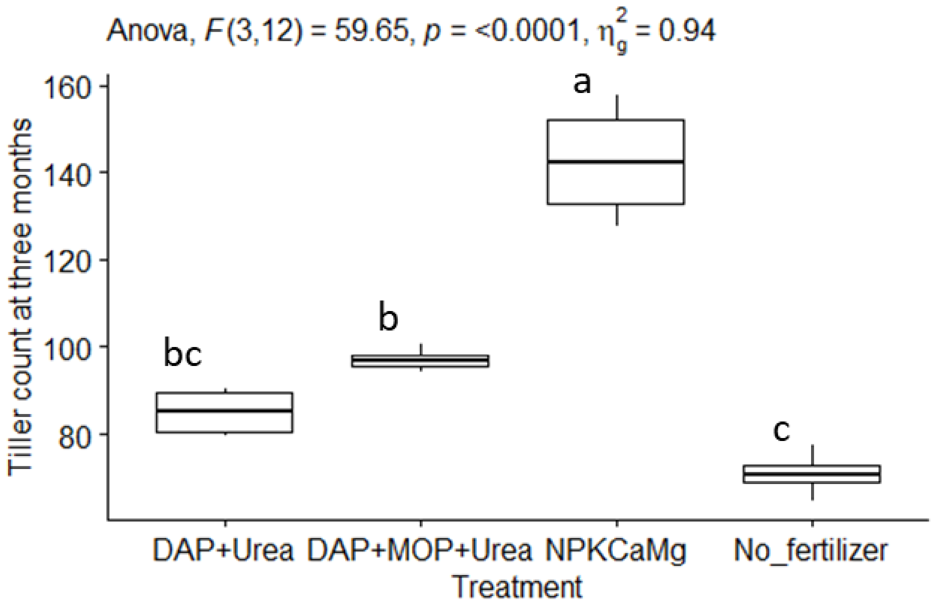


Figure 4.2: Effect of fertilizer formulations on cane yield (tiller count)

An increase in balanced fertilizer nutrients had a marked effect on the number of tillers (Figure 4.2). According to Mahar *et al.* (2008), application of NPK fertilizer at the rate of 225-112-168 kg ha^{-1} was more effective in production of significantly greater plant height, more tillers, and high cane yield ha^{-1}. Similarly, NPK rates of 68-112-112 NPK kg ha^{-1} was observed to increase the quantity of millable canes as well as the total yields (Wains *et al.*, 2012). The number of tillers an important component of yield which correlates positively with quantities of millable canes.

4.2.3 Sugarcane yield in tonnes canes per hectare (TCH)

Significant ($P \leq 0.05$) differences were recorded for cane yields among all the treatments and the highest cane yield (99.7 tonnes/ha) was observed in treatment F3 (NPKCaMg) + (NPKCaMg) followed by (61.4 tonnes/ha) observed in F2 (DAP +

MOP) + (Urea + MOP), then (50.1 tons/ha) and (37.6 tonnes/ha) for treatments; F1 (DAP) + (Urea) and F4 (NO Fertilizer) Control, respectively (Figure 4.3).

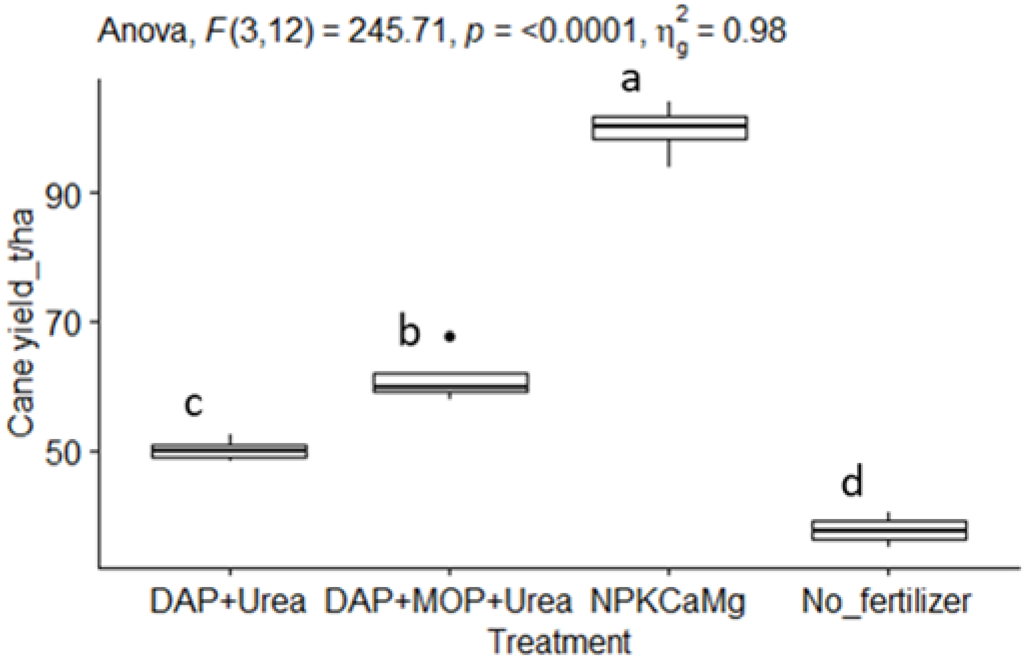


Figure 4.3: Effect of fertilizer formulations on cane yield (TCH)

The maximum yield was recorded in treatment F3 (NPKCaMg). This result corroborates with those of Soomro *et al.* (2014) who reported that through application of balanced NPK fertilizers, a higher yield of was obtained. Furthermore, treatment F3 had K macro element which is key in sugarcane production. According to several research findings, fertilizer formulations with different K rates have effect on cane yield (Filho 1985, Malavolta, 1994; Rawat *et al.*, 2016; Flores *et al.*, 2020), this agrees with the research findings on effect of fertilizer formulations on cane yield reported in this work. Lastly, Wains *et al.* (2012) revealed that sugar yield differed significantly at varied levels of NPK, hence a need to use recomended amounts in sugracene production. Good performance of NPKCaMg also indicates that addion of microelements to the fertilizer blends would enehce surgancae productivity in MSC sugarcane zone. Overally stalk height, stalk girth and tiller number were found to influence cane yields in termss of TCH. This agrees with findings of Junejo *et al.* (2010) who reported that cane girth, cane height, cane internode and millable canes are most important yield contributing parameters.

4.3 Influence of selected fertilizer formulations on sugarcane quality

4.3.1 Polarization measurement (Pol%)

The fertilizer formulation differed significantly ($P \leq 0.05$) in the available Pol %. The treatment F3 (NPKCaMg) + (NPKCaMg) recorded the highest 14.6 recoverable (Pol%) followed by F2 (DAP + MOP) + (Urea + MOP) with 13.0 available Pol %. Treatments F1 (DAP) + (Urea) and F4 (NO Fertilizer) Control did not differ significantly ($P < 0.05$) for pol % available, with Pol% values of 10.5 and 9.8 , respectively (Figure 4.4).

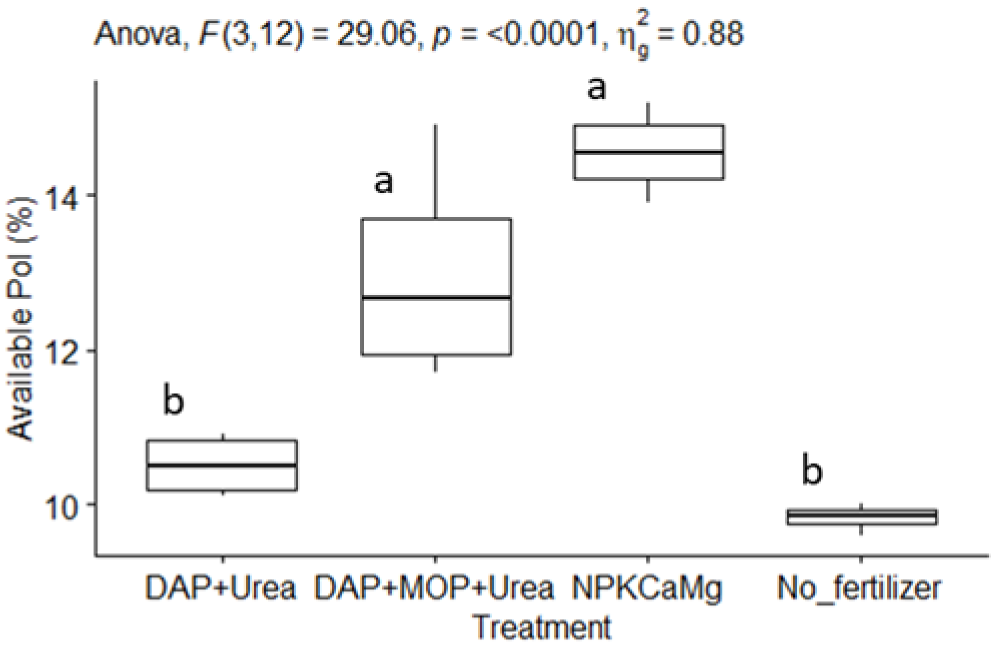


Figure 4.4: Effect of fertilizer formulations on available Polarization measurement (Pol%)

Pol% increased significantly in F3 (NPKCaMg) + (NPKCaMg) treatment. Source of Potassium (K) in the treatment increased Pol% since its associated with sucrose accumulation in the plants. For instance, high K demand by sugarcane is associated withe the role of K in several physiological and metabolic processes comprising photosynthesis, osmoregulation, nutrient transport, nitrogen absorption and synthesis of proteins and starch (Hawkesford *et al.*, 2011). Its reported tha K which is absorbed as K+ is the most abundant cation accumulating in the cell sap of sugarcane it functions in transport and storage of carbohydrates,through depolarizing the plasma membrane of the plant (Hawkesford *et al.*, 2011). Low K supply slows the rate of transport of sugars to the storage organs, therefore, the low sucrose levels observed in treatment F1 (DAP) + (Urea) was associated with the high N levels and low K levels in the formulation (Humbert, 1962).

