EFFECTS OF RATE AND TIMING OF NITROGEN APPLICATION ON GROWTH AND YIELD OF SEEDCANE *(Saccharum* spp)

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DECLARATION

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

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To my family, mentors and friends for continued support in my studies.

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ABBREVIATIONS AND ACRONYMS

BMPs	Best Management Practices
C	Carbon
DAP	Diammonium Phosphate
FAO	Food and Agricultural Organization
FRG	Farmers Research Group
FRI	Fractional Radiation Interception
GDP	Gross Domestic Product
Ha	Hectare
K	Potassium
KALRO	Kenya Agricultural and Livestock Research Organization
KESREF	Kenya Sugar Research Foundation
KNA	Kenya National Assembly
KSA	Kenya Sugar Authority
KSB	Kenya Sugar Board
LAI	Leaf Area Index
LM	Lower Midland
LSD	Least Significant Difference
LTM	Long term mean
MMS	Mumias Sugar
NAE	Nitrogen Agronomic Efficiency
NE	Nucleus Estate
NPE	Nitrogen Physiological Efficiency
NPK	Nitrogen Phosphorous Potassium
NRE	Nitrogen Recovery Efficiency
NUE	Nutrient Use Efficiency
OG	Out-growers
pH	Log [H+]
N	Nitrogen
PPM	Parts per Million

RCBD	Randomized complete block design
RUE	Radiation Use Efficiency
SPAD	Soil Plant Analysis Development
SRI	Sugar Research Institute
SSP	Single Super Phosphate
TCH	Tonnes Cane per Hectare
WV	Weight by Volume

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ABSTRACT

Nitrogen (N) is among the most important crop nutrient. Numerous metabolic activities, particularly those involved with crop growth, such as tillering and stalk elongation, rely on N. N deficiency reduces light interception and photosynthesis due to a reduction in leaf area, chlorophyll synthesis, and biomass production. Many intensive agricultural production systems, such as sugarcane systems, which collect a large quantity of biomass, necessitate higher N rates. N recommendations, on the other hand, should use an application rate that minimizes environmental impact while maintaining greater yields. This is accomplished by using the appropriate rate of N at the appropriate moment. Several studies have found that the optimum N treatment rate is affected by a variety of parameters, including soil type, crop age, plant and soil characteristics, climate, growing cycle length, and growing season duration. The influence of N rate and time of N-rate on growth and yield of two phenologically distinct sugarcane varieties is investigated in this study. Two experiments were conducted simultaneously at the Sugar Research Institute (SRI) of the Kenya Agricultural and Livestock Research Organization (KALRO) in Kibos (KALRO-SRI-Kibos) and at the Nucleus Section of Mumias Sugar Factory (MMS NE-Mumias) from October 2018 to July 2019. The design used was a RCBD with a 3 x 2 x 3 factorial arrangement of the treatments with three replications. The net plot size for data collection was 1.5 m x 2 rows x 5 m = 15 m2 in nucleus estate and 1.2 m x 2 rows x 5 m = 12 m2 in out growerTreatments included two varieties (KEN 82-216 and KEN 82-601), three N rates of 0, 60 and 120 kg N/ha supplied as fertilizer Urea (46 % N), and three timings of N application, which included one-time application at three months after planting (T1), two-equal split applications at three and six months after planting (T2), and a delayed one-time application at six months after planting (T3). Data was collected on percent seedling emergence, plant height, number of leaves per plant, internode length, stem girth, leaf area index, stalk population and cane yield. The two varieties recorded a significance difference ($P \leq 0.05$) in number of tillers in both Mumias and Kibos. At Mumias, interactions between variety and N-rate, resulted in a significant effect in leaf area index in the 5th month. At Mumias, N-rates significantly affected the number of leaves per plant in the 10th month. Variety KEN 82-601 recorded a higher average height

of (91cm) than variety KEN 82-216 (81 cm) in Kibos and Mumias respectively. A significant effect of N-rates on plant height between the varieties was recorded in the 7th and 10th months and N-rates and varietal interactions recorded a significant effect on stalk height in Mumias in the 5th and 7th month. At Kibos, the two varieties recorded a higher average dry mass of 415w/m^2 compared to 348w/m^2 recorded at Mumias. Nitrogen-rate recorded a significant effect on plant population in Mumias. Increase in N-rate resulted to a high plants/ha of 10151 at 120 kg/ha at Mumias compared to 8153 plant/ha in the control. There was no difference in yield at Kibos and Mumias in variety KEN 82-216. N-rate of 120 kg/ha resulted in high seed yield of 25 t/ha compared to 19 t/ha under control, and 23 t/ha for 60 kg/ha N. Mumias recorded a higher seed yield of 22.5 t/ha compared to Kibos at 20 t/ha. Time of N-rate application recorded a significant effect on leaf area index in the 3rd month at Kibos while at Mumias, non-significant effect of time of N-rate application on leaf areas index were recorded. N-rate application in the 6th month after planting (T3) recorded a higher internode length than T1 and T2, while in Mumias, N-rate application in the 3rd month after planting recorded a higher average length of 17cm compared to T2 (16.9 cm) and T3 (16 cm). Varieties grown at Mumias recorded a higher average number of leaves of 44 per plant compared to those grown at Kibos which recorded 40 leaves per plant. A high average number of leaves were recorded in the 7th month at Mumias (58leaves) and Kibos (50leaves). N-rate application at the 3rd month after planting (T1) recorded a higher stem girth of 2.4 cm compared to T2 (2.2 cm) and T3 (2.3 cm) in Kibos. A higher average plant height was recorded at T3 (N-rate application 6 months after planting) in Kibos (94.6 cm) and Mumias (89 cm). Interactions between varieties and time of N application had non-significant effect on number of tillers in Kibos and Mumias. Variety KEN 82-216, recorded a higher average plants/ha of 9225 than variety KEN 82-601 that recorded an average of 7714 plants per hectare. N-rate application at T3 (6 months after planting) recorded the highest dry weight of 467 w/m^2. From this study, it can be concluded that 120 kg of N applied in splits at 3rd and 6th months after planting may be suitable for seedcane production as they recorded high seedcane yield of 29 t/ha and better agronomic performance. Variety KEN 82-216 had a better response to N application, and thus it could be practiced in N-intensive farms.

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background

According to global sugar production statistics for 2020/2021, Brazil was the world's largest sugar-producing country, producing approximately 42 million metric tonnes of sugar. During that time, global sugar production was approximately 179 million metric tons (Shahbandeh, 2021) with Africa accounting for 5.8%. East Africa is a net importer of sugar, with production in 2011/12 totaling 1,018,572 MT versus consumption of 1,501,477 MT (Lichts, 2012). Kenya has approximately 202,000 ha of sugarcane production, with an average production of 5.262 million tonnes of cane being supplied to factories per year. Furthermore, average sugarcane yields have fallen from around 66.4 t/ha in 2015 to 55 t/ha in 2018 which are significantly lower than the global average of 63 t/ha (Mati and Thomas, 2019). Low quality sugarcane varieties, poor agronomic management, high input costs, delayed harvesting, and industry disillusionment are among the reasons for productivity decline (Mati and Thomas, 2019).

The sugar industry is important in the agricultural sector, employing approximately 6 million Kenyans both directly and indirectly (Boniface *et al.*, 2017). Sugar production is a major contributor to the economy and has led to approximately 16% growth to the nation's Gross Domestic Product .The sub sector despite of having greater contribution to the country its output rate is declining and for now it is at 65 tonnes per hectare comparing with the approximated average national output of 100 tonnes per hectare (Ambetsa *et al.*,2020)

Nitrogen is essential for healthy vegetative growth and crop development (Sreewarome *et al.,* 2007). It is a very difficult nutrient to manage when fertilizing sugarcane because it interacts with organic matter in the soil and can be lost in a variety of ways (Cantarella and Rossetto, 2014). Cane requires a high N fertilizer nutrient to produce biomass (Bohnet *et al.*, 2011). N is accumulated in stalks, with the above ground parts of the cane plant containing approximately 0.7 to 1.6 kg of N per ton of stalk and the entire plant requiring approximately 2 to 2.4 kg of N per ton of stalk. During harvesting, cane extracts containing more than 200 kg N/ha yielding 100 t/ha of stalks and 90 to 110 kg/ha are exported (Cantarella and Rossetto, 2014). However, excessive or insufficient uptake causes stunting by reducing photosynthesis. N nutrition affects yield by increasing sucrose accumulation in harvested cane, but the rate of varietal response to N application varies (Wood, 1990).

Little is known about how nitrogen rate and timing of application influences establishment and yields of seed cane crop in Kenyan sugar industry (Achieng *et al.,*2015) In addition, N by genotype interaction are only partially understood in seedcane crop but it is more understood in millable cane. Sugarcane cultivars are completely different in their performance, quality and yield due to their genetic variation (Pereira *et al., 2017).*

Phenology is elongation and growth development of sugarcane in relation to environment, most important temperature (Keller, 2010). It contributes to yields and crop adaptation of crop to different environments (Khan and Iqbal, 2007). In sugarcane as in most cereal crops phenology is strongly related to temperature and time recurring physiology of the crop and its surrounding environment interaction during the development stages (Dendrobium and Orchidaceae, 2012). Phenology and leaf area development influence biomass accumulation (Andrade *et al.,* 2016). In turn, biomass accumulation determines the amount of radiation intercepted and sucrose metabolism (Andrade and Bertini, 2006).

The relationship between Kenya's sugarcane hybrids temperature is only partially understood (Lingle, 1999). Temperature impacts the development stages, biomass accumulation and sugar levels in plant parts as well as enzymatic activity in sucrose metabolism. Sugarcane plants growing under constant temperature of 15^{o}C had slow crop growth rate and few leaves as well as few and short internodes (Ebrahim *et al.,*1998; Lingle, 1999). In addition, at 45^{o} C, tiller production is reduced when the crop is already developed and elongated. It was found that leaf senesced early under 45°C compared with 15^{o}C (Ebrahim *et al*., 1998). Sucrose concentration was also found to be higher in plants under 15°C and lower in 45°C. The Mediterranean climate of high temperature resulted in shorter internodes and lower sucrose content than crops under lower temperature (Shnghera *et al*., 2019)

1.2 Statement of the problem

Higher cane and sugar output is based on the selection of high-yielding varieties and adequate crop management, including the administration of balanced fertilizer at the appropriate rate and time. Nitrogen is necessary for plant growth. Adequate nitrogen availability to crops is known to increase photosynthetic activity, vigour in vegetative development, and dark green color in plant leaves Boddey, (1995). Nitrogen is the nutrient that has the most impact on how sugarcane grows and how much it produces (Clements, 1980). Climate, crop age, growth cycle length, plant traits, and soil factors all influence global N recommendations for sugarcane production (Wiedenfeld, 1995). Low sugarcane yields in Kenya are mostly related to poor N fertilizer management, among other issues. Unfortunately, fertilizer prices are exceedingly expensive all around the world.

Given that N fertilizer is mostly applied below the soil surface (8–10 cm) on sugarcane farms, ammonia volatilisation is nolonger considered a major issue. However, N losses through denitrification, leaching and runoff are still of great concern as sugarcane farms are mostly located in area with high rainfall more than 1200 mm/year (Wang *et al.,* 2016). Nitrogen-efficient management strategies are needed to mitigate N2O emissions from sugarcane farming while maintaining productivity and profitability.The apparent recovery of applied nitrogen by plants is rarely more than 50 percent, while the remainder is lost from the soil plant system (Whitfield, 1992), improved management practices can aid in nitrogen uptake efficiency.

Nitrogen deficiency in Western Kenya has contributed to low and declining sugarcane yields, as well as poor application timing. Environmental factors affect productivity of varieties with even high yielding potential resulting in low yields. Technologies such as agronomic practices, sugar processing technologies, market research, and technology dissemination revolve around the improved sugarcane variety. A comparative analysis of sugarcane productivity in terms of establishment and yield at various rates and times of nitrogen fertilizer application is required.

1.3 Justification of the study

It is critical to manage nitrogen application in order to maximize cane yield and obtain sugar recovery. Early N application may reduce total cane tonnage, whereas delayed application will result in delayed maturity and decreased sugar accumulation. According to Reghenzani *et al*., (1996), timing N application to coincide with conditions optimum for plant uptake can positively influence N uptake. With increased public concern about environmental quality, high production costs, and low nitrogen fertilizer use efficiency (NUE) (20-40%, (Vallis and Keating, 1994, Gava *et al*., 2005, Meyer *et al*., 2007), it is vital to enhance N management in sugarcane production. However, the N requirement of cane to produce maximum production differs between fields and cropping years. Several studies have demonstrated that sugarcane does not typically respond to N fertilizer because there is enough mineralized

Nitrogen available during the fallow period (Muchovej and Newman, 2004, Lofton and Tubaa, 2015). According to Wiedenfeld (1995), an overabundance of plant-available N could explain the increased quantity of immature stalks later in sugarcane growth (Salter and Bonnett, 2000). The higher quantity of immature stalks at harvest can dilute cane sugar, resulting in lower sucrose content and economic value. Inadequate N at tillering (rapid stalk formation), on the other hand, eventually lowered overall sugarcane biomass production due to decreased canopy photosynthesis and sugarcane's inability to sustain growth later in the season.

Studies (Meyer *et al*., 2007; Perez and Melgar, 1998) have shown that crop response to nitrogen fertilization is varied and complex, and often linked to availability of nitrogen held in soil organic matter. Correct N nutrition not only increases cane yield, but also improves the sucrose content in the harvested cane. This response to N rate varies with variety , region, temperature, number of sunny days and watering regime.

Several studies have documented the use of plant N response to enhance techniques of estimating crop N requirements based on chlorophyll readings (Peterson *et al*., 1993, Varvel *et al*., 1997). Lofton *et al*., (2012) discovered that the Normalized Difference Vegetation Index (NDVI) measured by an active canopy reflectance sensor during the late tillering stage of sugarcane may be utilized to evaluate the sugar production response to increased N fertilizer in sugarcane. However, unlike the widely studied Normalized Difference Vegetation Index (NDVI), the timing of N-rate application is not well documented. The study's objectives were to improve sugarcane production and quality by better regulating nitrogen through optimal N-rates and timing of N-application. This study's findings are applicable to crop management and variety selection (Robinson *et al*., 2007). As a result, it is critical to understand how the timing and amount of N applied affects sugarcane growth and yields.

1.4 Objectives

The broad objective of this study is to improve the yield of seedcane through better management of nitrogen supply.

This study has been conceived with the following specific objectives:

(i) To determine the effect of the rate of N application on growth and yield of two phenologically contrasting seedcane varieties

(ii) To determine the effect of timing of N application on growth and yield of two phenologically contrasting seedcane varieties

1.5 Hypotheses

(i) Sugarcane responds to increased nitrogen rate, irrespective of variety.

(ii) Timely nitrogen application improves sugarcane yield.

CHAPTER TWO: LITERATURE REVIEW

2.1 Botany and ecology of sugarcane

Sugarcane (*Saccharum ssp.)* was derived from indigenous wild species on Malanesia's lands by selecting wild canes in New Guinea, which were then carried as stem cuttings to various centers and were modified through natural hybridization with other wild grasses (Crisi *et al.*, 2022). Cane belongs to the Gramineae family. The plant consists of roots, stalks, leaves, and an above-ground stem with nodes, lateral buds, and a root band that serves as a sucrose reservoir. Sugarcane has alternate leaf arrangement which is more efficient for photosynthesis, with up to 2-3% light absorption as a C4 crop (Yadav, 2009).

Sugar cane is a warm-temperate and (sub)tropical crop which requires a warm, sunny and moist climate and fertile, deep and well aerated soils. The crop cycle, growth and maturation are largely influenced by climatic conditions, moisture and heat favor growth, while dry sunny periods and low night temperatures are favorable for maturation and sugar accumulation (Verheye, 2010).

2.2 Climatic requirements for sugarcane production

Sugarcane grows well on warm and humid climate with an annual ideal rainfall range of 1100-1500 mm is required for vegetative growth. At vegetative phase, sugarcane requires rains that is necessary for cane elongation and development. High rainfall at ripening stage dilutes sugar concentration, encourages vegetative growth and encourages shoot moisture concentration. Heavy rains impede harvesting and transport operations (Wang *et al.*, 2017). Crop growth is a function of temperature and photoperiod, temperatures required for germination of setts range from 32-38^{o}C above which it reduces the rate of light interception while increasing plant respiration. However, low temperatures at a range of 12^{o} – 14$^{o\,C}$ slow down ripening and sucrose metabolism (Wang *et al.,* 2017).

2.3 Sugarcane production trends in Kenya

2.3.1 Evolution of the sugar iIndustry in Kenya

Agrarian communities along riverside lands cultivate native sugarcane cultivars. The crop was consumed or used to make local brew (Barnes, 1953). Sugarcane was introduced as an industrial crop in Kenya in 1902, when the first experiments were established in Kisumu (Wanyande, 2001). In 1922, the first sugar industry was built in Miwani near Kisumu (Odada, 1986). From the 19th century until independence in 1963, sugar production policies were based on colonial law, which stipulated that only

Asians could cultivate sugarcane. The Swynerton Plan (Swynerton, 1955) policy reforms, which permitted Africans to produce certain cash crops, had no effect on sugar. That modified with the passage of Sessional Paper No. 10 of 1965 Wekesa *et al*., (1995), which authorized Africans to cultivate industrial sugarcane. Following independence in the 1960s, the government made a concerted effort to invest in sugar factories, primarily in western Kenya (Table 1).