4.4 Effect of different fertilizer formulations on soil chemical changes

Fertilizer treatments had significant effects at $P \leq 0.05$ on CEC, Ca, K, soil pH and P after cropping for two years (Table 4.2).

Table 4.2: Final soil chemical properties after application of fertilizer formulations

Fertilizer type	CEC	Ca	K	pH	P ppm
DAP + Urea	12.37c	1.07c	0.30c	4.85c	27.25a
DAP+MOP+Urea	16.55b	1.83b	2.14b	5.00b	23.65b
NPKCaMg + NPKCaMg	20.50a	2.29a	3.21a	5.50a	18.97c
Control	12.26c	1.12c	0.13d	4.98c	10.72d
P Value	<0.001	<0.001	<0.001	<0.001	<0.001
SED	0.1671	0.0452	0.1463	0.0412	0.642

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).

On CEC, the highest (20.50) was recorded at F3 (NPKCaMg + NPKCaMg) treatment, while the lowest (12.26) was recorded at in the control treatment. These observations are consistent with Brady and Weil (2007), and Partey *et al.* (2014), who observed that inorganic fertilizer application significantly ($p < 0.05$) increased CEC of soils. High 5.5 pH was recorded in F3 (NPKCaMg + NPKCaMg) treatment. The increase in soil pH in F3 treatment can be attributed to the addition of large quantities of inorganic fertilizer. This is consistent with the findings of Chuwku *et* *al.*, (2012) who noted that application of 300 kg/ha of NPK fertilizer lead to increase in soil pH. Furthermore, Partey *et al*. (2014) also observed a slight increase in soil pH for soils where inorganic fertilizer was applied compared to soils where no fertilizer was applied.

The total K status of the soil increased with increased application of NPK fertilizer, a build-up of available P was observed with the application DAP + Urea fertilizer, similar findings of increase in K as well as other elements upon application of fertilizers have also been reported by Adeniyan and Ojeniyi (2003) and Cui *et al.*, (2018). On the other hand, the depletion in total K observed in the control plots may be attributed to nutrient uptake by component crops and absence of K fertilizer application. Similarly, the available P was depleted in the control plots which may be attributed to uptake of the nutrients by sugarcane and probably due to fixation of the element that usually occur at low soil pH (Brady and Weil, 2007; Muindi *et al.*, 2015).

The soil nutrient balances were significantly different ($P \leq 0.05$). Treatment F3 NPKCaMg + NPKCaMg had high CEC, Ca, and K nutrient balance though on P the highest 11.11 ppm was observed in F2 DAP+MOP+Urea (Table 4.3).

Table 4.3: Soil nutrient balance at the end of the experiment due to fertilizer formulations

	CEC Difference	Ca Difference	K Difference	P Difference
DAP + Urea	-2c	-0.26b	0.16c	14.95a
DAP+MOP+Urea	2.25b	-0.23b	2.02b	11.22b
NPKCaMg + NPKCaMg	6.16a	0.69a	3.08a	6.68c
Control	-2.06c	-0.45c	0.005d	-1.62d
P Value	<.001	<.001	<.001	<.001
SED	0.1708	0.1145	0.1457	0.73

Means followed by the same letter within the same column are not significantly different (P ≤ 0.05).

4.5 Correlation analysis

In DAP+Urea blended fertilizer treatment there was a positive correaltion between the plant height and cane yield (r = 0.38) and plant height with available Pol% (r = 0.46). The correlation of stalk girth and available Pol% was negative but weak (r = -0.11), while the correaltion of the stalk girth and cane yield was strongly negative (r = -0.90). In this treatment, tiller count at three months had a positve correaltion with cane yield (r = 0.43). However, the correlation of the tiller count at three months to the stalk girth was strongly negative (r = -0.62) (Figure 4.5.1).

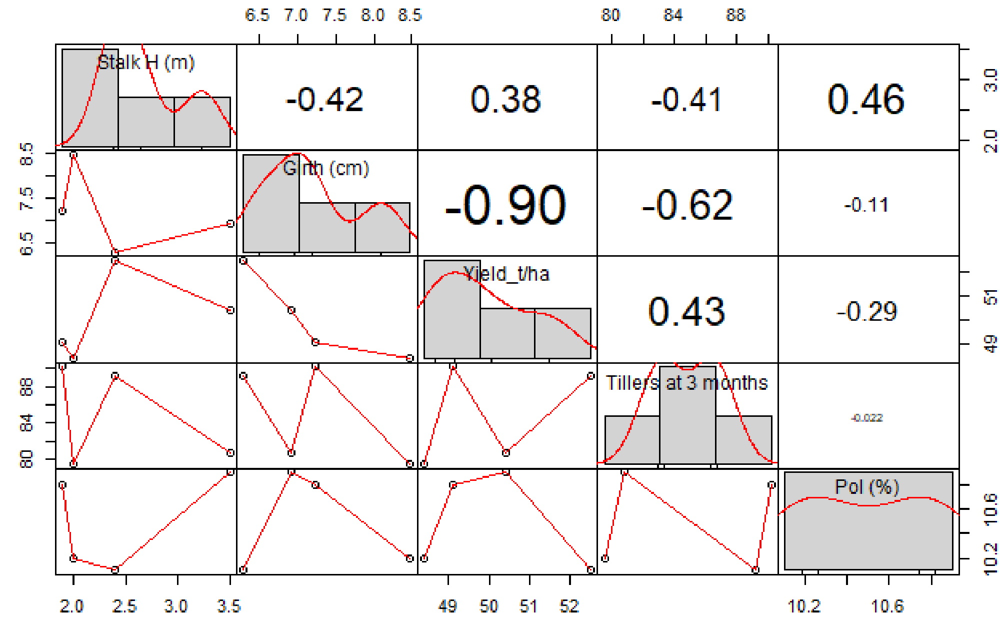


Figure 4.5.1: Correlation matrix of growth and yield parameters of Sugarcane under DAP+Urea blended fertilizer

In DAP+Urea, the weak negative correlation of cane girth and Pol% as well as that of number of tillers and Pol% may be due to the limited supply of K, other studies had already indicate that K is very key for tillering, general development and sucrose yields in sugarcane (Bhatt, 2020; Flores *et al.*, 2020). However, the above observations may also indicate luxurious use of N and P by the plant or inability to utilize these nutrients that were in excess supply, since K is very important in Uptake of other nutrients (Ali *et al.*, 2018), hence its absence may have resulted to less accumulation of sucrose. However, in this treatment, increase in cane stalk height was positively correlated with Pol%, that as the quantity of millable canes increase there is also an increase in sucrose yield, this is expected in any scenario with fertilizer application (Meyer and Wood, 2001; Alimohammadi *et al.*, 2020; Bhatt, 2020).

In DAP+MOP+Urea blended fertilizer treatment there was a very weak positive correaltion between the plant height and cane yield (r = 0.06) and plant height with available Pol% (r = 0.03). The correlation of stalk girth and available Pol% was positive but weak (r = 0.27), while the correaltion of the stalk girth and cane yield was strongly negative (r = -0.88). In this treatment, tiller count at three months had a weak negative correaltion with cane yield (r = -0.09). Similarly, the correlation of the tiller count at three months to the stalk girth was negative (r = -0.30) (Figure 4.5.2).

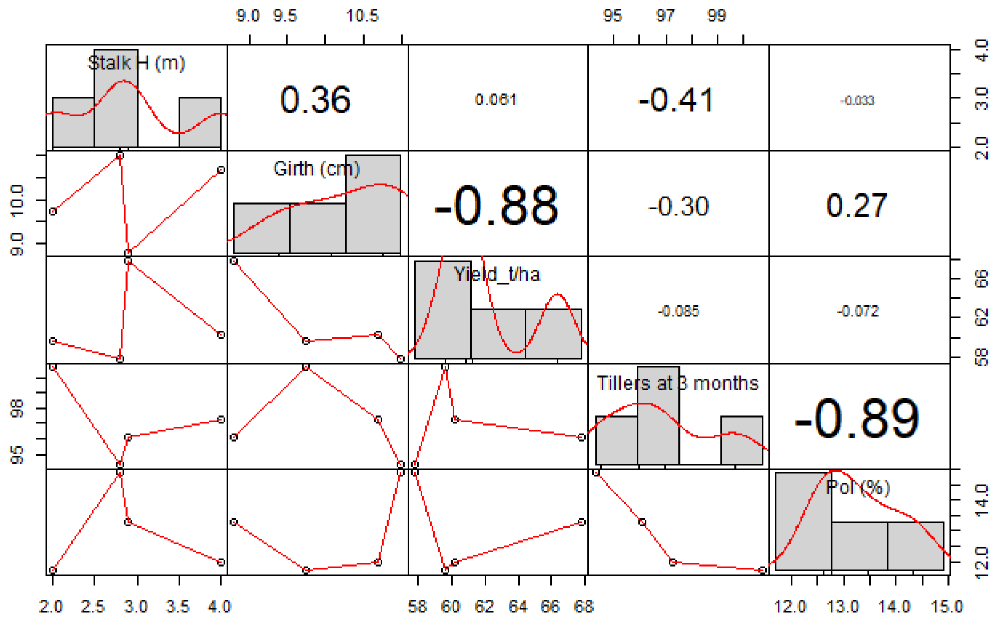


Figure 4.5.2: Correlation matrix of growth and yield parameters of Sugarcane under DAP+MOP+Urea blended fertilizers

A strong negative correlation of Pol% and tillering, in DAP+MOP+Urea blended fertilizers is an indicator of poor utilization of N and P. Furthermore, there is also weak negative correlation of Pol% withe the cane stalk height, therefore it may be possible that high amounts of N and P enhanced vegetative growth of the sugarcane but due to limiting levels of K, the sucrose accumulation was inhibited. There is Knowledge that sugarcane is able to mine K form soils with low supply as reported by Halpin *et al.* (2019), as such the positive correlation of cane girth and Pol% indicate that there was some level of N mining which promoted accumulation of sucrose in this treatment. , the weak negative correlation of cane girth and Pol% as well as that of number of tillers and Pol% may be due to the limited supply of K, numerus studies had already indicate that K is very key for tillering, general development and sucrose yields in sugarcane (Meyer, 2013; Ali *et al.,* 2018; Bhatt, 2020).