Table 1**.** Sugar factories establishment in Kenya and their capacities in 2015 and 2016

Sugar factory	Year established	Area under cane (ha)	Mill capacity (tonnes)	Available sugarcane (tonnes)
Miwani sugar company	1922	1860		28718
Muhoroni sugar company	1964	17503	360800	339258
Chemelil sugar company	1965	18442	451000	187234
Mumias sugar factory	1973	36582	1312000	1054759
Nzoia sugar sactory	1978	29022	492000	807651
South Nyanza sugar factory	1979	16186	410000	475900
West Kenya sugar company	1981	30104	688800	734609
Butali sugar mills	2005	29551	410000	479311
Soin sugar factory	2006	1769	24600	28929
Kibos sugar & allied industries	2007	6847	492000	149016
Kwale international sugar company	2007	5500	295200	274316
Busia sugar company	2008	-	-	-
Kisii sugar factory	2009	-	-	-
Transmara sugar company	2011	16445	656000	615176
Sukari industries Ltd	2011	9155	459200	232552
Total (Tonnes)		**218966**	**6051600**	**5407427**

Data source: Sugar history. Sugar Research Institute. http://www.kalro.org/sugar/?q=sugar-history and Agriculture and Food Authority-Sugar Directorate [AFA-SD] (2015) Cane Availability Survey 2015/16-16/17 Report. In 2015, Kenya had 15 sugar factories with milling capacities exceeding 6 million tonnes per year, but available cane was 5,407,427 tonnes per year (Table 1). Sugar production has remained below milling capacity to date.

2.3.2 Breeding of sugarcane in Kenya

Sugarcane farming in Kenya started in early 1900s by Indian settlers in Kibos (Technical bulleting, 2006). Production spread to lowland coastal regions in Ramisi around 1920s and extended to Western region between mid-1960s and early 1980s. Earlier varieties included Co 421, Co 617 and Co 331 which were released in 1950s as well as Co 945, Co 1148, CB 38-22 and N14 which were released in 1960s, in recent years the Sugar Research Institute (SRI) has intensified breeding efforts that led to release of 13 improved varieties that are adapted to diverse environments in the Kenya sugarcane belt. Some of these varieties include KEN 82-216, KEN 82-206, KEN 82-219, KEN 82-474, KEN 82-62, KEN 83-311, EAK 73-335 and EAK 73-293,which are adapted to highland regions and KEN 82-808, KEN 83-737, N14, CB 38-22, CO 945,CO 421 and D 84-84 that are well adapted to the lowlands (Ochami and Ochieng, 2020). Notably among these cultivars, KEN 82-216, KEN 82-219, KEN 82-808, KEN 83-737, D84-84 and KEN 82-601 cultivars are completely different in their performance, quality and yield due to great variation in their gene structure (Omondi *et al.*, 2016).

Variety performance is a phenotypic expression. When environmental conditions are addressed appropriately, sugarcane varieties perform well. Sugarcane yields have not increased proportionally over the last decade, despite the release of six Kenyan varieties bred for early maturity, including KEN 82-601 and KEN82-216 (Robinson *et al*., 2007). The aim of the present sugar cane breeding programmes is to develop high yielding, pest and disease resistant varieties, early maturity (harvest in 14-18 months) and high sucrose content, high nitrogen use efficiency and varieties that are adapted to the cane growing conditions in Kenya.

2.3.3 Sugar Production

Sugarcane is currently grown primarily in western Kenya and the coastal region. The majority of Kenya's cane mills are supplied by approximately 250,000 small-scale sugarcane farmers. The sugar industry supports the livelihoods of approximately six million Kenyans both directly and indirectly. Sugar is one of Kenya's most important commercial crops, along with tea, coffee, flowers, vegetables, and maize. However, average sugarcane yields have dropped from approximately 66 t/ha in 2015 to 55 t/ha in 2018. This can be attributed to low-quality sugarcane varieties, poor agronomic management, high input costs, late harvesting (Kenya Sugar Board, 2009). According to the Agriculture and Food Authority (AFA) area under sugarcane cultivation also decreased from 211,300 ha in 2014 to 202,400ha in 2018 and the total production decreased from 6.4million tonnes to 5.3million tonnes over the same period **(**AFA, 2015).

2.4 Constraints to sugarcane production in Kenya

Sugarcane yields are estimated at 55 t/ha which pales in comparison to the global average of 63 t/ha (Cane Availability Survey 2016/17 Report. Sugar Directorate, (AFA-SD, 2013) Sugarcane yield potential has been shown to range between 80 and 100 t/ha in researcher-managed experiments (KESREF, 2004). The yield gaps are caused by un certified cane seeds, declining soil fertility, poor sugarcane varieties, and over- reliance on rainfall.Weeds are the major constraints of sugarcane production being a long duration and widely spaced crop it provides an opportunity for several weeds to grow in space from planting to harvesting, in sugarcane production cane yields losses ranging from 20-90% were reported due to weeds in different country fierce competitors for moisture, light, and nutrients in the soil, during the first 50 days of planting, weeds consume four times the N, P, and K of sugarcane (Nasir *et al*., 2014).

Diseases on sugarcane are the important factors affecting the productivity of cane, in Kenya 30 diseases including major and minor diseases caused by fungi, bacteria, virus and phytoplasma were recorded on commercially cultivated sugarcane varieties, among these the most important diseases are Sugarcane smut, Ratoon stunting diseases, red rot, pineapple disease, sugar rust and sugarcane mosaic virus disease (Geobel *et al*., 2011).

Cane farmers are going for alternative crops to enhance food security and income because cane farming has proved to be a loss in the region as most of them are facing financial constraints leading sugar millers facing tough times and some have closed due to financial crises as they have failed to pay farmers for a long period (Mati *et al*., 2019). The survival of Kenyan sugar industry depends on the implementation of recommendation given by farmers and sugar industry in sugar industry policy is not stable in reduction of taxes on farm inputs and refined sugar to significantly increase the competitiveness of Kenyan sugar in both the domestic and foreign markets, also the government can give tax concessions to sugar companies that engage in research and developing of sugarcane varieties and husbandry (Inyang *et al.*, 2018).

2.5 Agronomic practices of sugarcane

Crop yields are most affected by agronomic practices, which include nurturing the crop to reach its full yield potential. Proper land preparation is required for crop establishment, it also aids in the control of weeds, diseases, and pests. Cane setts are used to propagate sugarcane vegetatively for commercial production. Fresh and healthy planting materials are required to improve a well-established crop stand (free of disease and pests). This equates to 5,000-30,000 setts per hectare at a seed rate of 6-10 t/ha Wawire *et al.,* (2006).

Sugarcane is grown as a monoculture, which exposes it to harmful fungi and nematodes that impede its establishment and growth during the initial stages, resulting in lower sugarcane yields (Pankhurst *et al*., 2005). Growing sugarcane, according to recent research, may result in a significant decrease in the amount of organic matter in the soil. Green cane harvesting, no-till farming, and the use of green manure crops, according to (Dominy *et al*., 2002), could help solve the problem.

Pests and diseases disrupt biochemical functions in the sugarcane crop system, resulting in a low expression of yield potential. Sugarcane smut, sugarcane mosaic virus, rust, brown eye spot, and brown stripe are among the diseases and pests identified in western Kenya, along with termites, shoot and stalk borers, scale insects, yellow aphids, and nematodes (Rono *et al*., 2007; Chirchir *et al*., 2011). Development of tolerant varieties has been used to alleviate the problem (Nzioki and Jamoza, 2006).

2.6 Phenology and physiology of sugarcane

Profitable sugarcane production depends on both quality of seed cane and crop husbandry. The grower should always aim at healthy seed cane materials which are not affected by disease and pests such as red rot, wilt, smut, ratoon stunting disease, scales, and borer. The materials should have buds with high moisture content and pure in quality. This ensures high germination percent and at least a 15% increase in sugarcane yield. All the required agronomic practices are followed and the seed cane plots inspected at regular intervals as per the seed cane certification standards. The crop is harvested at 10 to 12 months, above that age the seed cane is mature and prone to germination failure and below the age, the germination would be good but less economical because the cane weights are still very low (Van Heerden *et al.,* 2010).

2.7 Germination

Sugarcane germination is mainly influenced by temperature and soil moisture content. For germination, the soil temperature must be between 27 and 33 degrees Celsius, and the top 10 cm of soil must be moist for roots to grow (MSIRI, 2000). Planting material is made from the elongated stalks of cane plants and is usually placed at the bottom of a furrow before being covered with soil (Bakker, 2012). Intercalary roots develop and axillary buds emerge (Bakker, 2012).

2.7.1 Tillering

Tillering is the second stage of sugarcane development. At this stage of growth, newly sprouted plants enter a rapid tiller stage, with shoots sprouting from auxiliary buds at the base of existing shoots and the leaf appearance rate per shoot being relatively rapid. Variety, spacing, soil moisture, temperature, and nutrients all have an impact on tillering. Tillers grow best at 30^{o}C, and the best nitrogen and phosphorous levels are 100-150 kg/ha N and 80-100 kg/ha P (Cock, 2003). Nitrogen influences not only tiller emergence but also survival (KESREF, 2002). According to Shih and Gascho (1980), the tillering phase concludes when mutual shading occurs and the stems begin to grow longer.

2.7.2 Stem elongation

Elongation of the stalk begins 1200 to 1800 days after emergence. The number of stalks normally remains constant during the period of stalk elongation and maturation, while the leaf appearance rate per stalk decreases. The size of the new leaves grows and reaches a peak as late as nine months after planting (Marin *et al*., 2015). Nitrogen content decreases with leaf area and per unit weight . In this growth stage, leaf longevity is greater, with leaves frequently living for 5 months after appearance. There is little change in leaf size, and stalk elongation is associated with changes in assimilate partitioning and sucrose deposition, which begin in the lower nodes, stalks lengthen, the amount of dry matter in them increases from about 15% to 30% (Marin *et al*., 2015).

2.7.3 Ripening

Sugarcane stalk sucrose content increases during ripening. Variety, nitrogen, soil moisture, sunshine hours, and temperature all influence cane ripening. Sugarcane sucrose translocation is affected by altitude, soils, rainfall, and temperature. Young stalks contain more sucrose, which aids the plant's growth. However, older stalks are mostly used for storage (Wang *et al*., 2017).

2.7.4 Sugarcane flowering

Flowering is generally regarded as an undesirable trait in commercial sugarcane fields, but it is required for breeding programs and occurs in some varieties under specific conditions (Cheavegatti-Gianotto *et al*., 2011). Flowering is primarily induced by short day length. The plant must be well watered for induction to take place. The apex becomes reproductive, eventually producing inflorescence, and the shoot eventually dies (Thomas *et al*., 1985).

2.8 Nitrogen nutrition in sugarcane

Nitrogen is necessary for sugarcane growth because it helps with productivity, yield, dry matter accumulation, and sugar content. Sugarcane productivity is limited by insufficient N application, while excess supply may contaminate underground waters through leaching. Increased N levels cause a decrease in sucrose content, which is attributed to increased water retention in millable cane, resulting in a decrease in sucrose as a percentage of stalk fresh weight (Abazied *at el*., 2018).

Nitrogen fertilization of the crop has a strong influence on vegetative growth and development, which increases yields. Lack of N causes stunting and reduced leaf area thus, N is required for cell composition (Robinson *et al*., 2007). Nitrogen is a protein building block that is required for photosynthesis and sugar production. In excess, however, N prolongs the vegetative phase and delays maturity and ripening (Achieng *et al*., 2013).

The slow depletion of plant-available soil N supports the requirement for split application of the yearly total N rate in many sites. Crop modeling and statistical methodologies are used in small plot N rate field experiments to create a time series of N response curves that may be used to examine the climatic impact on crop responsiveness to applied N. This has been used to identify the most sustainable N rate for different meteorological conditions (like 'wet' vs. 'dry' years) and whether N fertilizer rates need to be adjusted for different climatic conditions (Srivastava and Suarez, 1992).

2.8.1 Nitrogen use efficiency

Better use of nutrients ,NUE is determined by N uptake efficiency, N recovery efficiency, and utilization efficiency (Benincasa *et al., 2011*), under irrigation management and rainfall regimes, best management practices such as environmental protection (Tandon and Roy, 2004), saving money, maximizing growth, and minimizing negative environmental effects, or testing through farmer implementation (Lowcock *et al.*,1991) N rate improves crop nitrogen use efficiency. Over fertilization primarily refers to low fertilizer-N use efficiency and economic return within the confines of limited environmental risks from leaching (Benincasa *et al*., 2011).

To improve nitrogen use efficiency, we must shift to methods that apply it only when the crop requires it, from an economic standpoint, N should not be at risk of being lost. This will necessitate improved monitoring to determine when and where N is required, as well as the use of in-season application methods such as side-dressing to apply N as needed by the plant. On many soils, increased use of inhibitors or controlled release fertilizers could also help improve nitrogen use efficiency. According to Asif *et al.*, (2012), there are three methods for measuring N use efficiency, including N agronomic efficiency expressed in yields (NAE), N recovery efficiency (NRE) and N-physiological efficiency (NPE), as shown in Equations 1, 2 and 3).

$$NUEA\ (kg\ kg-1) = \frac{\text{Stripped cane yieldF} - \text{Stripped cane yieldC}}{\text{Fertilizer nutrients applied (kg nutrients)}} \qquad \text{Equation 1}$$

Total N uptake by shoots of crop in each treatment was converted into ha^{-1} and the physiological nutrient efficiency (NUEP) was determined by the formula as follows:

$$NUEP\ (kg\ kg-1) = \frac{\text{Stripped cane yieldF} - \text{Stripped cane yieldC}}{\text{Fertilizer nutrients applied F (kg)} - \text{C (kg n)}} \qquad \text{Equation2}$$

Where F = Fertilized crop and C = Control crop

N recovery efficiency (NRE) is calculated following the formula given below

Fertilizer recovery (%) = (crop N uptake + N applied) – (crop N uptake + 0 N applied)/N applied x 100 Equation3

Excessive nitrogen application can reduce cane sugar content. While conventional management systems make recommendations for N application rates, there is little information on what the optimum N rate for sugarcane should be. Using the same N rates as in conventional management systems on sugarcane crops would almost certainly result in lower N-use efficiency and increased N losses to the environment. As a result, the outcome may be adverse to the desired benefits (Hemalatha, 2015).

2.9 Yield formation in sugarcane

2.9.1 Biomass accumulation

The amount of light intercepted within the leaves and the efficiency with which radiation is used both contribute to crop biomass accumulation (Van Heerden *et al*., 2010). Light intercepted by the crop, leaf area index in phenological stage, and environmental conditions all have an impact on carbon (IV) oxide and biomass production (Liu *et al.*, 2001) . The critical leaf area index (LAIc) is the minimum LAI that allows 95 percent interception of incident radiation, promotes maximum crop growth rate and manages the crop well to achieve highest ground cover in a short period of time (Van Heerden *et al*., 2010).

2.9.2 Radiation interception and use efficiency

The amount of incident PAR and fractional radiation interception (FRI) intercepted by the plant canopy affects the leaf area index (LAI) and the light extinction coefficient (K). The efficiency of radiation use is determined by photosynthetic metabolism. Environmental factors such as temperature, nutrition, and water availability influence canopy shape and biomass content (Wang *et al*., 2017). The cane's leaves grow slowly. Planting at higher densities and increasing N fertilization will boost leaf area index (LAI) and light interception, resulting in higher yields. However, Wang *et al*. (2017) indicates that too much N causes a drop in sucrose concentration and cane lodging.

2.9.3 Sucrose metabolism

Solar radiation affects biomass accumulation in sugarcane, and the amount of radiation intercepted by converting it into dry matter is a growth determinant. To achieve biomass in the crop, fertilizer use must be increased (Van Heerden *et al*., 2010). Sucrose accumulation in cane stalks is aided by sucrose supply, metabolism, and sink strength. The amount of sucrose to sink organs is determined by the amount of light absorbed in the leaves (Wang *et al*., 2017). Sugar accumulation in plant cane is governed by supply and demand. Source-limited plants occur when the source is insufficient to meet sink demand, whereas sink-limited plants occur when the source exceeds sink demand (Wang *et al*., 2017).

2.10 Timing of nitrogen supply on growth and yield

Proper land management plans should incorporate fertilization regimes that promote development while reducing nutrient leaching (Van Miegroet *et al*., 1994). Modifying fertilizer application rates and frequencies to improve N utilization is one such regime (Lee and Jose, 2005). Knust (1954), demonstrated that providing split N fertilizer to a 12-month cane crop could delay maturity and decrease sucrose. Early N fertilizer application reduced cane output, however late fertilizer application reduced sugar yield due to lower juice quality rather than any growth loss (Wiedenfeld, 1997). The specified fertilizer dose (150 kg/ha) applied in two equal splits, either at planting and within 30 days after planting (DAP) or at 30 and 60 DAP, boosted the crop by generating more millable canes at harvest, resulting in increased cane and sugar output (Lakshmi *et al*., 2003).

In addition to N rate, choosing the ideal time to apply fertilizer is another problem in N management. Wiedenfeld (1997) discovered that fertilizing with nitrogen outside of the optimal window affects cane tonnage and sugar output. This was due to early fertilization reducing cane tonnage and later fertilization reducing juice quality. Early fertilization, according to (Khan and Wegener,2016) made less N accessible to the plant via leaching or immobilization before the plant reached its full development potential. This is owing to the fact that N fertilization does not occur concurrently with sugarcane's quick absorption of N from the soil. If this occurs, a large amount of nitrogen fertilizer may leach from the soil system. Late fertilization also inhibit early growth, which could only be partially compensated for later in the growing season.