In NPKCaMg blended fertilizer treatment there was a strong positive correaltion between the plant height and cane yield (r = -0.89), while the correaltion of plant height with the available Pol% was positive but weak (r = 0.12). The correlation of stalk girth and available Pol% was negative (r = -0.31), while, the correaltion of the stalk girth and cane yield was positive (r = 0.36). In this treatment, tiller count at three months had a positve correaltion with cane yield (r = 0.63). Similarly, the correlation of the tiller count at three months to the stalk girth was positive but weak (r = 19) (Figure 4.5.3).

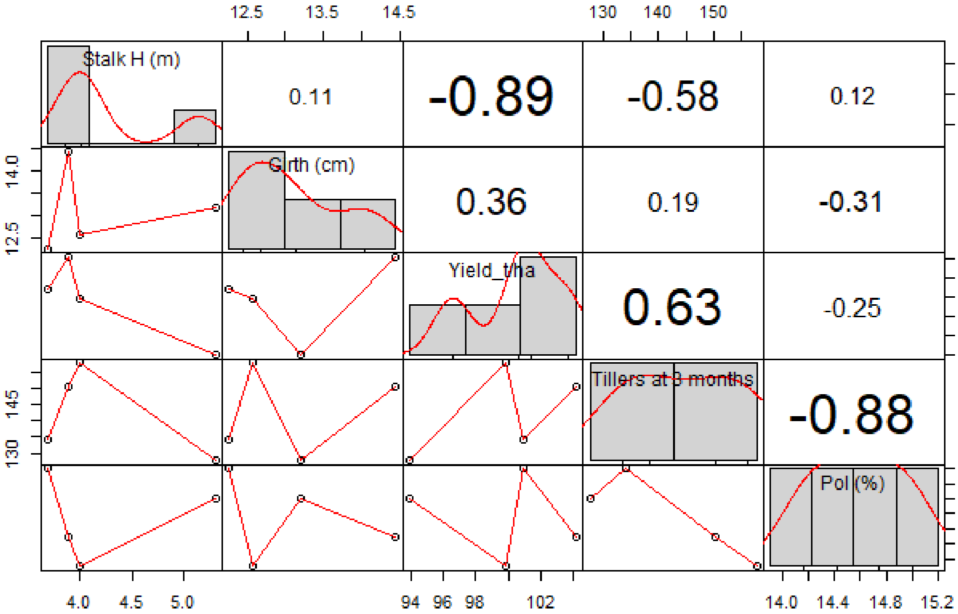


Figure 4.5.3: Correlation matrix of growth and yield parameters of Sugarcane under NPKCaMg blended fertilizer

K has been shown to promote tillering resulting in higher yields (Ali *et al.*, 2018); in sugarcane it also has role in increasing the accumulation of sucrose (Meyer and Wood, 2001), in NPKCaMg, there was a positive correlation of tillering and cane yield. High yields could have translated to high sucrose recovery, however, it is likely that the amount of K in this treatment among another elements were in abundance and hence low sucrose accumulation as observed in the negative correlation of Pol% and tillering and well as Pol% and cane girth, since during high supply of some nutrients the sucrose recovery level is usually low (Watanabe *et al.*, 2016; Roberts, 2017).

In Control, where there was no fertilzer application, there was a negative correaltion between the plant height and cane yield (r = -0.45), while the correaltion of plant height with the available Pol% was strongly positive (r = 0.51). The correlation of stalk girth and available Pol% was strohgly negative (r = -0.67), while, the correaltion of the stalk girth and cane yield was positive (r = 0.42). In this treatment, tiller count at three months had a weak positve correaltion with cane yield (r = 0.19). However, the correlation of the tiller count at three months to the stalk girth was strongly positive (r = 0.54) (Figure 4.5.4).

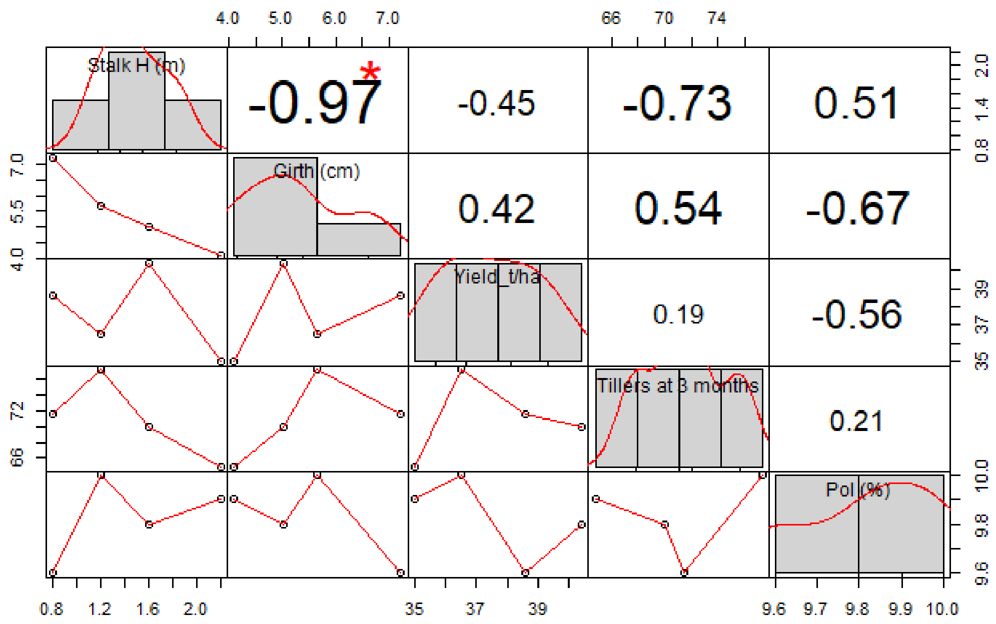


Figure 4.5.4: Correlation matrix of growth and yield parameters of Sugarcane without fertilizer application

***-significant relationship between variables at $P \leq 0.05$**

In control, there was a weak positive correlation of tillering and the cane yield. In this treatment nutrient supply was limited, therefore, the positive correlation observed between Pol% and tillering may indicate enabled nutrient use efficiency as well as nutrient mining from the soil. Furthermore, this treatment was observed to have a very strong negative correlation between the stalk height and girth compared to all the other treatments, this is a indicator of competition for nutrients such that affected balanced development of the canes. therefore, such cases limited nutrient supply is associated with poor sugarcane yields are reported by other researchers (Meyer and Wood, 2001; Oyamo *et al.*, 2017).

4.6 Regression analysis

Under DAP+Urea blended fertilizer treatment, the polynomial realtionship between cane height with the Pol% was positive (R^2 = 0.21). However, the polynomial reationships for the girth, tillering and cane yield with Pol% was negative (R^2 = 0.01, 0.001, and 0.08, respectivey) (Figure 4.6.1).

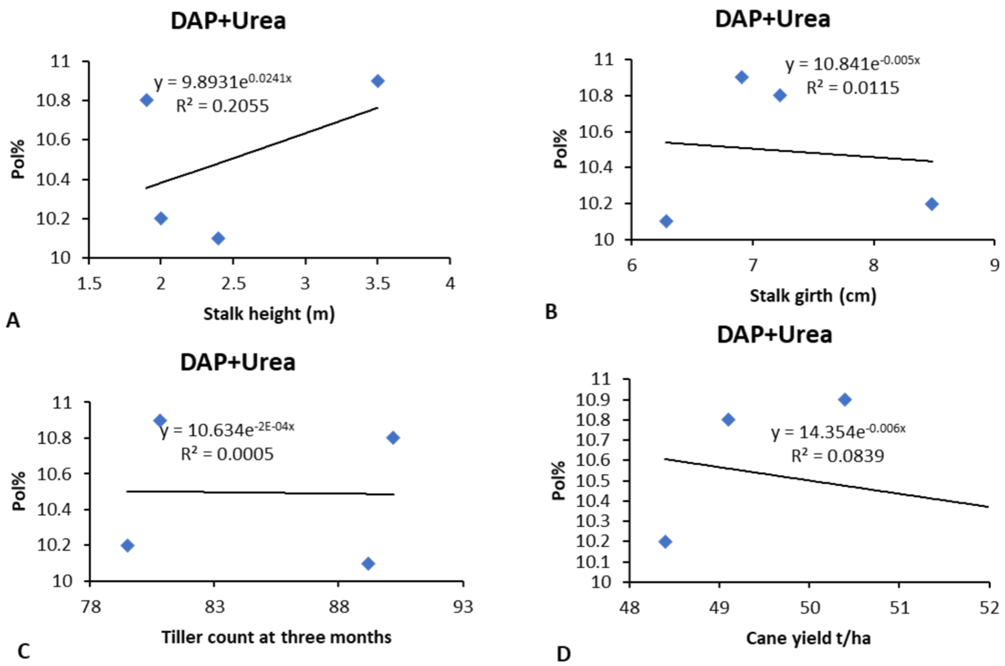


Figure 4.6.1: The exponential polynomial for the relationship between plant height, girth, tillering and cane yield with Pol% in DAP+Urea

On the other hand the polynomial relationship between cane height and tillering with cane yield was positive (R^2 = 0.21 and 0.19, respectively). However, the polynomial reationships for the girth with cane yield was negative (R^2 = 0.81) (Figure 4.6.2).