CHAPTER THREE: EFFECT OF NITROGEN RATE ON GROWTH AND YIELD OF TWO PHENOLOGICALLY CONTRASTING SUGARCANE VARIETIES

3.1 Abstract

Sugarcane fertilization is largely concentrated on Nitrogen (N). Recent soil analysis results indicate that soils in the Mumias Sugar (MMS) of western Kenya are low in Nitrogen content. In assessing the yield factor in sugarcane systems, adoption of balanced nutrition would help to improve seedcane productivity and enhance health crop. This study reports the effect of N-rate on growth and yield of two phenologically contrasting sugarcane varieties. Two experiments were set up simultaneously in KALRO-SRI-Kibos and MMS NE-Mumias from October 2018-July 2019. The treatments were laid out in a randomized complete block design with a 3 x 2 x 3 factorial arrangement of the treatments with three replications. The gross plot size was 1.5 m x 4 rows x 5 m = 30 m2 in nucleus estate and 1.2 m x 4 rows x 5 m = 24 m2 in out grower. Treatments included three rates of N (0, 60 and 120 kg/ha) supplied in form of Urea (46 % N). Data was collected percent sett establishment, plant height, number of leaves per plant, internode length, stem girth, leaf area index, number of plants and stalk yield. The two varieties recorded a significant difference at $P \leq 0.05$ in number of tillers in both Mumias and Kibos. The varieties recorded a non-significant variation to N-rate treatments. N-rate × variety interactions for chlorophyll content did not record significant effect at Mumias and Kibos. At Mumias, interactions between varieties and N-rates resulted in a significant effect in leaf area index in the 5th month. A significant effect of N-rates on plant height was recorded in the 7th and 10th months and N-rates. Varietal interactions recorded a significant effect on stalk height in N-rate. N-rate varietal interactions, resulted to a non-significant effect in dry mass production. In Kibos, a higher stem girth of 2.4 cm at 60 kg N/ha was recorded compared to control (2.3 cm) and 120 kg N/ha (2.2 cm) while in Mumias, a higher stem girth of 2.3 cm (120 kg N/ha) compared to 2.2 cm at 0 kg N/ha (control). N-rate recorded a significant effect on plant population/ha in Mumias. Increase in N-rate resulted to a high plant population/ha of 10151 at 120 kg/ha at Mumias, there was no difference in yield at Kibos and Mumias in variety KEN 82-216. The experimental study at Mumias recorded a higher seed yield of 22.5 t/ha compared to Kibos at 20 t/ha. N-rate of 120 kg/ha resulted in high seed yield of 25 t/ha compared to 19 t/ha (control), and 22.8 t/ha (60 kg/ha N). Therefore, 120 kg/ha N is recommended for seedcane plant which could produce

the highest sugar yield. Variety KEN 82-216 recorded significantly higher performance in response to varying N-rate in both sites compared to variety KEN 82-601.

3.2 Introduction

Currently, the sugar sector lacks a proper seed cane production and distribution mechanism, sugar mills generate seed cane for their own use as well as for contracted farmers. The institute also uses a farmers' research group (FRG) approach to replicate and distribute treated seed cane to sugarcane growers, however, the planting supplies are not certified. This frequently results in a high frequency of diseases and pests within the sugar sector. As a result, low cane yields and high sucrose levels are prevalent in the business Vennila *et al., (*2021) the low yield can be corrected by producing and utilizing high cane sugar production potential varieties, high quality seed cane, and making it easier for plants to take in and use nutrients.

Nitrogen is critical in sugarcane metabolism, influencing vital physiological processes such as photosynthesis and sugar production (MSIRI, 2000). Optimal N application boosts cane output and also improves the sugar content of harvested cane. However, N delays maturation and ripening when taken in excess. Late N also impacted sugar quality attributes such as purity, color, and clarity (Portz *et al.*, 2012). Fertilization becomes a crucial aspect when considering the quality factor in seedcane systems since it influences yield. The gradual depletion of plant-available soil N supports the requirement for split application of the yearly total N rate. (Cetto *et al.,*2000) research demonstrated this by demonstrating that the period between applying N fertilizer and sampling the soil had a detrimental effect on the amount of NO_3-N in the soil. This study aimed to determine how the rate and timing of N supply affected the growth and production of two sugarcane varieties with varied growth patterns.

3.3 Materials and methods

3.3.1 Experimental site description

During the 2019/2021 agricultural season, two experiments were carried out in Mumias and Kibos in Western Kenya 0^{o} 21'N, 34^{o} 30' E, and 1314 m altitude. The site is in the lower midlands (LM1) and has a bimodal rainfall range of 1500-2000 mm. The average maximum temperature ranges between 27 and 30^{o} C, and minimum temperature 16^{o} C. Soils of Munias contain a low clay content (above 60%), a pH range of 4.5-5, a high water retention capacity of 213 mm/m, an organic content of 0.5-0.75 percent, and negligible permeability.

In Kibos trials were conducted at the SRI research fields. This location is in the lower midlands (LM1), with an elevation of 0^{o} 24'N, 34^{o} 48'E, and a latitude of 1185m above sea level. The average maximum temperature ranges between 28 and 32 ^{o} C, and minimum temperature 23.8^{0} C. Soils of Kibos contain a high clay content (above 60%), a pH range of 5-6, a high water retention capacity of 213 mm/m, an organic content of 0.5-0.75 percent, and negligible permeability.

The two zones experiences a bimodal rainfall pattern, with two distinct wet seasons. A long rains season occurs from March to May and a short rains duration from September to October. Based on long term averages, the long rains seasons are wetter than the short season (Omondi, 2016)

3.3.2 Treatments and experiment design

Treatments included three rates of N (0, 60, and 120 kg/ha) sourced from urea (46% N). The design used was a randomized complete block design with a 3 x 2 x 3 factorial arrangement of the treatments with three replications. The gross plot size was 1.5 m x 4 rows x 5 m = 30 m^2 in nucleus estate N/E and 1.2 m x 4 rows x 5 m = 24 m^2 in out grower OG, based on the standard practice for spacing in the two sectors. The net plot size for data collection was 1.5 m x 2 rows x 5 m = 15 m^2 in nucleus estate and 1.2 m x 2 rows x 5 m = 12 m^2 in out grower. At planting, basal phosphorus single superphosphate (SSP) applied at 600g P/ha in O/G and 750g P/ha in N/E. All fertilizers were hand applied using graduated cups specific for each treatment after weighing on a Salter top balance in the laboratory. Other necessary agronomic practices like weed management and pest and disease observation were carried out as per KESREF (2002) recommendations. The two field sites, Mumias sugar and KALRO-SRI, were prepared before the onset of short rains in September and October, 2018.

3.3.3 Experiment management

Two newly released varieties of sugarcane (KEN 82 -216 and KEN 82-601) were used in the study as seedcane. Both varieties are early maturing with seedcane cutting at 10-12 months and attaining millable stalks at 14-18 months. Sugarcane setts were established from 8-10 month old setts. Each variety was spaced at 1.20 m and 1.50 m between rows in SRI and Mumias respectively with an inter-row spacing of

0.50 m. Plot size was 5 m long and 4 lines planted in October. At planting triple super phosphate was applied at 600g P/ha in O/G and 750g P/ha in N/E, weeds were controlled by pre-emergence herbicides which included, Dual 1.8 L/ha, Sencer 2 L/ha and Glyphosate 2 L/ha respectively as a cocktail for both broad and narrow-leaved weeds and manual weeding was carried out after germination. At harvesting, the canes were cut near to the ground after 10 months.

3.4 Data collection

3.4.1 Crop growth traits

Sett establishment, leaf area index, leaf count, tillering, stalk height, internode length, stem girth, and plant population, number of leaves, leaf area, and plant height were among the crop growth parameters measured.

A physical count of developed branches in the net plots at 30 and 45 days following planting was used to determine sett establishment. The largest number of emerged shoots given as a percent of the predicted was used to compute the average establishment. Tillering was evaluated between 3 and 8 months after planting. A physical count of the total number of shoots in the net plot was performed and the number of tillers/ha was extrapolated, to determine the inter-node length, the stalk height and number of internodes per stalk were measured on 5 plants in the net plot at harvest. A physical count of all stalks in the net plot was performed and the plant population per hectare was extrapolated.

At harvesting, five cane stalks were sampled for girth measurement at the middle level by use of Vernier caliper from each treatment. Leaf greenness determined with a handheld chlorophyll meter (Minolta SPAD-502). Measurement was collected from five leaves per plot by sampling the top visible dewlap leaf. SPAD (nm/m^2)reading was obtained at monthly interval from three months after planting (Amaral *et al*., 2012).

Leaf area index (LAI) was determined by use of tape measure by measuring the length from the petiole of the leaf attached to the stalk up to the apex of the leaf and the broad part of the leaf on upper most fully expanded leaf from five plants per plot. This carried out monthly from three months after planting through to harvesting. Leaf count was done on five sampled stalks in net plots, all green leaves were counted up to the fully top most opened leaf.

3.4.2 Yield components

Stalks from a net plot of 12 and 15m^2 were harvested at 10 MAP. Stalks were cut from the base with a panga and stripped-off leaves. The fresh weight of the stalks weighed with a suspension balance and yield converted to t/ha.

3.5 Data analysis

Data collected on cane growth and yields were subjected to analysis of variance using GenStat 15th edition. Least significant difference test (LSD) at 5% level of probability was used to compare treatment means (Vargas *et al*.,2015)

3.6 Results

3.6.1 Soil chemical properties

Soil was tested at 0–30 cm and 30–60 cm depths prior to planting in September,2018 to determine chemical properties . A glass electrode and pH meter S/N K 3386 and Mettler Toledo 345 were used to measure soil pH in a soil suspension with a soil:water ratio of 1:1 (w/v). The Calorimetric, Mehlich Double Acid, Flame photometry, and Kjeldahl procedures (Blamire, 2003) were used to assess soil organic matter (C), extractable P, K, and total N. Exchangeable cations were extracted with neutral 1N NH4Oac and quantified using flame emission for Na and K and EDTA titration for Ca and Mg (Okalebo *et al*., 2002). Soil study results from the experimental locations revealed that the soils in MMS NE and KALRO SRI are extremely highly acidic (pH range 4.5-5.0), very low in percent C, inadequate in exchangeable potassium (K), but somewhat sufficient in exchangeable calcium (Ca) (Table 2). Rainfall was observed over a 10-month crop growth period and was slightly above the long term mean (LTM) (Tables 3) The rainfall obtained over a 10-month crop growth period was recorded and compared to the long-term mean (LTM).

Table 2. Soil chemical properties of Mumias and Sugar Research Institute in Kibos

	Mumias		Kibos	
Property	Top soil	Sub soil	Top soil	Sub soil
pH	4.5-5.0	4.6-6.0	5.1-5.5	5.2-5.5
%C	0.940	0.820	1.4	1.3
%N	0.014	0.016	0.048	0.031
Na (ppm)	3.000	2.000	11.0	10.0
	2.000	1.000	2.00	1.00
Ca (ppm)	40.000	40.000	80.00	80.00

Soils of Kibos and Mumias are strongly acidic (p^H range 5.1 to 5.5 and 4.5 to 5.0) respectively and low in potassium (K) but moderate in calcium C% and are defient in N, the soil is very low in carbon %C but moderately sufficient in exchangeable calcium (Ca)

3.6.2 Weather data during the crop season and crop phenology

During the growing period, weather data was collected monthly from Octomber, 2018 to July, 2019, the highest average temperature of 32^0 C was at Mumias in the month of February 2019 while lowest minimum temperature of 26.4^0C was recorded in June 2019. At Kibos the highest maximum temperature of 30.8^0C was recorded in December 2018 while the lowest maximum temperature of 23.8^0 C was recorded in January 2019. At Mumias, the highest total rainfall of 305.2 mm was recorded in the month of May 2019 while the lowest total rainfall of 23.2 mm was recorded in January 2019. At Kibos, the highest total rainfall of 189.9 mm was recorded in June 2019 while the lowest total rainfall of 64 mm was recorded in July 2019, Crop growth stages (phenology) were monitored periodically and recorded but with emphasis on time to when 50% of plant population sprouting, tillering and stem elongation

Table 3. Mean monthly maximum (MaxT) and minimum (MinT) temperature and rainfall during the experimental season from August 2018 and August 2019 in Mumias and Kibos.

Year and month		**Mumia**			**Kibos**		
2018	Month	MaxT (oC)	MinT (oC)	Rainfall (mm)	MaxT (oC)	MinT (oC)	Rainfall (mm)
	October	28	15.1	190.2	28.9	16.1	148.8
	November	29.3	15	189.2	29.7	15.8	121
	December	28.8	15.4	176.9	30.8	15.3	178.6
2019	January	30.2	14.8	23.2	23.8	16	0
	February	32	15.4	46.8	23.9	15.4	96
	March	31.8	15.6	63.5	28	18.3	69.7
	April	30.2	16.3	252.3	29.2	17.8	126.5
	May	28.2	16.3	305.2	30.7	17.7	111.5
	June	26.4	16.3	293.6	30.2	17	189.9
	July	26.9	15.3	162.8	28	16.4	64

Source. Kenya Agricultural and Livestock Research Organization, Sugar Research Institute Headquarters**.**

3.6.3 Set establishment

In Kibos, variety KEN 82-216 recorded significantly higher germination rate (P = 0.04) compared with KEN 82-601. However, the two varieties did not show significant differences (P<0.05) in germination in Mumias (Figure 1).

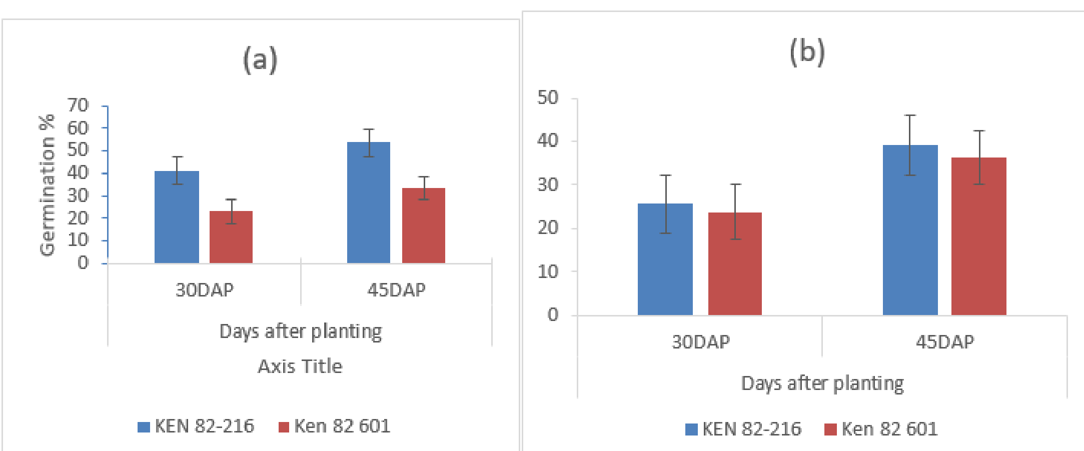

Figure1. Germination percentage of sugarcane at Kibos (a) and Mumias (b) respectively. Bars are standard error of mean

3.6.4 Tillering

The two varieties were significantly different (P≤0.05) in regard to the number of tillers in Mumias and Kibos experimental sites (Figure 2). This was noted from 4MAP across to 8MAP. Highest number of tillers per unit area were recorded in 5MAP in both sites (Figure 2a and b). In the 8MAP, a lower number of tillers were recorded in both sites which was the effect of competition for nutrients, light and space by tillers after prolonged drought . In Kibos, variety KEN 82-216 recorded the highest number of tillers compared to variety KEN 82-601 which in turn recorded highest number of tillers in Mumias. In Mumias and Kibos, N-rates did not significantly affect the number of tillers in both the varieties (Figure 2d and c). Generally, there was an increase in the number of tillers in both sites up to 5MAP where a dramatic decrease was recorded. There were non-significant interactions between the varieties and the nitrogen rates in Mumias and Kibos (Table 4).

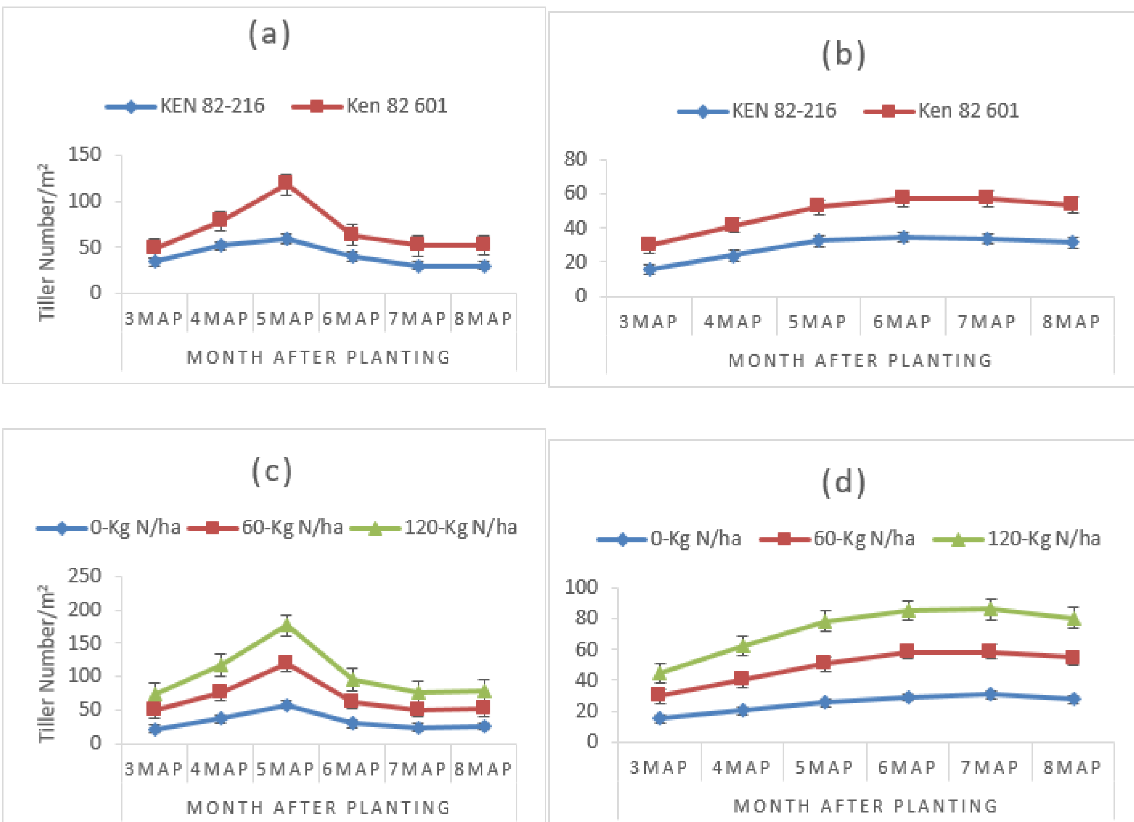

Figure 2. Average number of tillers/m^2 for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on on average number of tillers at Kibos (c) and Mumias (d). Bars are standard error of mean.

Table 4. Variety and N interaction effects on number of tillers/m2 at different months after planting (MAP) in Kibos and Mumias

MAP and N rates		Kibos				Mumias			
		KEN 82-216	KEN 82-601	LSD	Pvalue	KEN 82-216	KEN82-601	LSD	Pvalue
3 MAP	0 N	30.3	13.3	16.9	0.4	78.0	70.7	36.6	0.9
	60 N	39.4	14.5			82.7	66.0		
	120 N	33.8	16.6			80.0	68.0		
4 MAP	0 N	49.0	24.3	13.3	0.7	105.7	96.7	52.9	0.6
	60 N	53.0	24.8			113.3	85.3		
	120 N	53.7	30.3			137.3	85.0		
5 MAP	0 N	57.3	58.9	45.2	0.4	145.0	109.7	65.5	0.5
	60 N	64.1	59.6			154.7	98.7		
	120 N	56.1	57.7			185.3	91.7		
6 MAP	0 N	36.3	23.3	11.6	0.4	169.7	120.3	5.9	0.8
	60 N	43.0	23.3			178.7	114.0		
	120 N	41.8	23.4			173.7	97.3		
7 MAP	0 N	28.5	19.4	6.0	1.0	167.7	139.0	42.2	0.4
	60 N	32.0	21.9			158.3	117.0		
	120 N	31.2	21.9			174.0	104.0		
8 MAP	0 N	28.5	23.3	5.9	0.5	161.3	113.3	30.6	0.8
	60 N	31.0	21.9			154.7	115.7		
	120 N	31.9	22.0			155.7	103.7		

LSD is least significance difference

3.6.5 Leaf chlorophyll content

Varieties KEN 82-601 and KEN 82-216, recorded a non-significant difference ($P<0.05$) in chlorophyll content in both sites, Mumias and Kibos, except for the 7th MAP in Kibos (Figure 3 a, b, c and d). A progressive increase in chlorophyll content was recorded in the two varieties from 3rd MAP up to 8th MAP that was later accompanied by a decrease in 9th and 10th MAP in Mumias while in Kibos (Figure 3a and b), such an increase was recorded up to 9th MAP thereafter followed by a decrease in the 10th MAP (Figure 3 c and d). Variety KEN 82-601 recorded a non-significant higher chlorophyll content than variety KEN 82-216 in Mumias, likewise variety KEN 82-216 recorded a non-significant higher chlorophyll content than variety KEN 82-601 in Kibos. The varieties recorded a non-significant variation in chlorophyll in relation to variation in nitrogen rate application in Mumias and Kibos (Table 5).

Figure 3. Average percentage of chlorophyll nm/m2 for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on chlorophyll at Kibos (c) and Mumias (d). Bars are standard error of mean.

Table 5. Variety and nitrogen (N) interaction effects on chlorophyll nm/m^2 at different months after planting (MAP) in Kibos and Mumias

		Kibos				Mumias			
MAP and N rate		KEN82-216	KEN82-601	LSD	Pvalue	KEN82-216	KEN82-601	LSD	Pvalue
3 MAP	0 N	41.8	40.1	7.6	0.7	41.4	40.0	5.5	0.6
	60 N	40.7	38.7			41.8	39.7		
	120 N	41.0	37.1			39.2	40.3		
4 MAP	0 N	36.9	30.9	9.2	0.9	38.5	35.5	7.2	1.0
	60 N	36.1	28.4			37.9	35.5		
	120 N	36.1	29.3			39.5	36.3		
5 MAP	0 N	37.5	34.9	5.0	0.9	40.9	41.8	3.1	0.6
	60 N	36.7	35.2			41.3	43.6		
	120 N	36.5	36.3			40.4	40.5		
6 MAP	0 N	27.1	26.8	4.7	0.5	40.7	38.9	6.2	0.2
	60 N	27.0	24.8			41.5	37.5		
	120 N	28.2	27.3			39.2	41.9		
7 MAP	0 N	36.3	38.8	5.6	0.7	41.9	44.7	5.0	0.7
	60 N	34.7	40.2			41.1	44.1		
	120 N	32.6	35.3			41.0	45.0		
8 MAP	0 N	34.6	36.0	9.8	0.8	46.1	45.4	9.0	0.7
	60 N	34.6	33.5			43.3	43.7		
	120 N	28.9	31.0			44.8	46.8		
9 MAP	0 N	36.6	34.4	11.1	0.2	38.4	40.3	5.3	0.6
	60 N	34.4	33.8			39.3	40.0		
	120 N	32.6	35.1			38.2	42.6		
10 MAP	0 N	32.4	29.2	5.9	0.6	39.0	32.6	7.1	0.1
	60 N	31.3	29.7			35.8	41.9		
	120 N	30.7	27.7			38.1	38.8		

LSD is least significance difference,

3.6.6 Leaf count

Data was sampled on the net plots for number of leave and extrapolated to establishe the number of leaf formation. There were no significance differences between the varieties in number of leaves per plant in Kibos while a significance difference was recorded in Mumias at the 8th and 9th MAP (Figure 5a and b). A non-significant difference was recorded in the 6th MAP in Mumias. Variety KEN 82-601 recorded a non-significant number of leaves per plant than variety KEN 82-216 in Kibos and Mumias. The study recorded a progressive increase in leaf number from 3 MAP in both sites,in Kibos 6 MAP number of leaves reduced because of long droughts and in Mumias the number of leaves reduced due to leaf distraction by heavy rains up to 8th MAP and 9th MAP, in all the varieties and a decrease towards maturity in the 9th month and 10th month in both Mumias and Kibos respectively (Figure 5c and d). N-rates did not have significant differences in number of leaves per plant in Kibos while in Mumias N-rates recorded a significant effect in the 10th MAP. The interactions between varieties and N-rates recorded a non-significant effect on the number of leaves per plant in Mumias and Kibos (Table 7). Kibos recorded a relative low number of leaves in all varieties compared to Mumias due to prolonged drought in the region.

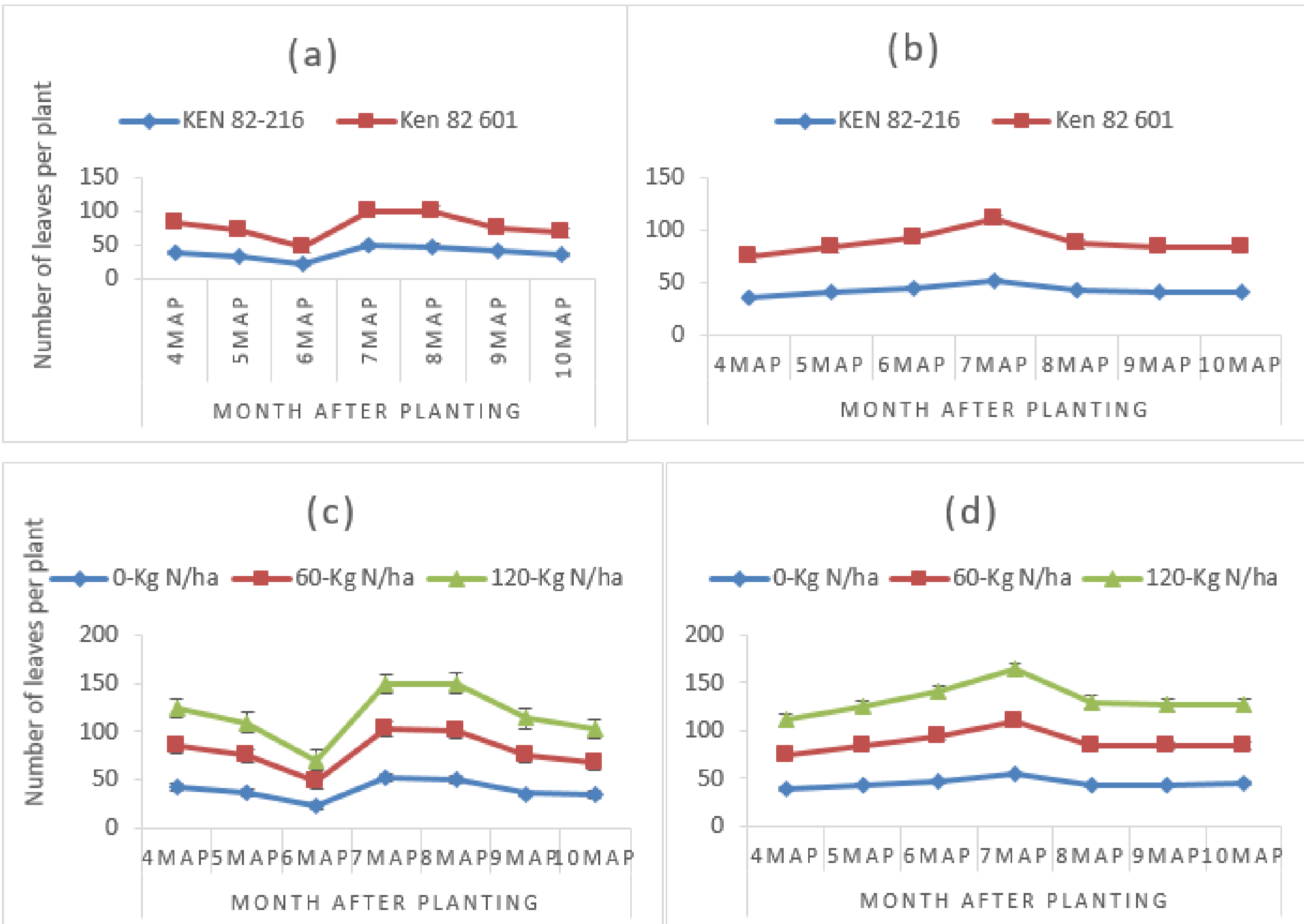

Figure 4. Average number of leaves/m^2 for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on on average number of leaves at Kibos (c) and Mumias (d). Bars are standard error of mean.

Table 6. Variety and nitrogen (N) interaction effects on number of leaves at different months after planting (MAP) in Kibos and Mumias

		Kibos				Mumias			
	Variety	KEN82-216	KEN82-601	LSD	Pvalue	KEN82-216	KEN82-601	LSD	Pvalue
3MAP	0N	41.8	40.1	7.6	0.7	41.4	40.0	5.5	0.6
	60N	40.7	38.7			41.8	39.7		
	120N	41.0	37.1			39.2	40.3		
4MAP	0N	36.9	30.9	9.2	0.9	38.5	35.5	7.2	1.0
	60N	36.1	28.4			37.9	35.5		
	120N	36.1	29.3			39.5	36.3		
5MAP	0N	37.5	34.9	5.0	0.9	40.9	41.8	3.1	0.6
	60N	36.7	35.2			41.3	43.6		
	120N	36.5	36.3			40.4	40.5		
6MAP	0N	27.1	26.8	4.7	0.5	40.7	38.9	6.2	0.2
	60N	27.0	24.8			41.5	37.5		
	120N	28.2	27.3			39.2	41.9		
7MAP	0N	36.3	38.8	5.6	0.7	41.9	44.7	5.0	0.7
	60N	34.7	40.2			41.1	44.1		
	120N	32.6	35.3			41.0	45.0		
8MAP	0N	34.6	36.0	9.8	0.8	46.1	45.4	9.0	0.7
	60N	34.6	33.5			43.3	43.7		
	120N	28.9	31.0			44.8	46.8		
9MAP	0N	36.6	34.4	11.1	0.2	38.4	40.3	5.3	0.6
	60N	34.4	33.8			39.3	40.0		
	120N	32.6	35.1			38.2	42.6		
10MAP	0N	32.4	29.2	5.9	0.6	39.0	32.6	7.1	0.1
	60N	31.3	29.7			35.8	41.9		
	120N	30.7	27.7			38.1	38.8		

LSD is least significant difference

3.6.7 Leaf area index

KEN 82-216 and KEN 82-601 recorded a significant difference in leaf area index (LAI) in the 9th and 10th month in Kibos unlike Mumias (Figure 4a and b) where such significant differences were not recorded. Leaf area index increased across the months up to 5 MAP in Kibos where it was affected by drought while in Mumias LAI was affected by heavy rains that distracted the leaves, after it increased up to maturity in both sites. Variety KEN 82-601 recorded a significant higher area index than variety 82-216 in the 9th and 10th month in Kibos (Figure 4c and d). N-rates treatment recorded a significant effect in leaf area index between the varieties in the 10th month in Mumias while in Kibos (Table 6), N-rates recorded a non-significant effect in leaf area index between the two varieties. At Mumias, interactions between varieties and N-rates, significantly affected the leaf area index in the 5th month while in Kibos, there was no significant effect.

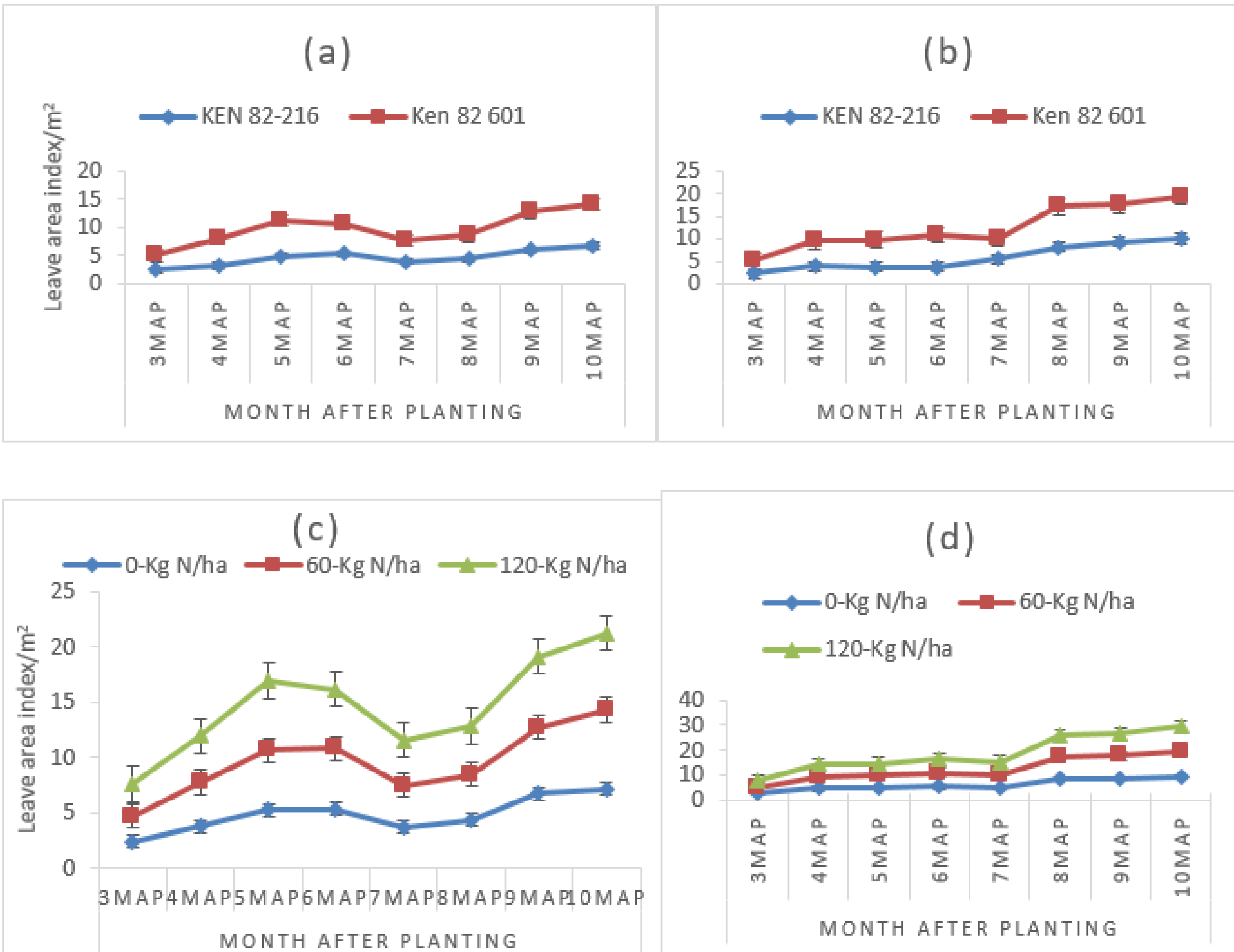

Figure 5. Average leaf area index(m^2) for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on average leaf area index at Kibos (c) and Mumias (d). Bars are standard error of mean.

Table 7. Variety and nitrogen (N) interaction effects on leaf area index(m^2) at different months after planting (MAP) in Kibos and Mumias

MAP and N rate		Kibos				Mumias			
		KEN82-216	KEN82 601	LSD	Pvalue	KEN82-216	KEN82 601	LSD	Pvalue
3 MAP	0 N	2.3	2.5	1.2	0.9	2.4	3	0.9	0.4
	60 N	2.4	2.3			2.4	3.4		
	120 N	2.7	3.0			2.2	2.7		
4 MAP	0 N	2.8	4.8	2.1	0.4	3.6	5.9	1.2	0.6
	60 N	3.5	4.4			4.2	5.9		
	120 N	3.4	5.1			3.9	5.7		
5 MAP	0 N	4.3	6.3	2.0	0.7	3.3	6.5	1.0	0.3
	60 N	4.9	5.9			3.6	6.1		
	120 N	5.7	6.9			3.9	5.9		
6 MAP	0 N	5.5	5.2	2.6	0.7	3.6	7.2	1.4	0.3
	60 N	5.0	6.0			3.7	7.4		
	120 N	5.7	5.0			4.2	6.9		
7 MAP	0 N	3.7	3.7	1.1	0.7	5.4	4.8	2.3	1.0
	60 N	3.8	3.8			5.2	4.7		
	120 N	4.3	3.9			5.6	4.7		
8 MAP	0 N	4.2	4.4	2.9	0.8	7.9	9.3	3.0	0.8
	60 N	4.5	3.8			8.0	8.8		
	120 N	4.5	4.2			8.3	8.5		
9 MAP	0 N	6.6	7.0	1.5	0.9	8.7	8.3	2.9	1.0
	60 N	5.5	6.4			9.3	8.8		
	120 N	6.0	6.8			9.5	8.6		
10 MAP	0 N	6.9	7.5	1.0	0.8	9.7	9.0	1.2	0.5
	60 N	6.7	7.6			10.0	9.8		
	120 N	6.7	7.2			10.1	9.2		

LSD is least significance difference

3.6.8 Stalk height

In Kibos, varieties recorded no significant difference ($P < 0.05$) in plant height while in Mumias, the varieties recorded significant difference in the 4th month. There was a steady increase in plant height up to maturity between the varieties in both sites (Figure 6a and b, c and d). Variety KEN 82-601 recorded a higher average height of (91cm) than variety KEN 82-216 (81cm) in Kibos and Mumias. N-rate treatments recorded no significant effect on plant height on both the varieties in Kibos while in Mumias, a significant effect of N-rates on plant height between the varieties was recorded in the 7th and 10th months. N-rates and varietal interactions had no significant effect on stalk height in Kibos while in Mumias, a significant effect was recorded in the 5th and 7th month (Table 8). Generally, Mumias recorded a higher average stalk height of 86.5 cm compared to Kibos with an average plant height of 84.9 cm (Figure 6c and d).