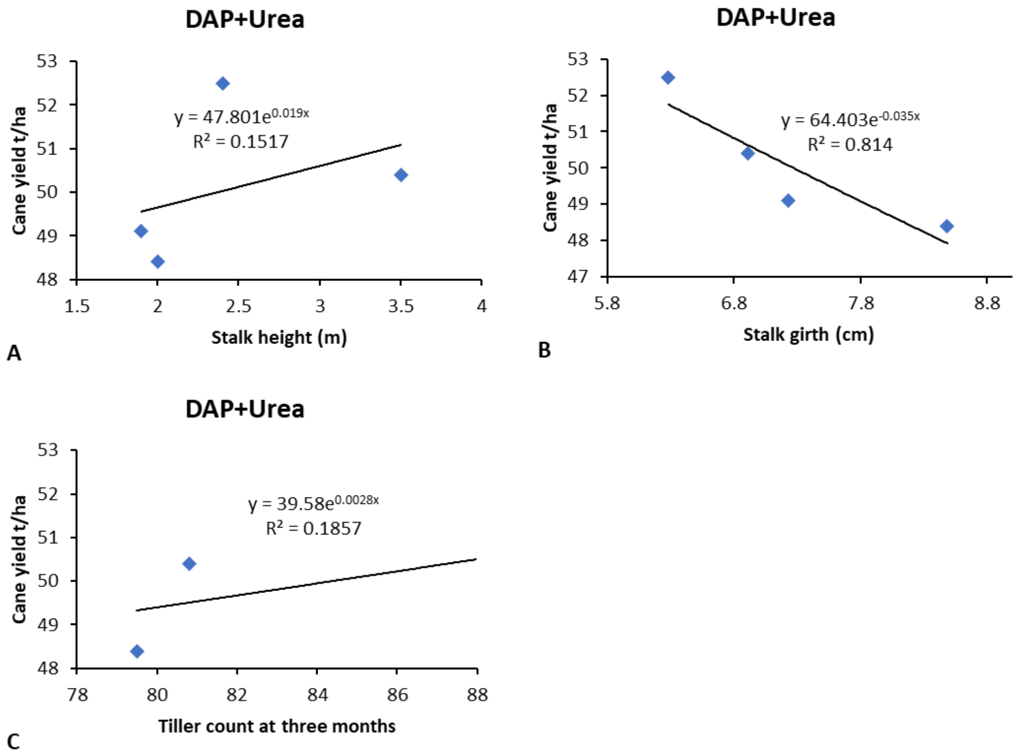


Figure 4.6.2: The exponential polynomial for the relationship between plant height, girth and tillering with cane in DAP+Urea

Under DAP+MOP+Urea blended fertilizer treatment, the polynomial realtionship between cane height with the Pol% was negative (R^2 = 0.001). However, the polynomial reationships for the girth was posive (R^2 = 0.01). In this treatment, the polynomial relationship for the tillering and cane yield with the Pol% was negative (R^2 = 0.80 and 0.002, respectiveyl) (Figure 4.6.3).

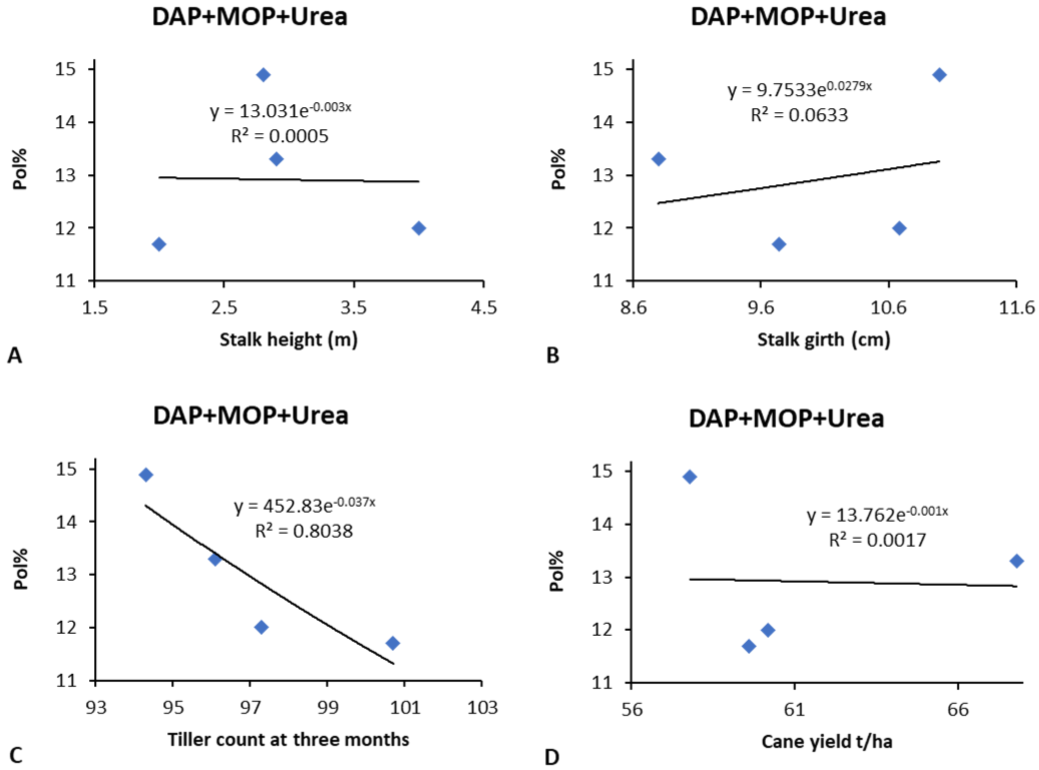


Figure 4.6.3: The exponential polynomial for the relationship between plant height, girth, tillering and cane yield with Pol% in DAP+MOP+Urea

The polynomial relationship between cane height with cane yield was positive (R^2 = 0.004). However, the polynomial reationships for the girth and tillering with cane yield was negative (R^2 = 0.78 and 0.01, respectively) (Figure 4.6.4).

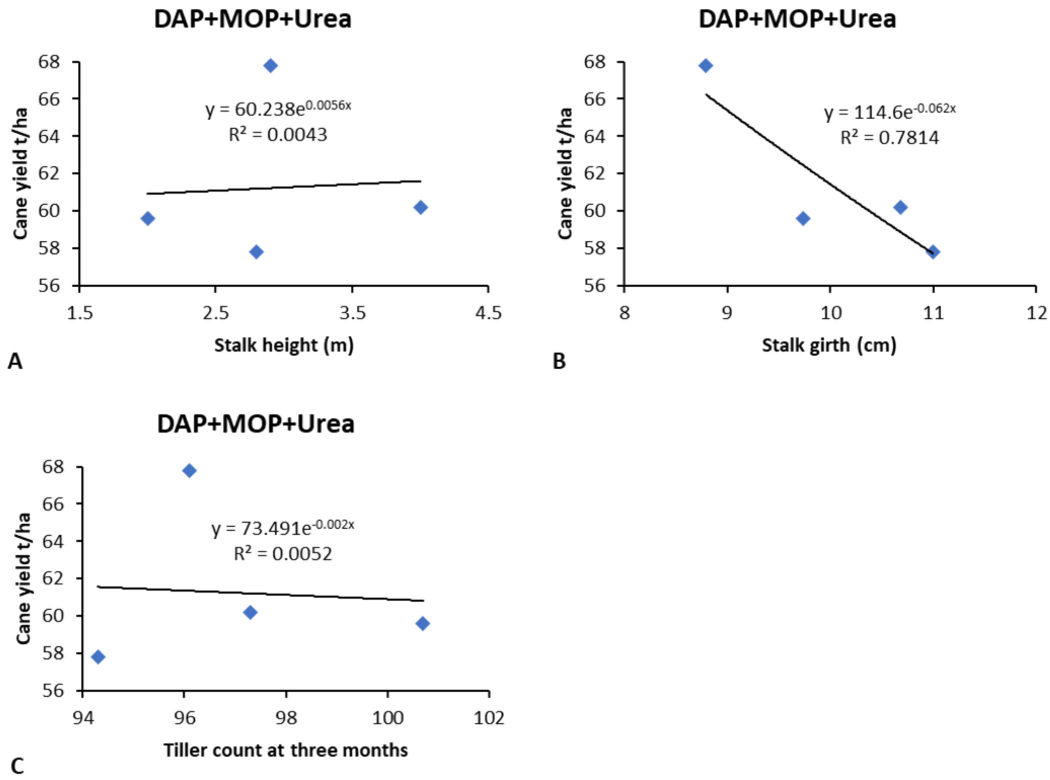


Figure 4.6.4: The exponential polynomial for the relationship between plant height, girth and tillering with cane in DAP+MOP+Urea

Under DAP+MOP+Urea blended fertilizer treatment, the polynomial realtionship between cane height with the Pol% was positive (R^2 = 0.02). However, the polynomial reationships for the girth, tillering and cane yield with Pol% was negative (R^2 = 0.09, 0.78, and 0.07, respectivey) (Figure 4.6.5).

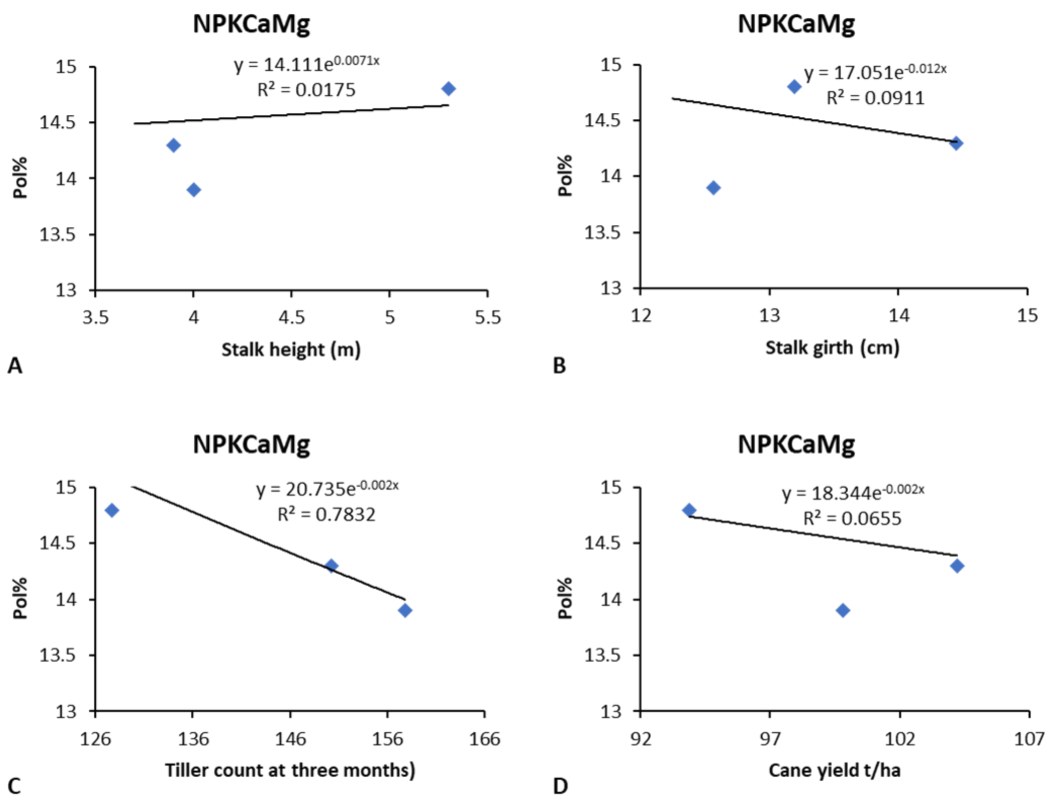


Figure 4.6.5: The exponential polynomial for the relationship between plant height, girth, tillering and cane yield with Pol% in NPKCaMg

The polynomial relationship between cane height with cane yield was negative (R^2 = 0.81). However, the polynomial reationships for the girth and tillering with cane yield was positive (R^2 = 0.12 and 0.40, respectively) (Figure 4.6.6).

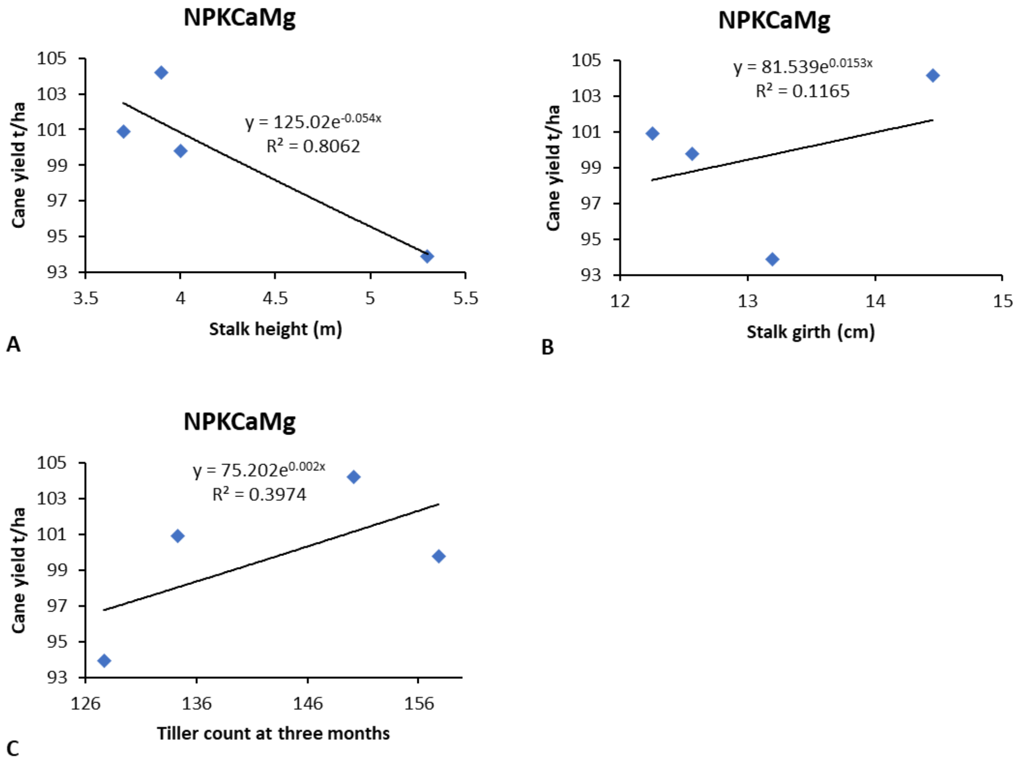


Figure 4.6.6: The exponential polynomial for the relationship between plant height, girth and tillering with cane in NPKCaMg

Under no fertilizer application, the polynomial realtionship between cane height and tillering with the Pol% was positive (R^2 = 0.26 and 0.04, respectively. However, the polynomial reationships for the girth and cane yield with Pol% was negative (R^2 = 0.46 and 0.31, respectivey) (Figure 4.6.7).

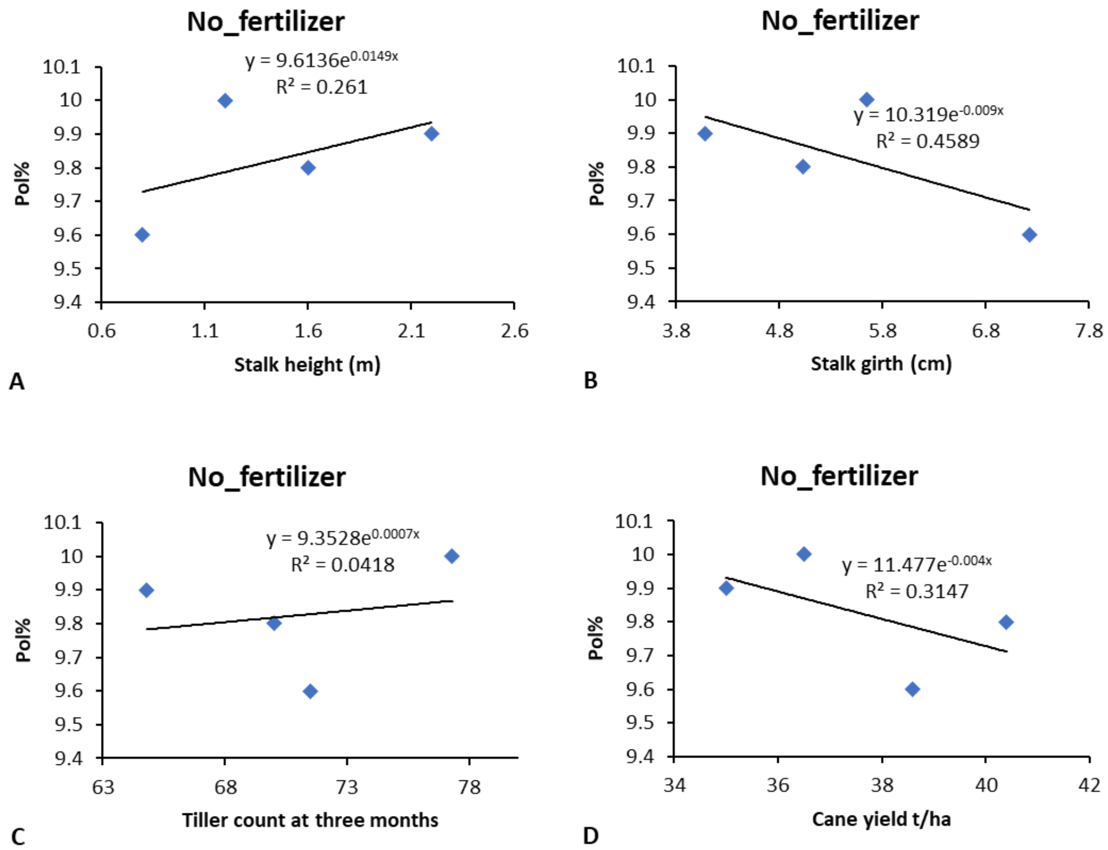


Figure 4.6.7: The exponential polynomial for the relationship between plant height, girth, tillering and cane yield with Pol% in No fertilizer application

The polynomial relationship between cane height with cane yield was negative (R^2 = 0.22). However, the polynomial reationships for the girth and tillering with cane yield was positive (R^2 = 0.19 and 0.04, respectively) (Figure 4.6.8).