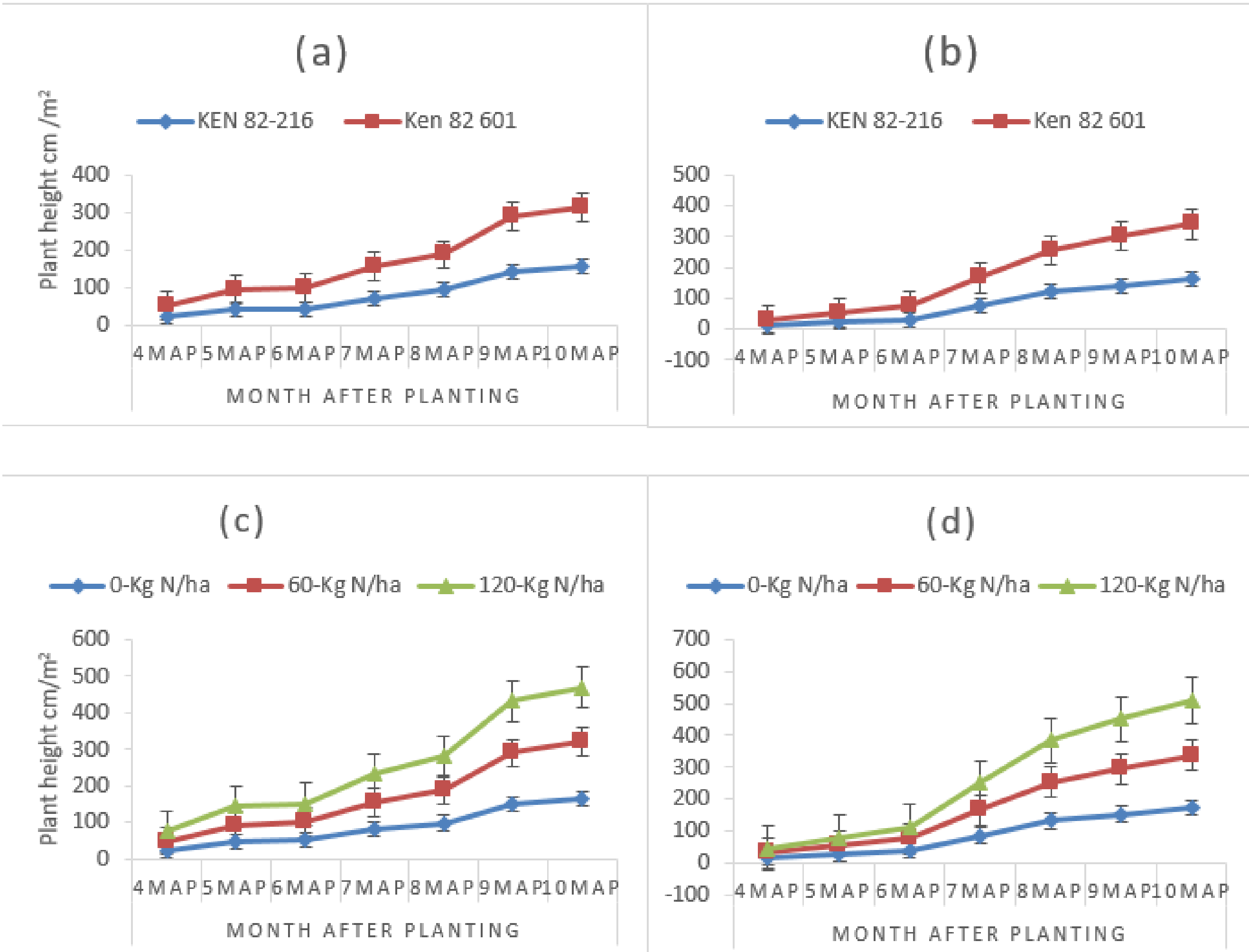

Figure 6. Average height /m^2 for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on on average height /m^2 at Kibos (c) and Mumias (d). Bars are standard errors of means.

Table 8. Variety and nitrogen (N) interaction effects on height at different months after planting (MAP) in Kibos and Mumias

MAP and N rate		Kibos				Mumias			
		KEN 82-216	KEN 82-601	LSD	Pvalue	KEN 82-216	KEN 82-601	LSD	Pvalue
4 MAP	0 N	21.3	28.7	8.9	0.8	13.6	18.3	2.6	0.2
	60 N	22.0	26.6			13.4	17.8		
	120N	21.8	30.5			13.6	15.0		
5 MAP	0 N	35.6	56.4	20.9	0.6	21.4	32.4	7.1	0.0
	60 N	40.6	50.1			21.4	30.3		
	120N	44.8	58.8			22.9	27.2		
6 MAP	0 N	41.3	63.5	25.9	0.5	32.1	46.4	15.1	0.5
	60 N	44.3	51.7			29.8	42.8		
	120N	42.7	57.0			32.0	41.9		
7 MAP	0 N	78.3	82.7	47.3	0.2	73.6	95.8	23.1	0.0
	60 N	70.3	77.3			73.7	87.3		
	120N	64.8	89.5			80.0	89.0		
8 MAP	0 N	98.8	98.2	90.5	0.9	122.3	141.1	27.5	0.4
	60 N	92.3	87.1			118.5	122.6		
	120N	92.4	92.1			125.7	137.3		
9 MAP	0 N	149.9	146.0	71.4	0.7	141.5	164.1	22.2	0.6
	60 N	139.6	143.3			129.4	155.3		
	120N	132.7	153.7			148.5	163.1		
10MAP	0 N	165.9	163.3	93.3	0.3	162.7	184.1	20.2	0.1
	60 N	158.7	151.2			163.3	163.3		
	120N	137.3	163.3			167.6	176.9		

LSD is least significance difference

3.6.9 Dry weight

Varieties recorded a significant difference ($P< 0.05$) in dry weight in the 8th and 9th months in Mumias and Kibos respectively (Figure 7a and b). Dry weight continued to increase up to maturity in all varieties in all sites. Highest average dry weight of 723 w/m^2 and 761 w/m^2 were recorded in the 10th month in Kibos and Mumias respectively (Figure 7c and d), Variety KEN 82-601 recorded highest average dry weight of 456 g/m^2 and 416 w/m^2 compared to variety KEN 82-216 that recorded average dry weight of 377.8 w/m^2 and 278.6 w/m^2 in Kibos and Mumias respectively. N-rates did not significantly affect dry weight of the two varieties in both sites (Figure7c and d). Interactions between varieties and N-rates resulted to a non-significant effect on dry weight in varieties in the two locations (Table 9), at Kibos, the two varieties recorded a higher average dry mass of 416.9 w/m^2 compared to 347.6 w/m^2 recorded at Mumias.

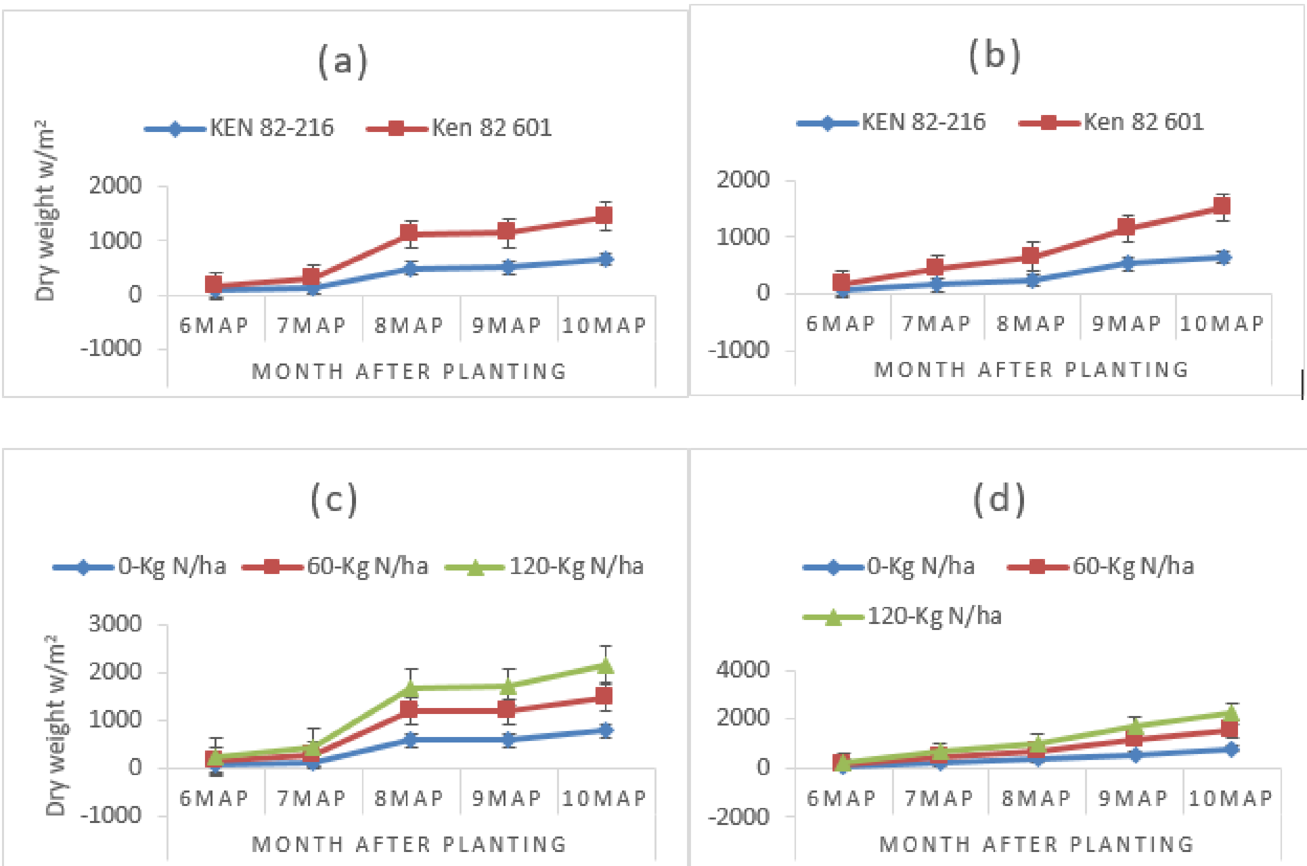

Figure 7. Average dry weight (w/m^2) for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on on average dry weight (w/m^2) at Kibos (c) and Mumias (d). Bars are standard errors of means.

Table 9. Variety and nitrogen (N) interaction effects on dry weight (w/m) at different months after planting (MAP) in Kibos and Mumias

MAP and N rate		Kibos				Mumias			
		KEN 82-216	KEN 82-601	LSD	Pvalue	KEN 82-216	KEN 82-601	LSD	Pvalue
6 MAP	0 N	66.3	66.9	37.8	0.7	58.6	99.8	29.7	0.1
	60 N	102.3	82.5			67.2	77.6		
	120N	92.2	73.9			97.8	85.3		
7 MAP	0 N	128.1	150.7		0.8	147.0	270.0	114.6	0.2
	60 N	135.4	183.4	66.5		160.0	364.0		
	120N	129.8	153.7			157.0	228.0		
8 MAP	0 N	530.0	659.0	246.2	1.0	305.0	386.0	160.4	0.4
	60 N	538.0	670.0			220.0	459.0		
	120N	420.0	564.0			211.0	383.0		
9 MAP	0 N	547.0	649.0	133.8	0.9	526.0	613.0	297.6	0.3
	60 N	517.0	659.0			563.0	633.0		
	120N	464.0	585.0			526.0	675		
10MAP	0 N	692.0	872.0	222.0	0.5	650.0	891.0	468.6	0.5
	60 N	637.0	756.0			574.0	904.0		
	120N	666.0	714.0			694.0	854.0		

LSD is least significant difference

3.6.10 Internode length

Varieties in Kibos recorded non-significant difference in internode length while at Mumias, a significant difference between the varieties was recorded in the 9th month. Varieties recorded a lower internode length of 17cm in the 10th month compared to 18.5 cm in the 9th month at Kibos, while in Mumias, a higher internode length of 17.8 cm was recorded in the 10th month compared 17.6 cm recorded in the 9th month (Figure 8a and b). Variety KEN 82-601 recorded a higher internode length of 18 cm and 18.9 cm than variety KEN 82-216 with internode length of 17.8 cm and 16 cm in Kibos and Mumias respectively. N-rates did not significantly affect internode length of the two varieties used in the study (Figure 8c and d). Variety and N-rate interactions, resulted to non-significant effect on the internode length in Kibos and Mumias (Table 10). A higher internode length of was recorded at 120 kg N/ha (18 cm) compared to control (17.7 cm) in Kibos while in Mumias, internode length was lower at 120 kg N/ha (17 cm) compared to control (18 cm). Generally, Kibos recorded a higher average internode length of 18 cm than Mumias that recorded 17.7 cm.

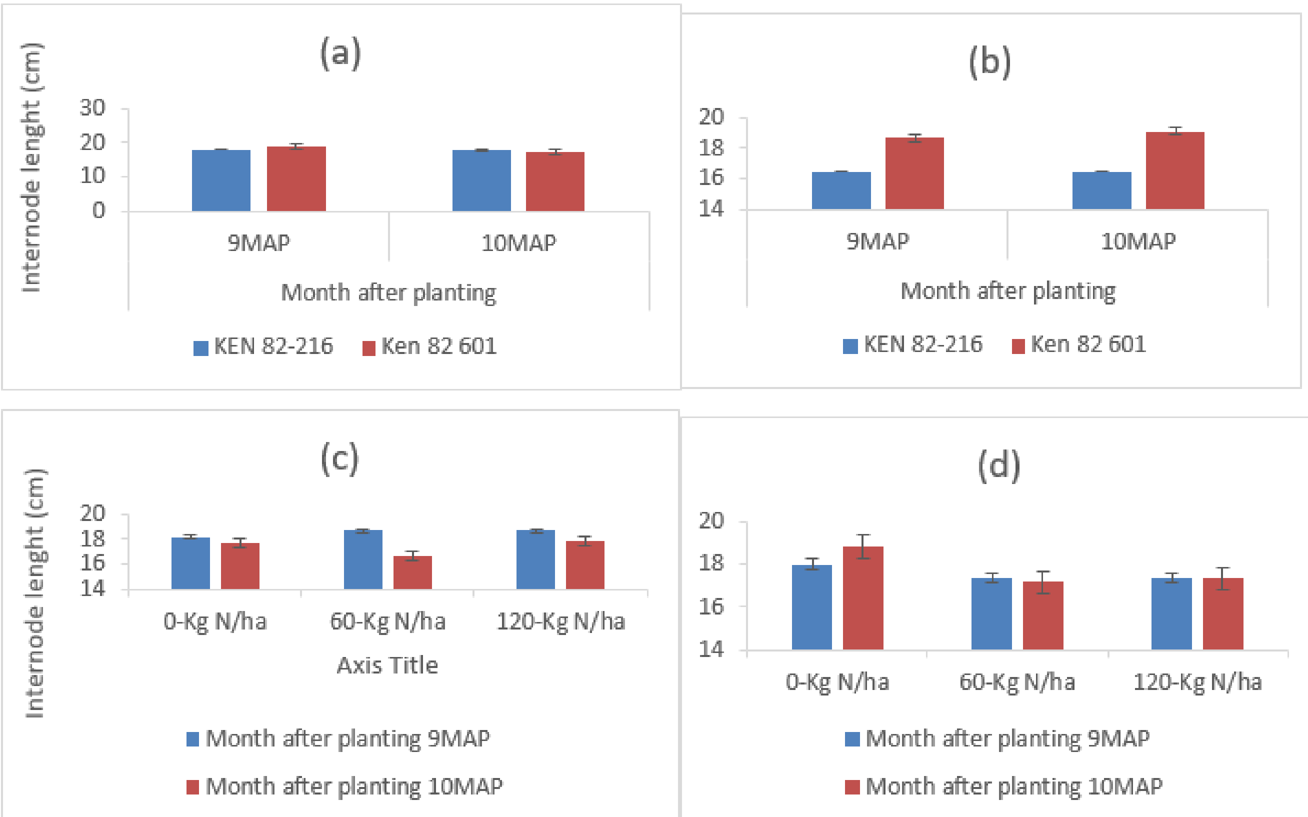

Figure 8. Average internode cm/m^2 for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on on average internode at Kibos (c) and Mumias (d). Bars are standard errors of means.