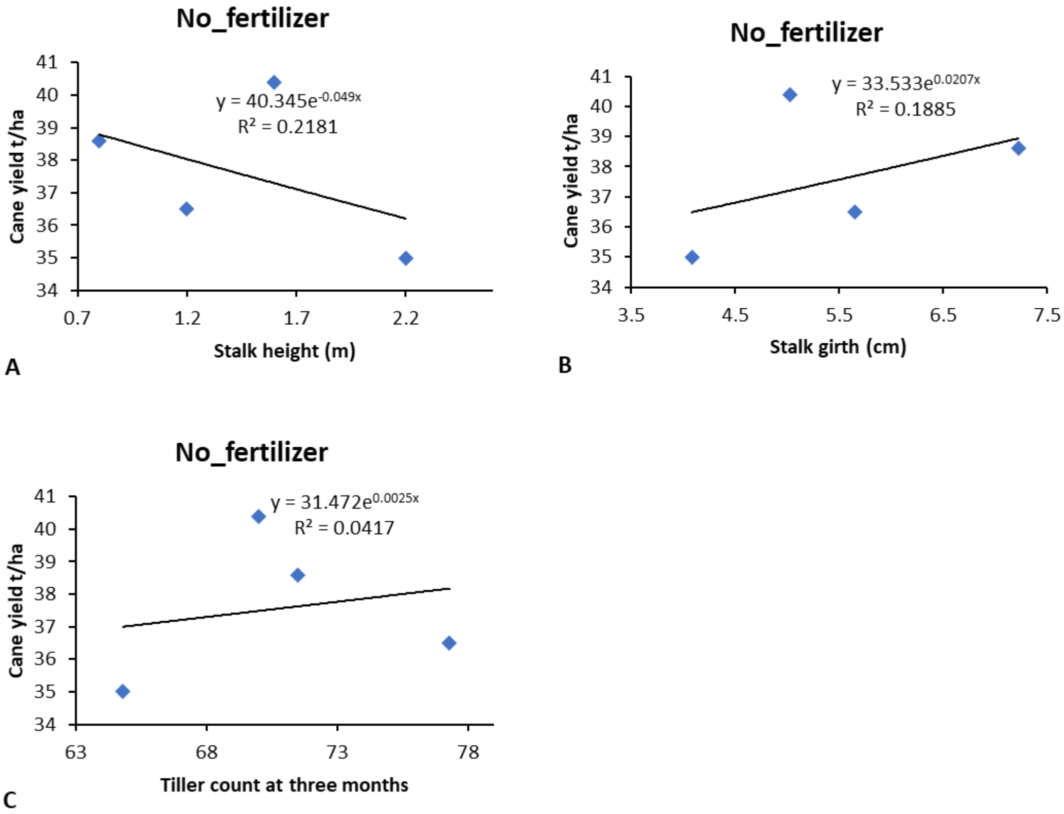


Figure 4.6.8: The exponential polynomial for the relationship between plant height, girth and tillering with cane in No fertilizer application

In general, from the regression analysis blended fertilizers appear to result to high influence of sugarcane development in terms of height and girth on the sugarcane yields and sucrose recovery, since as observed above, height increase appeared to have a neglible influence >10% to the Pol% in a relatively balanced fertilizer application of DAP+MOP+Urea and NPKCaMg compared to No fertilizer and DAP+Urea fertilizer application where the influence was very high >20%. It is likely that under limited plant nutrients the case of no fertilizer and F1 (DAP+Urea) treatment, the supply of nutrients was limited and indicating poor general productivity, however, in such scenarios an increase in plant heigh would ultimately correspond to increase in cane yields, and this may indicate enhanced mineral mining from the soil. This especially the case for F1 treatment, since it had addition of P and N, although K was missing it is already known that an increase in fertilizer would likely lead to higher sugarcane cane height and yields as reported in other studies (Meyer and Wood, 2001; Alimohammadi *et al.*, 2020; Bhatt, 2020).

From the regression it is possible that there was excessive tillering in DAP+MOP+Urea and NPKCaMg, hence the negative influence on Pol% compared to No fertilizer and DAP+Urea, these was indicate of luxurious development due high amounts of plant nutrients. However, the higher tillering in appeared to positively influence cane yields. these observations agree with Meyer, (2011) who indicate that under excess supply of nutrients in sugarcane there reaches a point of diminishing returns.

Although the influence of tillering on cane yield at No fertilizer, NPKCaMg, DAP+Urea was positive this was not the case with DAP+MOP+Urea and it indicates that increase in N, P without K would not enhance tillers. In fact, it is documented that K has a key role in sugarcane tillering (Flores *et al.*, 2020; Vijayakumar *et al.*, 2020). Therefor the observation of a very strong positive influence of number of tillering on cane yields observed in NPKCaMg was due to a the inclusion of K alongside other major plant nutrients N and P as well as addition of Ca and Mg in the treatment, this is in agreement with many other research findings where balanced fertilizers results to increased sugarcane yields (Mayer and Wood, 2001; Tsado *et al.*, 2013: Roberts, 2017; Bhatt, 2020). In general, the above observed support a need for a balanced nutrient supply to for enhanced sugarcane productivity in MSC sugarcane zone.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

i. There were significant differences in cane growth and yield when different fertilizer formulations were applied to sugarcane in the target study area.

ii. Conversion of reducing sugars to sucrose (Pol% cane) was enhanced when K containing fertilizers were applied on sugarcane.

iii. There were changes in soil chemical properties with different formulations with NPKCaMg having higher positive impact on soil chemical properties.

5.2 Recommendation

i. The research recommends that farmers use fertilizer blends as opposed to acidic fertilizers that have traditionally been used in this area.

ii. For increased sucrose and sugar cane quality farmers are advised to use blends/formulations containing K (if companies pay as per Pol%). However, they should consider use of more N if payment is as per biomass.

iii. There is need to further conduct NPK field response studies in the varying sugar growing agro ecological zones in Kenya to ascertain specific formulations for improved longterm soil chemical properties and optimum sugarcane growth, yield and sucrose recovery.

REFERENCES

Addiscott, T. M. (1970). The uptake of initially available soil potassium by rye grass. *The Journal of Agricultural Science, 74*(01), 123-129.

Adeniyan, O.N. and Ojeniyi, S.O. (2003). Comparative effectiveness of different levels of poultry manure with NPK fertilizer on residue soil fertility, nutrient uptake and yield of maize. *Moor Journal of Agriculture*. Ibadan 2: 191-197.

Ali, H., Ahmad, I., Hussain, S., Irfan, M., Areeb, A. and Shabir, R. N. (2018). Basal application of potassium nutrition enhances cane yield, juice quality and net returns of sugarcane (Saccharum officinarum L.). *Pakistan Journal of Agricultural Sciences, 55*(2).

Ali, M. A., Hassan, M. S., Mohamed, B. D. and Ali, M. H. (2020). Performance and stability analysis of some sugarcane genotypes across different environments. *SVU-International Journal of Agricultural Sciences*, *2*(2), 192-213.

Alimohammadi, M., Panahpour, E.and Naseri, A. (2020). Assessing the effects of urea and nano nitrogen chelate fertilizers on sugarcane yield and dynamic of nitrate in soil. Soil Science and Plant Nutrition, 1-8.

Amolo, R. A., Sigunga, D. O. and Owuor, P. O. (2017). Evaluation of soil properties of sugarcane zones and cropping systems for improved productivity in Western Kenya.

Bachchhav, S. M. (2005). Fertigation technology for increasing sugarcane production. *Indian Journal of Fertilisers, 1*(4), 85.

Bhatt R. (2020) Resources Management for Sustainable Sugarcane Production. In: Kumar S., Meena R.S. and Jhariya M.K. (eds) Resources Use Efficiency in Agriculture. Springer, Singapore. https://doi.org/10.1007/978-981-15-6953-1_18

Blume, H. (1985). Geography of sugar cane: environmental, structural and economical aspects of cane sugar production. Verlag Dr. Albert Bartens.

Bonnett, G. D. (2013). Developmental stages (phenology). Sugarcane: physiology, biochemistry, and functional biology, 35-53.

Bora, A. (2017). Application of Manures and Chemical Fertilizers in Assam-A Study in Historical Perspective.

Brady, N.C. and Weil, R.R. (2007). The Nature and Properties of Soils (13th Ed.) Prentice Hall, New Jersey.

Cai, A., Xu, M., Wang, B., Zhang, W., Liang, G., Hou, E. and Luo, Y. (2019). Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. *Soil and Tillage Research, 189*, 168-175.

Chandiposha, M., Kunedzimwe, N., Gwazane, M. and Chiriman'ombe, D. (2014). Comparisons of sugar blend 1 plus fertilizer over straight fertilizer as basal application on growth and yield of sugarcane (*Saccharum officinarum* L).

Chen, D., Jiang, Y., Ao, J., Zhou, W., Huang, Y., Shen, D., ... and Li, Q. (2017). Research progress on potassium nutrition in sugarcane. *Journal of Agricultural Sciences, 7*(6), 443-450.

Chen, J., Lü, S., Zhang, Z., Zhao, X., Li, X., Ning, P. and Liu, M. (2018). Environmentally friendly fertilizers: A review of materials used and their effects on the environment. *Science of the total environment, 613*, 829-839.

Cui, X., Zhang, Y., Gao, J., Peng, F. and Gao, P. (2018). Long-term combined application of manure and chemical fertilizer sustained higher nutrient status and rhizospheric bacterial diversity in reddish paddy soil of Central South China. *Scientific reports, 8*(1), 1-11.

Dave, A. M., Mehta, M. H., Aminabhavi, T. M., Kulkarni, A. R. and Soppimath, K. S. (1999). A review on controlled release of nitrogen fertilizers through polymeric membrane devices. *Polymer-Plastics Technology and Engineering*, *38*(4), 675-711.

de Castro Assumpção, D., Hamaguchi, M., Rocha, J. D. and Mariano, A. P. (2020). Green Energy in Africa, Asia, and South America. Green Energy to Sustainability: *Strategies for Global Industries*, 57-75.

de Matos, M., Santos, F. and Eichler, P. (2020). Sugarcane world scenario. In Sugarcane Biorefinery, Technology and Perspectives (pp. 1-19). Academic Press.

de Oliveira, M. W., Macêdo, G. A. R., Martins, J. A., da Silva, V. S. G. and de Oliveira, A. B. (2018). Mineral nutrition and fertilization of sugarcane. Sugarcane: *Technology and Research*, 169.

Farm Management Handbook of Kenya Vol. II- Natural Conditions and Farm Management Information 2nd edition. Part A West Kenya (Subpart A1-Western

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

Flores, R. A., Andrade, A. F. D., Casaroli, D., Quirino, D. T., Abdala, K. D. O., Martins, C., ... and Evangelista, A. W. P. (2020). Potassium Fertilization in Sugarcane Ratoon Yield Grown in a Tropical Region. *Communications in Soil Science and Plant Analysis*, *51*(7), 896-910.

Gachene, C.K.K., Mureithi, L.G., Anyika, F. and Makau, M. (2000). Incorporation of green manure cover crops in maize based cropping systems in semi-arid and subhumid environments of Kenya. Proc. KARI Scientific Conference of Soil Management and Legume Research Network project pp 144 151.

Glassop, D., Hodson, M. P., Chrysanthopoulos, P. K. and Rae, A. (2020). The Developmental Stages of Sugarcane Stalk are Equivalent between Plants of Different Chronological Ages. *Tropical Plant Biology*, *13*(2), 136-149.

Gopalasundaram, P., Bhaskaran, A. and Rakkiyappan, P. (2012). Integrated nutrient management in sugarcane. *Sugar Tech*, *14*(1), 3-20.

Grimme, S. (2012). Supra molecular binding thermodynamics by dispersion-corrected density functional theory. Chemistry-A *European Journal*, *18*(32), 9955-996.

Haerdter, R. and Fairhurst (2003). Nutrient use efficiency in upland cropping systems of Asia. IFA Regional Conference, Cheju Island, Korea 6-8 October, 2003.

Halpin, N. V., Bell, M. J., Rehbein, W. E. and Moody, P. W. (2019). Potassium fertilisation strategies for rotational grain-legume crops—Implications for the subsequent sugarcane crop. In 41st Australian Society of Sugar Cane Technologists Conference, ASSCT 2019 (pp. 251-258). Australian Society of Sugar Cane Technologists.

Hassan, S. F. (2008). Development of sugar industry in Africa. *Sugar Tech*, *10*(3), 197-203.

Hawkesford, M., Horst, W., Kichey, T., Lambers, H., Schjoerring, J., Müller, I.S. and White, P. (2011). Functions of macronutrients: Potassium. In: Marschner, Petra. (Ed) Marschner's Mineral Nutrition of Higher Plants. Elsevier, Adelaide. pp 178-189.

Humbert, R.P. (1962). Potash and sugarcane quality. Proceedings of the Congress of the International Society of Sugar Cane Technologists11: 115-123.Humbert, R.P. 1968. The growing of sugarcane. Elsevier Publishing Co. Ltd, Amsterdam.

Iqbal, A., Ehsanullah and K. Iqbal (2002). Biomass production and its portioning in sugarcane at different nitrogen and phosphorus application rates. *Pakistan. Sugar J. 17*(2): -17

Irfan, S. A., Razali, R., KuShaari, K., Mansor, N., Azeem, B. and Versypt, A. N. F. (2018). A review of mathematical modeling and simulation of controlled-release fertilizers. *Journal of Controlled Release, 271*, 45-54.

Isherwood K. (2006). Fertilizer development during the 20th century. *Farming outlook 5* (1) :3-1082.

Jaetzold, R., Schmidt, H., Hornetz, B. and Shisanya, C. (2005). Ministry of Agriculture. Farm Management Handbook of Kenya Vol. II- Natural Conditions and Farm Management Information 2nd edition. Part A West Kenya (Subpart A1-Western province), pp 36-38.

Jamoza, J. (2005, July). Sugarcane variety improvement in Kenya. In Proceedings of the 79th Annual Congres s of South African Sugar Technologists' Association, held at Kwa-Shukela, Mount Edgecombe, South Africa, 19-22 July 2005 (pp. 230-234).

Jamoza, J. E., Amolo, R. A. and Muturi, S. M. (2013). A baseline survey on the status of sugarcane production technologies in Western Kenya. In Proceedings of international society of sugarcane technologists (Vol. 28).

Karthika, K. S., Rashmi, I. and Parvathi, M. S. (2018). Biological functions, uptake and transport of essential nutrients in relation to plant growth. In Plant nutrients and abiotic stress tolerance (pp. 1-49). Springer, Singapore.

Kawamitsu, Y., Nagae, T., Ohmi, N., Ueno, M., Sun, L. and Tokashiki, Y. (1997). Improvement of Sugar Production in Sugarcane with Crop, Soil and System Engineering: I. Relationship between sugar content and elements in Minamidaitou and Ishigaki Islands. *Japanese Journal of Crop Science, 66* (1): 262–263.

Kenya Sugar Board (2010). Yearbook of Statistics. 100 pp

Khan, I. A., Bibi, S., Yasmin, S., Khatri, A., Seema, N. and Abro, S. A. (2012). Correlation studies of agronomic traits for higher sugar yield in sugarcane. *Pak. J. Bot, 44*(3), 969-971.

Khosa, T.M. (2002). Effect of different levels and sources of potassium on growth, yield And quality of sugarcane. Better Crops International, Vol. 16, No. 1, p 14-15.

Kirungu, C. A. (2011). The impacts of weather on sugarcane production in the mumias sugar zone of western Kenya (Doctoral dissertation).

Kwong Ng Kee, K.F. (2000). The Effects of Potassium on Growth, Development, Yield and Quality of Sugarcane. Sugar Industry Research Institute, Réduit, Mauritius.

la S, M. and Dlamini, C. S. (2012). The concept of sustainable sugarcane production: Global, African and South African perceptions. *African Journal of Agricultural Research, 7*(31), 4337-4343.

Liang,R., Yuan, H., Xi, G. and Zhou, Q. (2009) Synthesis of wheat straw-g-poly (poly (acrylic acid) superabsorbent composites and release of urea from it. *CarbohydrPolym77*:181–187

Mahamuni, I., Lakshmanan, C. and Krishnamurthy, K.S. (1975). Studies on NPK fertilization on yield and juice quality of sugarcane variety Co 658 in the soils of Lalgudi tract in Trichy district. *Indian J. Agric. Chemistry 8* (1+2), p 1-7.

Mahar, G.M., U. A. Buriro, F. C. Oad and.S. A. Shaikh (2008). Cane Yield and Sugar Recovery of Sugarcane Variety Larkana-2001under Different Fertilizer Sources. *Asian J. Plant Sci. 7* (2): 237-240

Malavolta, E. (1994). Nutrient and fertilizer management in sugarcane. International Potash Institute Bulletin No. 14. International Potash Institute, Basel, Switzerland.

Mati, B. M. and Thomas, M. K. (2019). Overview of sugar industry in kenya and prospects for production at the coast. *Agricultural Sciences, 10*(11), 1477-1485.

Mbene, K., SuhTening, A., Suh, C. E., Fomenky, N. N. and Che, V. B. (2017). Phosphorus fixation and its relationship with physicochemical properties of soils on the Eastern flank of Mount Cameroon. *African Journal of Agricultural Research, 12*(36), 2742-2753.

Meyer, J. (2011). Sugarcane nutrition and fertilization. Good management practices manual for the cane sugar industry. Eds. J. Meyer. The International Finance Corporation (IFC). Johannesburg. South Africa, 173-226.

Meyer, J.H. (2013). 28th Int. Soc. Sugar cane Technol. Congress, Brazil. pers. comm.

Meyer, J.H. and Wood, R.A. (2001). The Effects of Soil Fertility and Nutrition on Sugarcane Quality – a Review. *Proc. S. Afr. Sugar Tecnol. Ass. 75,* p 242-247.

Moody, P.W. and Aitken, R.L. (1997). Soil Acidification under some Tropical Agricultural systems. *Australian J. of Soil Research 35* (1): 163-174.

Moraes, M. A. F. D., Oliveira, F. C. R. and Diaz-Chavez, R. A. (2015). Socio-economic impacts of Brazilian sugarcane industry. *Environmental Development*, *16,* 31-43.

MSC (2012). Agronomy Annual Reports 2000-2012.

MSIRI (2000). 34th Certificate Course in Sugarcane Agronomy, Sep – Nov 2000. http//pages.intnet.mu/rasitc.

Muindi, E. M., Mrema, J. P., Semu, E., Mtakwa, P. W., Gachene, C. K. and Njogu, M. K. (2015). Phosphorus adsorption and its relation with soil properties in acid soils of Western Kenya.

Mutonyi, J, S. S., Chemining'wa, G., Olubayo, F., Nyongesa, H. and Konje, M. M. (2014). Effects of N and K fertilization of sugarcane (Saccharum oficinarum) on acrisols in western Kenya. *Elixir Agriculture, 67*(21669–21675).

Mutonyi, J. (2014). Management strategies for potassium deficiency and low pH on sugarcane growth, yield and quality in the Mumias Sugar Zone of Western Kenya (Doctoral dissertation).

Oyamo, S., Serrem, C. and Otinga, A. N. (2017). Restoring soil fertility in previously sugarcane cropped farms for maize production in Butere-Kakamega County. *African Journal of Agricultural Research, 12*(33), 2598-2607.

Oyugi, B. A. (2016). Socio-Economic Impacts of Sugarcane Farming on Livelihoods and The Biophysical Environment in Transmara Sub-County, Kenya. Kenyatta University.

Partey, S. T., Preziosi, R. F. and Robson, G. D. (2014). Short-term interactive effects of biochar, green manure, and inorganic fertilizer on soil properties and agronomic characteristics of maize. *Agricultural Research, 3*(2), 128-136.

Perez, O. and Melgar, M. (1998). Sugarcane response to Nitrogen, Phosphorus and Potassium in Andisol soils. *Better Crops International Vol. 12*, No. 2 p 20-24.

Perez, O. and Melgar, M. (2000). Sugarcane Response to Potassium in Andisol soils. *Better Crops International Vol. 12*, No. 2 p 20-24.

Plaut, Z., Meinzer, F. C. and Federman, E. (2000). Leaf development, transpirationtranspiration, and ion uptake and distribution in sugarcane cultivars grown under salinity. *Plant and Soil*, *218*(1-2), 59-69.

Priya, M. S., Reddy, K. H. P., Kumar, M. H., Rajarajeswari, V., Naidu, G. M. and Reddy, B. (2016). Sugarcane for Diversified Uses. *Electronic Journal of Plant Breeding, 7*(3), 677-683.