Table 10. Variety and nitrogen (N) interaction effects on internode cm/m^2 at 9th and 10th months after planting (MAP) in Kibos and Mumias

MAP and N rate		Kibos				Mumias			
		KEN 82-216	KEN82-601	LSD	Pvalue	KEN 82-216	KEN82-601	LSD	Pvalue
9 MAP	0 N	17.3	19.0	3.6	0.4	16.7	19.3	1.8	0.9
	60 N	18.3	19.0			16.3	18.3		
	120N	18.3	19.0			16.3	18.3		
10 MAP	0 N	17.7	17.7	4.5	0.6	17.0	20.7	2.2	0.4
	60 N	17.3	16.0			15.7	18.7		
	120N	17.7	18.0			16.7	18.0		

LSD is least significant difference

3.6.11 Stalk girth

Varieties at Mumias recorded a significant effect ($P < 0.05$) on stem girth while those at Mumias did not record a significant effect. Variety KEN 82-601 recorded a higher average stem girth of 2.5 cm in Kibos and Mumias (Figure 9a and b), N-rate treatment recorded non-significant effect on the stalk girth of the studied varieties. In Kibos, a higher stem girth of 2.4 cm at 60 kg N/ha was recorded compared to control (2.3 cm) and 120 kgN/ha (2.2 cm) (Figure 9c and d). In Mumias, a higher stem girth of 2.3 cm (120 kgN/ha) compared to 2.2 cm at 0 kg N/ha (control). Interaction between varieties and N-rates had non-significant effect on the stalk girth (Table 11). A higher average stalk girth of 2.3 cm was recorded at Kibos than that recorded at Mumias (2.2 cm).

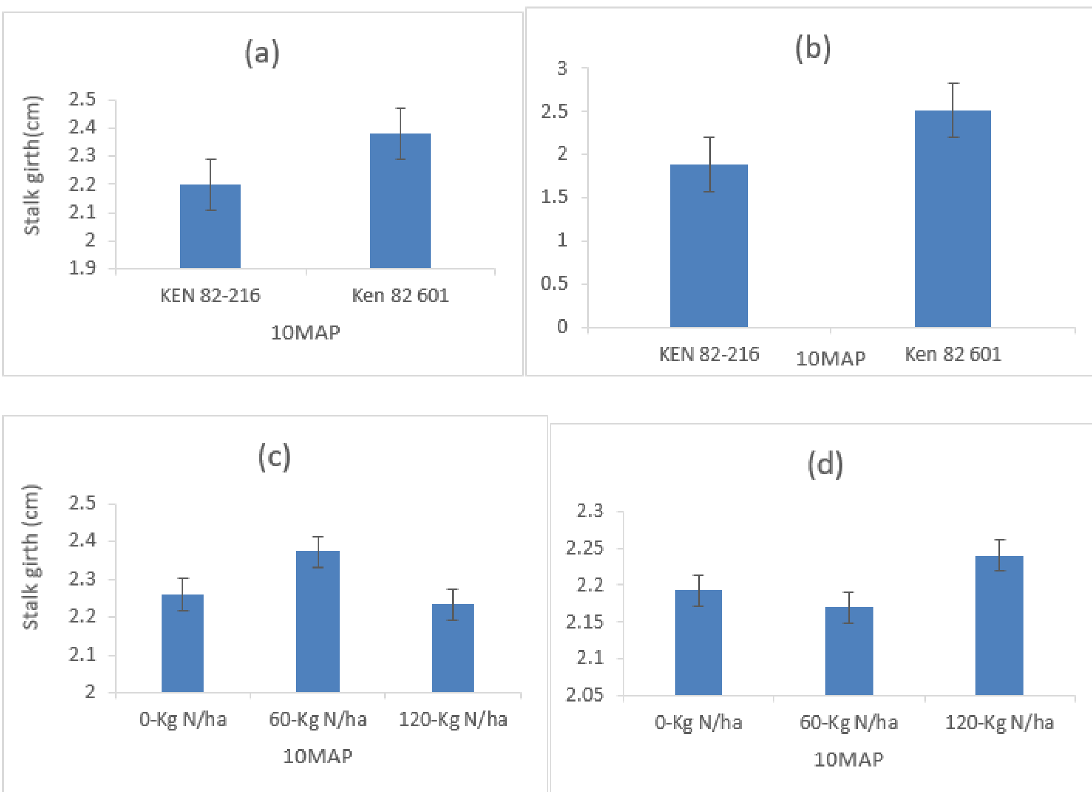

Figure 9. Average stalk gith cm/m^2 for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on on stalk gith at Kibos (c) and Mumias (d). Bars are standard errors of means.

Table 11. Variety and nitrogen (N) interaction effects on stalk girth cm/m^2 in different months after planting (MAP) in Kibos and Mumias

MAP and N rate		Kibos				Mumias			
		KEN 82-216	KEN82-601	LSD	Pvalue	KEN 82-216	KEN 82-601	LSD	Pvalue
10MAP	0N	2.2	2.4	0.3	0.43	1.8	2.6	0.27	0.44
	60N	2.2	2.5			1.8	2.5		
	120N	2.2	2.3			2	2.5		

LSD is least significant difference

3.6.12 Plant population

Varieties did not record a significant difference (P< 0.05) in plant population at Mumias and Kibos. Variety KEN 82-216 recorded a high average plants per hectare of 8565 and 9353 at Kibos and Mumias respectively (Figure 10a and b). N-rates recorded a significant effect on plants per hectare in Mumias unlike Kibos where the effect was not significant. Increase in N-rate resulted to a high plants per hactare of 10151 at 120 kgN/ha at Mumias (Figure 10c and d). Interactions between N-rate and varieties did not record significant effect on the plants per hactare in both sites (Table 12). Varieties grown at Mumias recorded a high average plant/ha of 8764 compared to Kibos that recorded 8273 plants.

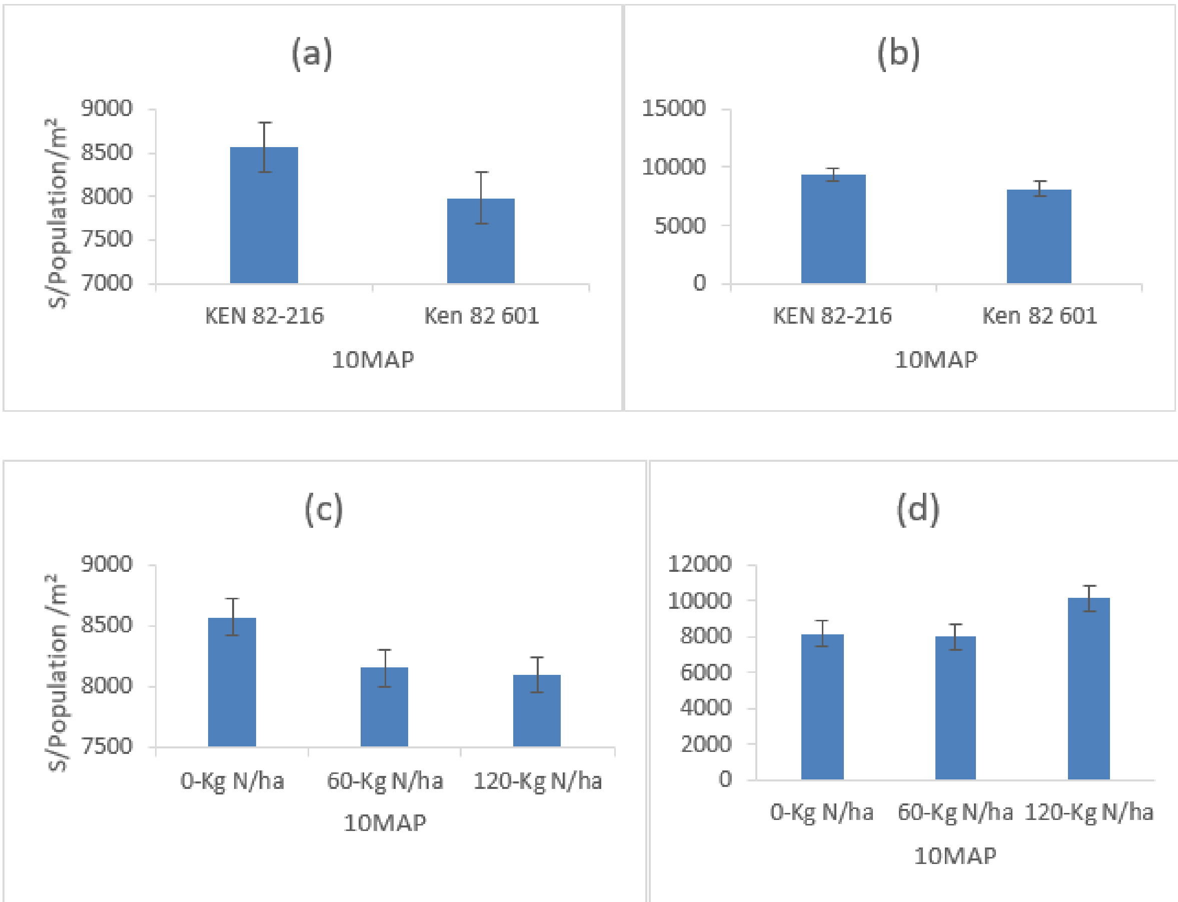

Figure 10. Average stalk population /m^2 for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on stalk population at Kibos (c) and Mumias (d). Bars are standard errors of means.

Table 12. Variety and nitrogen (N) interaction effects on plant population/m^2 in 10th months after planting (MAP) in Kibos and Mumias

	Kibos				Mumias			
N Rate	KEN 82-216	KEN 82 601	LSD	Pvalue	KEN 82-216	KEN 82 601	LSD	Pvalue
0 N	8861.0	8277.8	2133.6	0.8	8639.0	7666.6	2229.5	0.3
60 N	8639.0	7666.6			9255.6	6722.2		
120 N	8194.4	8000.0			10164.0	10138.8		

LSD is least significant difference

3.6.13 Seedcane yield (t/ha)

There were no significance differences (P< 0.05) in cane yield in Kibos and Mumias in this study. KEN 82-216 recorded a non-significant high yield of 20 t/ha and 24.5 t/ha compared to 19.9 t/ha and 20 t/ha at Kibos and Mumias respectively (Figure 11a and b). N-rate treatment did not significantly affect seed cane yield between the varieties in Mumias and Kibos, Seedcane yields were also not significantly affected by treatment interactions in both study sites (Table 13). At Mumias, N-rate of 120 kg/ha N resulted in high seed yield of 25 t/ha compared to 19 t/ha (control), and 22.8 t/ha (60 kg/ha N) (Figure 11c and d). Mumias recorded a higher seed yield of 22.5 t/ha compared to Kibos at 20 t/ha.

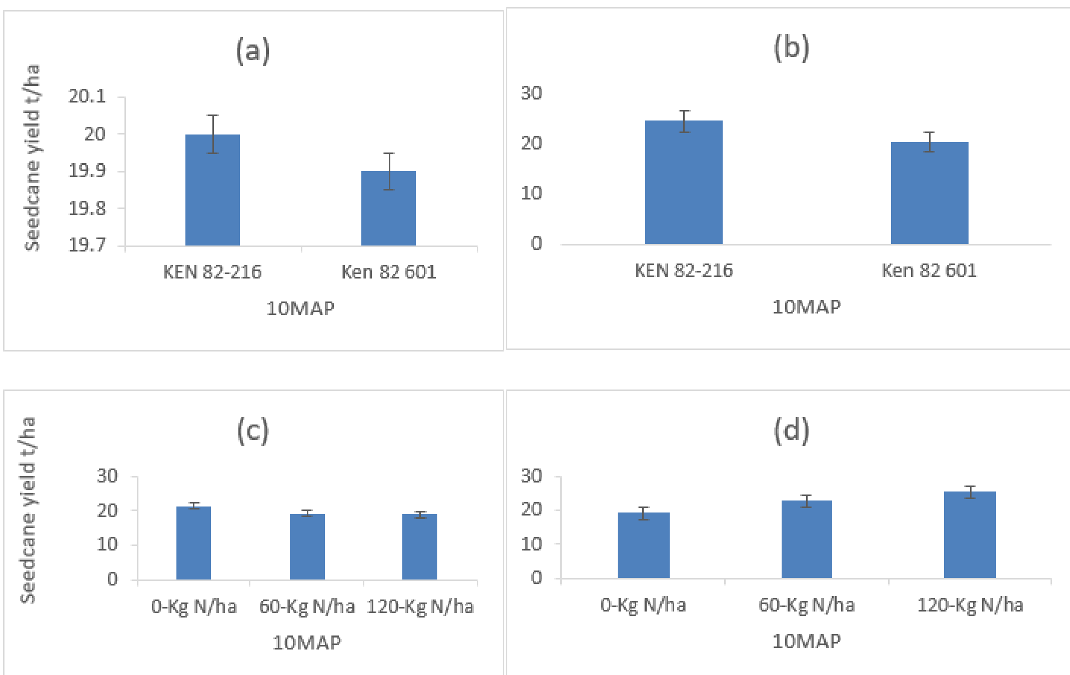

Figure 11. Average yield t/ha for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of N rate on yield t/ha at Kibos (c) and Mumias (d). Bars are standard errors of means.

Table 13. Variety and nitrogen (N) interaction effects on yield t/ha in 10th months after planting (MAP) in Kibos and Mumias

	Kibos				Mumias			
N rate	KEN 82-216	KEN 82- 601	LSD	Pvalue	KEN 82-216	KEN 82- 601	LSD	Pvalue
0 N	22.2	20.8	31.2	0.1	22.2	16.3	14.1	0.1
60 N	22.2	16.3			29.5	16.0		
120 N	15.5	22.6			21.9	28.9		

LSD is least significant difference

3.7 Discussion

3.7.1 Crop phenology and growth

The results of this study revealed a non-significant difference in germination between the two varieties, KEN 82-216 and KEN 82-601, in Mumias and Kibos, implying that both varieties had comparable germination potential regardless of genotypic variations (Sreewarome *et al.*, 2007). Tillers per hectare for KALRO-Kibos and Mumias did not differ significantly across all N applications. Tillers in KALRO-Kibos were reduced from 5 MAP, which was ascribed to extended drought, which resulted in competition for both space and nutrients, and water, resulting in a reduction in tiller mortality, whereas tillers in Mumias were affected by competition for space and nutrients for survival. At Kibos, 33 tillers were recorded at 0 kg (control), whereas increasing the N-rate to 60 kg/ha resulted in 36 tillers/m2. The most essential component of yield is the number of tillers per unit area. The more tillers there are, especially fruitful tillers, the higher the yield. The larger number of tillers/m2 in the experiment could be attributed to the availability of nitrogen, which is essential for cell division (Chaturvedi, 2005). In general, the number of tillers rose, although insignificantly, with increasing N-rate, with the largest number recorded at 120 kg/ha N. This was consistent with the findings of Australian studies, which revealed that crops with insufficient nitrogen have fewer leaves and less root mass (Mutonyi *et al.*,2014).

3.7.2 Leaf area and leaf greenness

Since chlorophyll concentration and nitrogen content in leaves have a strong correlation, the N content in leaves can be estimated indirectly by measuring the SPAD value of leaves (Yang *et al.*, 2014). The use of N fertilizer considerably increased the SPAD value in sugarcane leaves in this study and decreased with plant growth. Previous research found that leaves are the main N sink organ in the early growth stage, and N content in green leaves decreased with growth, with the stalk being the largest N pool in sugarcane (Allison *et al*., 1997, Zhu *et al*., 2020). A steady increase in chlorophyll content was seen in both types from the third to the eighth MAP, which was afterwards accompanied by a drop in the ninth and tenth MAP in Mumias, and a decrease in the ninth and tenth MAP in Kibos (Figure 3c and d). Zhu *et al*., (2020) found a steady increase in chlorophyll content up to the seventh month, when the SPAD value dropped considerably, supporting our findings in this study. The drop in SPAD value in the ninth and tenth months could be attributed to N transfer from leaf to stem.

In both sites, the leaf area index grew over the months leading up to maturity. In Kibos, variety KEN 82-601 had a much higher area index than variety KEN 82-216 in the ninth and tenth months. In Mumias, the N-rates treatment produced a substantial variation in leaf area index between kinds in the 10th month. Wiedenfeld and Enciso (2008) discovered similar results, namely that increasing the N rate resulted in an increase in LAI, However, the response was quadratic. With an increase in N-rates, there was a non-significant rise in leaf area index in Kibos, 4.8 cm2 (60 kg N/ha) and 5.1 cm2 at 120 kg N/ha. Rupp and Hubner (1995) similarly found that increasing the applied N increased the leaf area index.

N-rates significantly affected the number of leaves per plant in the 10th MAP at Mumias, whereas an increase in N-rate raised leaf number from 39 leaves (control) to 40 leaves per plant at 60 kg/ha. The increase in leaf count might be related to appropriate N nutrition, which could be explained by an improvement in the plant's nutrient mining capability as a result of greater root development and enhanced carbohydrate translocation from source to growing sites in well-fertilized plots (Singh and Agarwal, 2001). Charturvedi (2005) has also reported similar findings.

3.7.3 Yield and yield components

In Kibos, N-rate treatments had no significant effect on plant height on either variety, however in Mumias, N-rate treatments significantly affected the plant height in the 7th and 10th months. The rise in plant height in response to N fertilizer application is most likely owing to increased nitrogen availability, which increased leaf area, resulting in higher photosynthetic rates and thus more dry matter accumulation. The findings of Xu *et al*., (2012) back up these conclusions. N-rates and varietal interactions had no effect on stalk height in Kibos, whereas Mumias had a substantial effect in the 5th and 7th months. Mumias had a greater average stalk height of 86.5 cm than Kibos, which had an average plant height of 84.9 cm. Varietal reaction to N-rate treatment was time and site dependent, owing to varied agro-ecological variables. Several research (Wiedenfeld, 1995; Wood *et al*., 1996, Legendre *et al*., 2000) have discovered that the ideal N treatment rate is affected by factors such as soil type, crop age, plant and soil characteristics, climate, growing cycle length, and growing season duration.