Quemener, J. (1986) 'Nutrient balances and need for potassium', Thirteen International Potash Institute Congress, International Potash Institute, Reims, pp. 41-69.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Rawat J., Sanwal P. and Saxena J. (2016) Potassium and Its Role in Sustainable Agriculture. In: Meena V., Maurya B., Verma J., Meena R. (eds) Potassium Solubilizing Microorganisms for Sustainable Agriculture. Springer, New Delhi. https://doi.org/10.1007/978-81-322-2776-2_17

Rethinam, F. J., Oli, D. A., Ramasamy, S. and Ramasamy, P. (1993). Growth and Characterisation of Pure and Nickel-doped Strontium Tartrate Tetrahydrate Single Crystals. *Crystal Research and Technology, 28*(6), 861-865.

Roberts, S. (2017). The fundamentals of sucrose accumulation in sugarcane.

Römheld, V. and Kirkby, E. A. (2010). Research on potassium in agriculture: agriculture needs and prospects. *Plant and Soil, 335*(1-2), 155-180.

Shi, C., Xie, C., Zhang, Z., Rackemann, D., Wei, B., Hang, F., ... and Doherty, W. O. (2020). Sugar and value-added products derived from retentate concentrate of sugarcane juice. *Journal of Cleaner Production, 123915*.

Shikanda, E., Jamoza, J. and Kiplagat, O. (2017). Genotypic evaluation of sugarcane (Saccharum spp. Hybrids) clones for sucrose content in western Kenya. *Journal of Plant Breeding and Crop Science, 9*(3), 30-36.

Singh, V.K., Shukla, A.K., Gill, M.S., Sharma, S.K. and Tiwari, K.N. (2008). Improving Sugarcane Productivity Through Balanced Nutrition with Potassium, Sulphur and Magnesium. Better Crops - India pp 12-14.

Soomro, A. F., Tunio, S., Keerio, M. I., Rajper, I., Chachar, Q. and Arain, M. Y. (2014). Effect of inorganic NPK fertilizers under different proportions on growth, yield and juice quality of sugarcane (*Saccharum officinarum* L). Bio, 3(1), 10-18.

Thomas, S., Conlong, D. E., Barton, M. G., McElligott, D. M., Maher, G. and Terblanche, J. S. (2018). Impacts of sampling effort on estimating abundance of the aphid Sipha flava (Forbes) in sugarcane in Mazabuka, Zambia. In Proceedings of the Annual Congress-South African Sugar Technologists' Association (No. 91, pp. 78-82). South African Sugar Technologists' Association.

Timilseana YP, Adhikani R, Casey P, Muster T, Gill H and Adhikari B (2014). Enhanced efficiency fertilizers: a review of formualationsformulations and nutrient release patterns. (Wileyonlinelibrary.com). Doi 10.1002/jsfa6812. Retrieved 18. August18. August 2016

Tisdale, S. L. and Nelson, W. L. (1966). Soil fertility and fertilizers. Soil Science, 101(4), 346.

Trenkel, M.E. (2010). Slow- and Controlled-release and Stabilized Fertilizers: An Option for Enhancing Nutrient Use Efficiency in Agriculture. International Fertilizer Industry Association (IFA), Paris

Tsado, P. A., Lawal, B. A., Igwe, C. A., Adeboye, M. K. A., Odofin, A. J. and Adekambi, A. A. (2013). Effects of sources and levels of phosphorus on yield and quality of sugarcane in Southern Guinea Savanna Zone of Nigeria. *Agriculture Science Developments, 2*(3), 25-27.

Vijayakumar, M., Thirunavukkarasu, M., Pandian, R. D. and Mahendran, P. P. (2020). Enhancement of Sugarcane Productivity through STCR based Balanced Fertilization. *Int. J. Curr. Microbiol. App. Sci*, *9*(5), 3433-3449.

Wains, G. M., Mudassir, M. A., Ghaffar, A., Fiaz, N., Sarwar, M. A., Ali, Z. and Ferdosi, M. F. (2012). Performance of autumn planted sugarcane at varied fertilizer levels. *Mycopath*, *10*(1), 21-23.

Wang, Y., Zhu, Y., Zhang, S. and Wang, Y. (2018). What could promote farmers to replace chemical fertilizers with organic fertilizers?. *Journal of cleaner production*, *199*, 882-890.

Watanabe, K., Nakabaru, M., Taira, E., Ueno, M. and Kawamitsu, Y. (2016). Relationships between nutrients and sucrose concentrations in sugarcane juice and use of juice analysis for nutrient diagnosis in Japan. *Plant Production Science*, *19*(2), 215-222.

Wiedenfeld, B., Enciso, J., Fipps, G. and Robinson, J. (2005). The Irrigation of Sugarcane in Texas. Texas Agricultural Experiment Station, Texas Cooperative Extension, Texas A & M University System.

Yadav, B. K. and Sidhu, A. S. (2016). Dynamics of potassium and their bioavailability for plant nutrition. In Potassium solubilizing microorganisms for sustainable agriculture (pp. 187-201). Springer, New Delhi.

Yang, L., Shen, S. Y., Wang, Z. N., Yang, T., Guo, J. W., Hu, R. Y., ...and Ying, X. M. (2020). New Value-Added Sugar and Brown Sugar Products from Sugarcane: A Commercial Approach. Sugar Tech, 1-5.

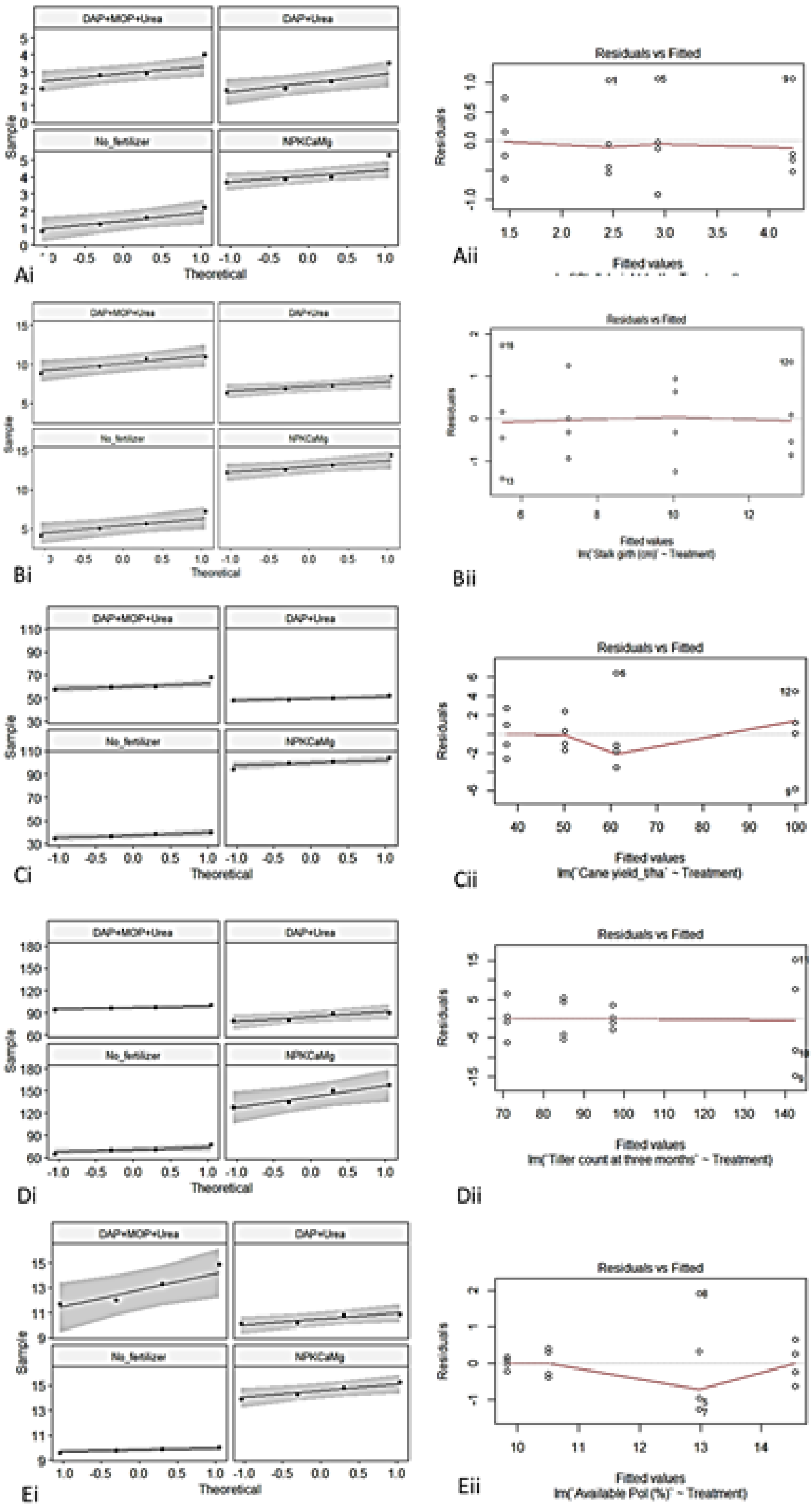
Yue, X., Zhang, J., Shi, A., Yao, S. and Zhang, B. (2016). Manure substitution of mineral fertilizers increased functional stability through changing structure and physiology of microbial communities. *European Journal of Soil Biology*, *77*, 34-43.

APPENDICES

Appendix 1: Field activities and sugarcane crop development

(A) Preparation of seedbed for planting; (B) Planting of seed cane; (C) Fertilizer application during planting; (D) Sugarcane growing in a neatly weeded field; (E) Mature sugarcane ready for harvesting; (F) Weighing of harvested sugarcane.

Appendix 2: Normality and homogeneity of variance checks for the data



(i)Normality check QQ plot, (ii) The residuals versus fits plot. A) Stalk height (m); B) Stalk girth (cm); C) Cane yield t/ha; D) Tiller counts/number at three months; E) Available Pol (%).