The internode length of the two types tested was unaffected by the N-rate treatments. In Kibos and Mumias, interactions with variety and N-rate have little effect on node length. This may be due to the wide variety of N-rate recommendations. Nitrogen fertilizer application rates for sugarcane cultivation range from 45 to 300 kg N/ha over the world (Srivastava and Suarez, 1992). Internode length in Kibos was greater at 120 kg N/ha (18 cm) than in the control (17.7 cm). Mumias with 120 kg N/ha had a shorter internode length (17 cm) than the control (17.7 cm) (18 cm). According to Thorburn *et al*., (2005) and van Heerden *et al*., (2010), greater N is required for various intensive farming practices, such as sugarcane cultivation.

Kibos had a greater stem girth of 2.4 cm at 60 kg N/ha compared to the control (2.3 cm) and 120 kg/ha (2.2 cm). Mumias had a larger stem girth of 2.3 cm (120 kg N/ha) than 2.2 cm (control). Gana, (2008) found similar results, reporting an increase in stalk length with increasing N rate, however this increase was non-significant at 120 kg/ha. The interaction between varieties and N-rates had no impact on stalk girth. This variation in effect between the two sites could be attributed to dryness during the production period. These results are consistent with those reported by Bangar and Sharma (1992) and Shafshak *et al*., (2001), who attained maximum cane girth at higher NPK dosages.

In Mumias, the N-rate had a substantial effect on the stalk population, whereas in Kibos, there was no significant effect. At Mumias, an increase in N-rate led in a high stalk population of 10151/m^2 at 120 kgN/ha, which was non-significant when compared to 60 kg/ha N. Kolage *et al*., (2001), and Singh *et al*., (2005) all found an increase in the number of stalks per unit area as the N dose increased. Mishra *et al*., (2004), on the other hand, observed no significant variation in the number of millable canes, which agrees with our recorded findings in Kibos, where a non-significant drop in the number of stalks was reported at 120 kg/ha N compared to 60 kg/ha N.

Muchow *et al*., (1996) discovered that, while a high N rate (268 kg N/ha) reduced sucrose content somewhat, higher N rates increased cane yield to levels that produced equivalent sugar yields to the low

N rate. This implies that lower N fertilization rates could result in comparable sugar yields with less cane tonnage, this would reduce manufacturing and transportation costs.

A 120 kg/ha N N-rate resulted in a high cane yield of 25.4 t/ha at Mumias, compared to 19.2 t/ha (control) and 22.8 t/ha (60 kg/ha N). Significant increases in stripped cane production have already been observed in response to increasing levels of N (Mishra *et al*., 2004, Singh *et al.*, 2005). Mumias had a greater seed production of 22.5 t/ha than Kibos, which had a yield of 20 t/ha.

Higher stripped cane yield at higher nutrient levels, notably in Mumias, was attributable to greater cane length, cane girth, and cane stalk number. At Kibos, the control yielded 21.5 t/ha, the 60 kg/ha N yielded 19.2 t/ha, and the 120 kg/ha N yielded 19 t/ha. In general, cane yield did not respond much to N-rate in this region. Similar findings were reported by Ramesh and Varghese (2000), who found no discernible variation in sugar yield due to fertilizer applications. Muchovej and Newman (2004), on the other hand, reported a numerical rise in sugar output with increased N rate at each recorded harvest.

3.8 Conclusion

Appropriate application of nitrogen fertilizer promotes the tillering, growth, chlorophyll content, leaf area index, leaf count, stalk height, dry weight, internode length, stalk girth, stalk population and seedcane yield. It was concluded that, appropriate N-rate application significantly improves nitrogen use efficiency and cane and sugar productivity in sugarcane, but there were no significant interactions between N application level and sugarcane varieties. Under the condition of the present study, 120 kg/ha N is good for plant which could produce the highest sugar yield though in most parameters, it was non-significant compared to 60 kg/ha N. Variety KEN 82-601 recorded significant performance in response to varying N-rate in both sites compared to variety KEN 82-216.

CHAPTER 4: EFFECT OF TIMING OF NITROGEN APPLICATION ON GROWTH AND YIELD OF TWO PHENOLOGICALLY CONTRASTING SUGARCANE VARIETIES

4.1 Abstract

Nitrogen N deficiency reduces light interception and photosynthesis by decreasing leaf area, chlorophyll synthesis, and biomass production, is a critical crop nutrient for the numerous metabolic activities, particularly those related to crop growth, require N. N recommendations, on the other hand, should use an application rate that reduces environmental effect while maintaining productive agronomic yields. This is accomplished by employing the optimal rate of N within the specified duration. This chapter reports the effect of time of N-rate on the growth and yield of two phenologically contrasting sugarcane varieties. Two experiments were set up simultaneously in KALRO-SRI-Kibos and MMS NE-Mumias from October 2018 to July 2019. The treatments included nitrogen rates of N (0, 60, and 120 kg/ha) from a fertilizer urea (46% N) source and fertilizer application time at T1 (three months after planting), T2 (split application at three months, first split and second split repeated at six months), and T3 (six months after planting). P from single superphosphate (SSP) was used to give 600g P/ha in O/G and 750g P/ha in N/E, this was done in plots where N was also used. Data was collected on percent seed emergence, plant height, number of leaves per plant, internode length, stem girth, leaf area index, plant population, and stalk yield. Time of N-rate application recorded a significant effect on leaf area index in the 3rd month at Kibos, while at Mumias, a non-significant effect of time of N-rate application on leaf area index was recorded. A higher average chlorophyll content of 40 was recorded at Mumias compared to 34 recorded in Kibos. A high average chlorophyll content was recorded in the 3rd and 8th months at Kibos and Mumias, respectively. In the 6th month after planting (T3), recorded a higher internode length than T1 and T2, while in Mumias, N-rate application in the 3rd month after planting recorded a higher average height of 17 (cm) compared to T2 (16.9 cm) and T3 (16 cm). Varieties grown at Mumias recorded a higher average number of leaves of 44 per plant compared to those grown at Kibos, which recorded 40 leaves per plant, although both sites wa affected by climate change Kibos experienced prolonged drought which let to tiller moterlity in some month henced reduced both leaf area and number of leaves per plant, in Mumias site was affected by heavy rains that let to distraction of leave which reduced both leave area and number of leaves pe plant. A high average number of leaves were recorded

in the 7th month at Mumias (58 leaves) and Kibos (50 leaves). In Kibos, N-rate application in the 3rd month after planting (T1) recorded a higher stem girth of 2.4 cm compared to T2 (2.2 cm) and T3 (2.3 cm). A higher average plant height was recorded at T3 (N-rate application 6 months after planting) in Kibos (94.6 cm) and Mumias (89 cm). Interactions between varieties and time of N-rate application had no significant impact on the number of tillers in Kibos and Mumias. Variety KEN 82-216 recorded a higher average plants per hectre of 9225 than variety KEN 82-601, which recorded an average of 7714 plants. The highest N-rate application at T3 (6 months after planting) recorded the highest dry weight of 467 w/m^2. It can be concluded Split N-rate application at the third and sixth (T2) months after planting resulted in a higher seedcane yield of 29 t/ha than T1 (25.8 t/ha) and T3 (28.6 t/ha).

4.2 Introduction

Nitrogen is a key agricultural crop input (N). One reason is that many metabolic activities, particularly those associated to crop growth, such as tillering and stalk elongation, requires nitrogen (Koochekzadeh *et al*., 2009). Many intensive agricultural production methods, such as sugarcane, necessitate higher rates of N. Thorburn *et al*., (2005), van Heerden *et al*. (2010) N recommendations, on the other hand, should use an application rate that minimizes environmental impact while maintaining productive agronomic yields. This is accomplished by employing the optimal N rate at the proper timeframe.

The rates and timing of N fertilizer application for sugarcane production vary greatly over the world (Srivastava and Suarez, 1992). The specific challenges facing Kenyan sugarcane production, such as drought, salinity, and nutrition during the growing season, have changed the N fertilization standards in comparison to other growing regions. Currently, N recommendations for Kenyan sugarcane production range from 67 to 135 kg N/ha, depending on crop age and soil type (Legendre, 2001). N recommendations vary based on crop maturity, with ratoon cane frequently receiving higher N rates than planted cane (de Geus, 1973).

Overuse of fertilizer N can reduce sugarcane yield and be damaging to the environment. Aside from N rate, another problem with N management is optimizing the fertilizer application timing. According to Wiedenfeld (1997), early application of N during the growing season results in decreased cane tonnage while late fertilization decreased the juice quality. They assumed that early fertilization rendered N less available to plants because it’s leached out or locked up before plants reached their full development potential.

Late fertilization inhibited early development and according to Samuels (1969), sugarcane N requirements are greatest early in the growing season during germination and the "boomstage," or grand growth stage. Misalignment of N fertilization and rapid sugarcane uptake of soil N may result in considerable N fertilizer loss from the soil system. However, little research has been conducted to determine the effects of early and late fertilizer applications on Kenyan seedcane cultivars KEN 82-216 and KEN 82-601. A lack of understanding of ideal time could have a substantial influence on crop output.

Proper nitrogen control is essential for sugarcane output to remain sustainable by determining the ideal N rate and important application timing, as well as variations in the optimum N rate in relation to other N timings, would enable for the future use of technologies that can more correctly regulate N applications in sugarcane production. Remote sensing technology is one example of a potentially beneficial technology. However, no data are available on the impact of varying N rates on fertilization rates on sugarcane productivity in Kenya. The purpose of this study was to determine how the timing of N application affects the growth and yield of several seedcane cultivars.

4.3 Materials and Methods

4.3.1 Treatments and experiment design

The experimental design was RCBD with a 3x2x3 factorial arrangement of the treatments and three replications, the treatments included nitrogen rates and time of N-rate application, which was N (0, 60, and 120 kg/ha from fertilizer Urea (46 percent N) source and time of fertilizer application at T1 (three months after planting), T2 (split application at three months, first split and second split repeated at six months), and T3 (six months after planting). The gross plot size in NE was 1.5 m x 4 rows x 5 m = 30 m^2 and 1.2 m x 4 rows x 5 m = 24 m^2 in out-growers based on the standard spacing in the two sectors. The net plot size for data collection in NE was 1.5 m x 2 rows x 5 m = 15 m2 and in out-growers was 1.2 m x 2 rows x 5 m = 12 m^2. Experimental site is as described in section 3.2.1.

4.3.2 Experimental layout, design and crop husbandry

The newly produced seedcane varieties KEN 82-216 and KEN 82-601 were employed as test crops in the study. These are early maturing sugarcane cultivars collected between 14 and 18 months, and seedcane harvested between 10 and 12 months. The apparent sucrose concentration at maturity is predicted to be 12-14 percent, with fibre content ranging between 15 and 18 percent for millable cane (Jagathesan *et al*., 1990). All tests evaluated seedcane data after 10 months of growth in a single season.

Sugarcane plants were established from seedlings aged 8-10 months. A sett is made up of three eye buds. Each type was separated by 0.50 m within each row, with lines separated by 1.20 m and 1.50 m in SRI and Mumias, respectively, a 5 m long plot with four lines was planted in October of 2018. During planting, 600g P/ha in O/G and 750g P/ha in N/E of triple super phosphate was applied within the rows. Weeds were controlled using pre-emergence herbicides Dual 1.8L/ha, Sencer 2L/ha, and Glyphosate 2L/ha as a cocktail for both broad and narrow-leafed weeds, and human weeding after germination. After 10 months, the canes were harvested near the ground.

4.4 Data collection

4.4.1 Crop growth traits

Data on growth, physiology, and yield were obtained. Plant emergence, leaf area index, leaf count, tillering, stalk height, internode length, plant population, and stem girth were all measured for growth. Physiological data on chlorophyll, dry and wet weight, and yield data on stalk mass in t/ha were obtained. A physical count of emerging shoots was performed in the net plots 30 and 45 days following planting. The largest number of emerged shoots reported as a percent of the predicted was used to compute the average emergence.

Tillering was evaluated between 3 and 8 months after planting, a physical count of the total number of shoots in the net plot was performed and the number of tillers/ha was extrapolated. To determine the inter-node length, the stalk height and number of internodes per stalk were measured on 5 plants in the net plot at harvest. To avoid the border effect, the randomly selected plants were placed 2 m from the plot's edge on either side, stalk height and internode length were measured in centimeters. A physical count of all stalks in the net plot was performed and the stalk population per hectare was extrapolated, five cane stalks were collected during harvesting for girth measurement at the middle level using a Vernier caliper.

A handheld chlorophyll meter was used to determine the greenness of the leaves (Minolta SPAD-502). The measurement was taken from five leaves per plot, with the uppermost visible dewlap leaf sampled. The SPAD reading was acquired from three MAPs at monthly intervals (Amaral *et al.*, 2012). The leaf area index (LAI) was established by measuring the highest fully grown leaf on five plants per plot from three MAP to harvesting, in net plots, five stalks were sampled and their leaves counted and all green leaves were counted until the fully uppermost open leaf was reached.

4.4.2 Yield components

Yields at harvest was determined by weighing all stalks from the net plots, a tripod stand and calibrated suspension balance was used for measurement and cane weight in tonnes realized was extrapolated to plot sizes to determine the cane yield in t/ha.

4.5 Data analysis

Data collected was subjected to analysis of variance using GenStat. Least significant difference test (LSD) at 5% level of probability was used to compare treatment means (Vargas *et al.*, 2015).

4.6 Results

4.6.1 Germination percentage

Varieties recorded a significant variation ($P \leq 0.05$) in germination percentage at 45 days after planting at Kibos while in Mumias there were non-significant variations in germination percentage. Variety KEN 82-216 recorded a high average germination percentage of 42% and 35% at Kibos and Mumias respectively while variety KEN 82-601 recorded an average germination percentage of 25 % and 29 % at Kibos and Mumias (Table 14). A high average germination percentages were of 39 % and 37% recorded in 45 days after planting at Kibos and Mumias respectively. Varieties grown at Kibos recorded an average higher germination percentage of 39 % than those grown at Mumias which recorded a germination percentage of 32%. Generally, the varieties recorded a low germinations percentage.

Table 14. Germination percentage of two selected seedcane varieties at 30 and 45 days after planting

	Kibos			Mumias		
Variety	30DAP	45DAP	Mean	30DAP	45DAP	Mean
KEN 82-216	34.5	50.1	42.3	29.9	39.2	34.6
KEN 82-601	22.1	28.3	25.2	23.3	34.7	29.0
Mean	28.3	39.2	33.8	26.6	37.0	31.8
$LSD_{\leq 0.05}$	NS	17.3*		NS	NS	
P-value	0.157	0.035		0.174	0.319	

DAP is days after planting, LSD is least significant difference, * is significant, NS is not significant

4.6.2 Effect of time of nitrogen application on Leaf area index (LAI) (m/m^2) of seedcane varieties

Varieties recorded a significant variation ($P \leq 0.05$) in leaf area index in the 5th, 6th and 7th month after planting at Mumias while at Kibos, varieties did not record significant variation in leaf area index. Time of N-rate application recorded a significant effect on leaf area index in the 3rd month at Kibos while at Mumias, no significant effect was recorded. Varieties at Mumias recorded a significant higher average leaf area index of 6 cm^2 than at Kibos which recorded a leaf area index of 5 cm^2. At Kibos, N-rate application at 6th month (T3) recorded a higher leaf area index of 5 cm^2 compared to N-rate application at T1 (N-rate application after 3 months after planting) and T2 (split application at 3rd and 6th month) (Table 15). At Mumias, N-rate application after 3 months of planting recorded a high leaf area of 6.4 cm^2 compared to N-rate application at T2 (6.2 cm^2) and T3 (6.1 cm^2). At Kibos, varieties recorded a high leaf area index of 6 cm^2 and 6.9 cm^2 in the 9th and 10th month and a low leaf area index in the third month, similar findings were recorded in Mumias which recorded a high leaf area index of 9 cm^2 and 9.9 cm^2 in the 9th and 10th month and a low leaf area index of 2 cm^2 in the 3rd month. Interactions between varieties and time of N-rate application significantly affected the leaf area index at Kibos only in the 5th month while in Mumias there were no significant interactions recorded (Table 16).

Table 15. Time and nitrogen (N) effect on leaf area index(m/m^2) at different months after planting (MAP) in Kibos and Mumias

	Kibos					Mumias				
Variety	KEN 82-216	KEN 82-601	Mean	$LSD_{\leq 0.05}$	P-value	KEN 82-216	KEN 82-601	Mean	$LSD_{\leq 0.05}$	P-value
3 MAP	2.6	2.4	2.5	0.7	0.367	2.4	2.4	2.4	1.7	0.987
4 MAP	3.8	4.5	4.2	2.6	0.377	4.2	5.6	4.9	2.5	0.128
5 MAP	5.2	6.0	5.6	1.8	0.189	3.6	6.1	4.9	1.8*	0.025
6 MAP	5.0	5.1	5.1	1.7	0.717	3.7	7.4	5.6	1.2**	0.006
7 MAP	3.9	3.7	3.8	0.5	0.213	5.2	4.7	5.0	0.5*	0.043
8 MAP	4.3	3.9	4.1	2.2	0.57	8.0	8.8	8.4	4.7	0.517
9 MAP	5.8	6.5	6.2	1.8	0.238	9.3	8.8	9.1	1.0	0.192
10 MAP	6.7	7.1	6.9	0.4	0.074	10.0	9.8	9.9	0.7	0.407
Mean	4.7	4.9	4.8			5.8	6.7	6.3		

	Kibos						Mumias					
N-rate	T1	T2	T3	Mean	$LSD_{\leq 0.05}$	P-value	T1	T2	T3	Mean	$LSD_{\leq 0.05}$	P-value
3 MAP	2.4	2.1	3.1	2.5	0.7*	0.044	2.6	2.1	2.5	2.4	0.9	0.408
4 MAP	4.0	3.7	4.9	4.2	1.0	0.058	4.8	4.5	5.4	4.9	1.2	0.335
5 MAP	5.4	5.8	5.7	5.6	1.2	0.673	4.9	4.7	5.0	4.9	0.7	0.568
6 MAP	5.5	4.3	5.4	5.1	2.0	0.362	5.4	5.9	5.4	5.6	0.5	0.064
7 MAP	3.8	3.8	3.9	3.8	0.6	0.896	5.1	5.2	4.6	5.0	0.6	0.169
8 MAP	4.2	4.2	3.9	4.1	0.9	0.759	9.0	8.2	8.0	8.4	1.1	0.125
9 MAP	5.9	6.5	6.1	6.2	0.8	0.411	9.4	9.1	8.7	9.1	0.7	0.159
10 MAP	7.1	6.8	6.8	6.9	0.8	0.614	10.4	9.8	9.5	9.9	0.7	0.066
Mean	4.8	4.6	5.0	4.8			6.4	6.2	6.1	6.2		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting. ** is highly significant, * is significant

Table 16. Time and nitrogen (N) interaction effects on leaf area index m/m^2 at different months after planting (MAP) in Kibos and Mumias

MAP and	Timing	Kibos					Mumias				
		KEN 82-216	KEN 82-601	Mean	$LSD_{\leq 0.05}$	P-value	KEN 82-216	KEN 82-601	Mean	$LSD_{\leq 0.05}$	P-value
3 MAP	T1	2.4	2.3	2.4	0.9	0.601	2.1	2.8	3.5	1.4	0.21
	T2	2.4	1.9	2.1			2.5	1.6	2.1		
	T3	3.0	3.1	3.1			2.3	2.6	2.5		
4 MAP	T1	3.5	4.4	4.0	2.0	0.795	3.8	5.8	4.8	2.0	0.326
	T2	3.5	3.8	3.7			3.6	5.4	4.5		
	T3	4.5	5.2	4.9			5.1	5.6	5.4		
5 MAP	T1	4.9	5.9	5.4	1.6*	0.041	3.5	6.3	4.9	1.4	0.267
	T2	6.2	5.4	5.8			3.2	6.2	4.7		
	T3	4.6	6.9	5.7			4.0	6.0	5.0		
6 MAP	T1	5.0	6.0	5.5	2.4	0.601	3.6	7.2	5.4	1.0	0.417
	T2	4.2	4.4	4.3			3.9	8.0	5.9		
	T3	5.7	5.0	5.4			3.6	7.1	5.4		
7 MAP	T1	3.8	3.8	3.8	0.8	0.815	5.4	4.8	5.1	0.8	0.788
	T2	4.0	3.6	3.8			5.6	4.9	5.2		
	T3	4.0	3.8	3.9			4.8	4.5	4.6		
8 MAP	T1	4.5	3.8	4.2	1.7	0.709	8.5	9.6	9.0	3.8	0.356
	T2	4.2	4.3	4.2			7.5	8.9	8.2		
	T3	4.1	3.7	3.9			8.0	8.0	8.0		
9 MAP	T1	5.5	6.4	5.9	1.4	0.73	9.6	9.1	9.4	1.0	0.962
	T2	6.3	6.7	6.5			9.4	8.9	9.1		
	T3	5.8	6.5	6.1			8.9	8.5	8.7		
10MAP	T1	6.7	7.6	7.1	1.0	0.348	10.4	10.3	10.4	0.9	0.835
	T2	6.9	6.7	6.8			9.8	9.8	9.8		
	T3	6.6	7.0	6.8			9.7	9.3	9.5		
	Mean	4.7	4.9	4.8			7.0	6.7	6.9		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting, * is significant

4.6.3 Effect of time of nitrogen application on chlorophyll content of selected seedcane varieties

Significant variations ($P \leq 0.05$) were recorded among the varieties in the 3rd month at Kibos and 3rd, 4th and 10th month at Mumias. Time of N-rate application significantly affected chlorophyll content in the 10th and 5th months at Kibos and Mumias respectively (Table 17). A higher average chlorophyll content of 40 was recorded at Mumias compared to 34 recorded in Kibos. A high average chlorophyll content was recorded in the 3rd and 8th month at Kibos and Mumias respectively (Table 17). N-rate application at 6th (T3) and 3rd (T1) recorded a high chlorophyll content at Kibos and Mumias respectively. Interaction between varieties and time of N-rate application in the 7th month had significant effect on chlorophyll content at Kibos while at Mumias there were non-significant interaction effect on chlorophyll content (Table 18).

Table 17. Time and nitrogen (N) effect on chlorophyll nm/m^2 at different months after planting (MAP) in Kibos and Mumias

	Kibos					Mumias				
Variety	KEN 82-216	KEN 82-601	Mean	$LSD_{\leq 0.05}$	P-value	KEN 82-216	KEN 82-601	Mean	$LSD_{\leq 0.05}$	P-value
3 MAP	41.6	38.5	40.1	0.4**	<.001	41.3	38.9	40.1	1.3*	0.016
4 MAP	35.8	30.3	33.1	17.0	0.3	38.4	36.1	37.3	1.7*	0.029
5 MAP	36.5	36.5	36.5	1.7	0.98	40.0	40.4	40.2	8.1	0.864
6 MAP	27.1	27.1	27.1	7.3	0.972	41.3	38.3	39.8	8.1	0.249
7 MAP	36.0	38.3	37.1	5.6	0.222	42.7	44.2	43.4	3.3	0.186
8 MAP	33.2	36.0	34.6	6.3	0.19	44.2	44.7	44.5	0.8	0.121
9 MAP	34.4	35.4	34.9	9.5	0.701	38.1	39.6	38.8	4.1	0.257
10MAP	29.4	28.7	29.1	1.9	0.294	35.5	39.7	37.6	1.2*	0.004
Mean	34.3	33.8	34.1			40.2	40.2	40.2		

	Kibos						Mumias					
N rate	T1	T2	T3	Mean	$LSD_{\leq 0.05}$	Pvalue	T1	T2	T3	Mean	$LSD_{\leq 0.05}$	Pvalue
3 MAP	39.7	39.7	40.8	40.1	4.1	0.8	40.8	39.1	40.5	40.1	2.7	0.371
4 MAP	32.3	34.7	32.3	33.1	2.6	0.109	36.7	37.1	38.0	37.3	3.5	0.701
5 MAP	36.0	35.9	37.6	36.5	3.6	0.481	42.5	38.0	40.2	40.2	2.3*	0.006
6 MAP	25.9	28.3	27.0	27.1	2.7	0.183	39.5	40.2	39.6	39.8	4.1	0.913
7 MAP	37.4	36.0	38.0	37.1	3.7	0.447	42.6	43.8	43.8	43.4	2.7	0.53
8 MAP	34.0	33.5	36.3	34.6	6.7	0.61	43.5	46.3	43.6	44.5	4.7	0.35
9 MAP	34.1	34.3	36.4	34.9	3.4	0.275	39.7	37.2	39.7	38.8	4.1	0.325
10MAP	30.5	29.2	27.5	29.1	1.7*	0.01	38.9	36.3	37.8	37.6	5.3	0.544
Mean	33.7	33.9	34.5	34.0			40.5	39.7	40.4	40.2		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting, * is significant

Table 18. Time and nitrogen (N) N interaction effects on chlophylly nm/m^2 at different months after planting (MAP) in Kibos and Mumias

MAP and Time		Kibos					Mumias				
		KEN 82-216	KEN 82-601	Mean	$LSD_{\leq 0.05}$	P-value	KEN 82-216	KEN 82-601	Mean	$LSD_{\leq 0.05}$	P-value
3 MAP	T1	40.7	38.7	39.7	4.8	0.837	41.8	39.7	40.8	3.2	0.962
	T2	41.7	37.6	39.7			40.4	37.9	39.1		
	T3	42.4	39.1	40.8			41.8	39.2	40.5		
4 MAP	T1	36.1	28.4	32.3	15.1	0.171	37.9	35.5	36.7	4.1	0.997
	T2	36.1	33.2	34.7			38.2	35.9	37.1		
	T3	35.3	29.4	32.3			39.0	36.9	38.0		
5 MAP	T1	36.7	35.2	36.0	4.2	0.647	41.3	43.6	42.5	6.4	0.235
	T2	35.1	36.6	35.9			38.7	37.3	38.0		
	T3	37.6	37.6	37.6			40.1	40.4	40.2		
6 MAP	T1	27.0	24.8	25.9	5.6	0.339	41.5	37.5	39.5	6.6	0.675
	T3	28.0	28.7	28.3			42.2	38.2	40.2		
	T3	26.4	27.7	27.0			40.2	39.0	39.6		
7 MAP	T1	34.7	40.2	37.4	5.1*	0.036	41.1	44.1	42.6	3.5	0.116
	T2	37.8	34.1	36.0			42.2	45.5	43.8		
	T3	35.5	40.5	38.0			44.7	42.9	43.8		
8 MAP	T1	34.6	33.5	34.1	8.2	0.328	43.3	43.7	43.5	5.5	0.984
	T2	32.7	34.3	33.5			46.2	46.4	46.3		
	T3	32.3	40.3	36.3			43.2	44.0	43.6		
9 MAP	T1	34.4	33.8	34.1	7.30.9	0.42	39.3	40.0	39.7	5.0	0.843
	T2	34.2	34.4	34.3			36.6	37.7	37.2		
	T3	34.8	38.1	36.4			38.3	41.0	39.7		
10MAP	T1	31.3	29.7	30.5	2.1	0.502	35.8	41.9	38.9	6.1	0.735
	T2	29.1	29.3	29.2			35.0	37.5	36.3		
	T3	27.7	27.2	27.5			35.8	39.7	37.8		
Mean		34.3	33.9	34.1			40.2	40.2	40.2		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting, * is significant

4.6.4 Effect of time of nitrogen application on the internode length (cm) of selected seedcane varieties

Varieties showed significant variations ($P \leq 0.05$) in internode length in the 10th month at Kibos and Mumias. Time of N-rate application recorded a significant effect on internode length at Mumias in the 10th month while no significant effect was recorded at Kibos. At Kibos, N-rate application in the 6th month after planting (T3) recorded a higher internode length than T1 and T2, while in Mumias, N-rate application in the 3rd month after planting recorded a higher average length of 17 cm compared to T2 (17 cm) and T3 (16 cm) (Table 19). A high internode length of 18 cm was recorded in Kibos than in

Mumias at 17cm. Interactions between varieties × time of N-rate application recorded a non-significant effect on internode length at Kibos and Mumias (Table 20).

Table 19. Time and nitrogen (N) effect on internode/m^2 at different months after planting (MAP) in Kibos and Mumias

	Kibos			Mumias		
Variety	9MAP	10MAP	Mean	9MAP	10MAP	Mean
KEN 82-216	18.8	17.0	17.9	15.7	15.6	15.6
KEN 82-601	19.0	17.2	18.1	17.8	18.3	18.1
Mean	18.9	17.1	18.0	16.7	16.9	16.8
LSD	1.0	1.3		3.3	1.3	
P-value	0.423	0.529		0.113	0.011*	
T1	18.7	16.7	17.7	17.3	17.2	17.3
T2	19.0	17.0	18.0	16.5	17.3	16.9
T3	19.0	17.7	18.3	16.3	16.3	16.3
Mean	18.9	17.1	18.0	16.7	16.9	16.8
LSD	0.6	2.2		1.6	1.1	
P-value	0.41	0.586		0.34	0.011*	

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting, * is significant

Table 20. Time and nitrogen (N) interaction effects on internode at 9 and 10th months after planting (MAP) in Kibos and Mumias

MAP and time		Kibos KEN 82-216	Kibos KEN 82-601	Mean	LSD	P-value	Mumias KEN 82-216	Mumias KEN 82-601	Mean	LSD	P-value
9MAP	T1	18.3	19.0	18.7	0.9	0.41	16.3	18.3	17.3	2.7	0.149
	T2	19.0	19.0	19.0			14.7	18.3	16.5		
	T3	19.0	19.0	19.0			16.0	16.7	16.3		
10MAP	T1	17.3	16.0	16.7	2.6	0.27	15.7	18.7	17.2	1.4	0.41
	T2	17.0	17.0	17.0			15.7	19.0	17.3		
	T3	16.7	18.7	16.7			15.3	17.3	16.3		
	Mean	17.9	18.1	17.9			15.6	18.1	16.8		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

4.6.5 Effect of time of nitrogen application on number of leaves per plant of selected seedcane varieties

Varieties did not show significant variations in number of leaves per plant (Table 21). Varieties grown at Mumias recorded a higher average number of leaves of 44 per plant compared to those grown at Kibos which recorded 40 leaves per plant. A high average number of leaves were recorded in the 7th month at Mumias (58 leaves) and Kibos (50 leaves). N-rate application in the 3rd month, recorded a high average number of leaves of 40 per plant compared to split application of N-rate and application in the 6th month after planting. At Mumias, N-rate application in the 6th month after planting recorded a high average number of leaves per plant of 45 compared to T1 and T2 (Table 21). Interactions between varieties and time of N-rate applications did not significantly affect the number of leaves per plant in both locations (Table 22).

Table 21. Time and nitrogen (N) effect on number of leaves per plant at different months after planting (MAP) in Kibos and Mumias

	Kibos					Mumias				
Variety	KEN 82-216	Ken 82-601	Mean	LSD	P-value	KEN 82-216	KEN 82- 601	Mean	LSD	P-value
4 MAP	39.7	43.8	41.7	10.1	0.223	37.1	37.9	18.6	6.9	0.675
5 MAP	33.2	37.3	35.3	9.7	0.209	41.9	42.9	20.9	6.0	0.546
6 MAP	25.2	25.3	25.3	9.9	0.966	44.9	48.3	22.4	10.8	0.304
7 MAP	48.9	51.9	50.4	8.4	0.264	52.1	58.4	26.1	9.7	0.108
8 MAP	49.3	53.3	51.3	24.5	0.555	43.4	45.0	21.7	5.8	0.369
9 MAP	41.0	36.8	38.9	9.1	0.185	40.2	42.0	20.1	4.2	0.208
10MAP	35.9	34.4	35.2	1.9	0.083	41.1	41.9	20.6	2.7	0.336
Mean	39.0	40.4	39.7			43.0	45.2			

	Kibos						Mumias					
N rate	T1	T2	T3	Mean	LSD	Pvalue	T1	T2	T3	Mean	LSD	Pvalue
4 MAP	42.7	41.7	40.8	41.7	5.2	0.729	36.7	38.5	37.3	37.5	2.8	0.348
5 MAP	37.5	33.2	35.0	35.2	7.0	0.407	41.3	43.5	42.3	42.4	2.8	0.251
6 MAP	24.3	28.5	23.0	25.3	8.4	0.341	46.7	45.8	47.3	46.6	4.6	0.759
7 MAP	50.2	51.3	49.7	50.4	8.0	0.888	55.3	52.2	58.3	55.3	6.0	0.117
8 MAP	50.8	50.2	53.0	51.3	11.7	0.847	41.3	45.0	46.3	44.2	5.6	0.165
9 MAP	40.3	37.5	38.8	38.9	5.2	0.482	39.7	41.0	42.7	41.1	3.5	0.199
10MAP	34.2	35.7	35.7	35.2	3.9	0.604	39.5	41.8	43.2	41.5	3.0	0.061
Mean	40.0	39.7	39.4	39.7			43.0	44.0	45.4	44.1		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

Table 22. Time and nitrogen (N) interaction effects on chlophylly nm/m^2 at different months after planting (MAP) in Kibos and Mumias

MAP and Time		Kibos					Mumias				
		KEN 82-216	KEN 82- 601	Mean	LSD	Pvalue	KEN 82-216	KEN 82- 601	Mean	LSD	Pvalue
4 MAP	T1	40.3	45.0	42.7	8.3	0.791	37.0	36.3	36.7	5.3	0.593
	T2	39.0	44.3	41.7			37.7	39.3	38.5		
	T3	39.7	42.0	40.8			36.7	38.0	37.3		
5 MAP	T1	35.3	39.7	37.5	9.4	0.862	41.3	41.3	41.3	4.7	0.768
	T2	30.3	36.0	33.2			42.7	44.3	43.5		
	T3	34.0	36.3	35.2			41.7	43.0	42.3		
6 MAP	T1	26.0	22.7	24.4	10.7	0.619	44.3	49.0	46.7	8.4	0.844
	T2	28.7	28.3	28.5			44.7	47.0	45.8		
	T3	21.0	25.0	23.0			45.7	49.0	47.3		
7 MAP	T1	50.0	50.3	50.2	10.0	0.804	52.0	58.7	55.4	8.6	0.43
	T3	49.0	53.7	51.4			48.3	56.0	52.2		
	T3	47.7	51.7	49.7			56.0	60.7	58.4		
8 MAP	T1	46.7	55.0	50.9	19.5	0.514	41.3	41.3	41.3	6.9	0.234
	T2	51.7	48.7	50.2			46.0	44.0	45.0		
	T3	49.7	56.3	53.0			43.0	49.7	46.3		
9 MAP	T1	44.0	36.7	40.3	7.7	0.333	38.7	40.7	39.7	4.4	0.968
	T2	37.7	37.3	37.5			40.3	41.7	41.0		
	T3	41.3	36.3	38.8			41.7	43.7	42.7		
10MAP	T1	36.3	32.0	34.2	4.5	0.292	39.3	39.7	39.5	3.6	0.843
	T2	35.0	36.3	35.7			41.7	42.0	41.8		
	T3	36.3	35.0	35.7			42.3	44.0	43.2		
	Mean	39.0	40.4	39.7			43.0	45.2	44.1		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

4.6.6 Effect of time of nitrogen application on stalk girth (cm) of selected seedcane varieties

Varieties showed significant variations ($P \leq 0.05$) in stem girth at Mumias while at Kibos, there were no significant variations recorded among the varieties (Figure 12a and b). Time of N-rate application did not have significant effect on stem girth on the two varieties. Variety KEN 82-601 recorded the highest average stem girth of 2.5 cm than variety KEN 82-216 that recorded stem girth of 2 cm. Varieties at Kibos recorded an average stem girth 2.3 cm while those at Mumias recorded an average stem girth of 2.2 cm. N-rate application at the 3rd month after planting (T1) recorded a higher stem girth of 2.4 cm compared to T2 (2.2 cm) and T3 (2.3 cm) in Kibos (Figure 12c and d). Interactions between N-rate applications and varieties did not have significant effect on the stem girth in both experimental sites (Table 23).

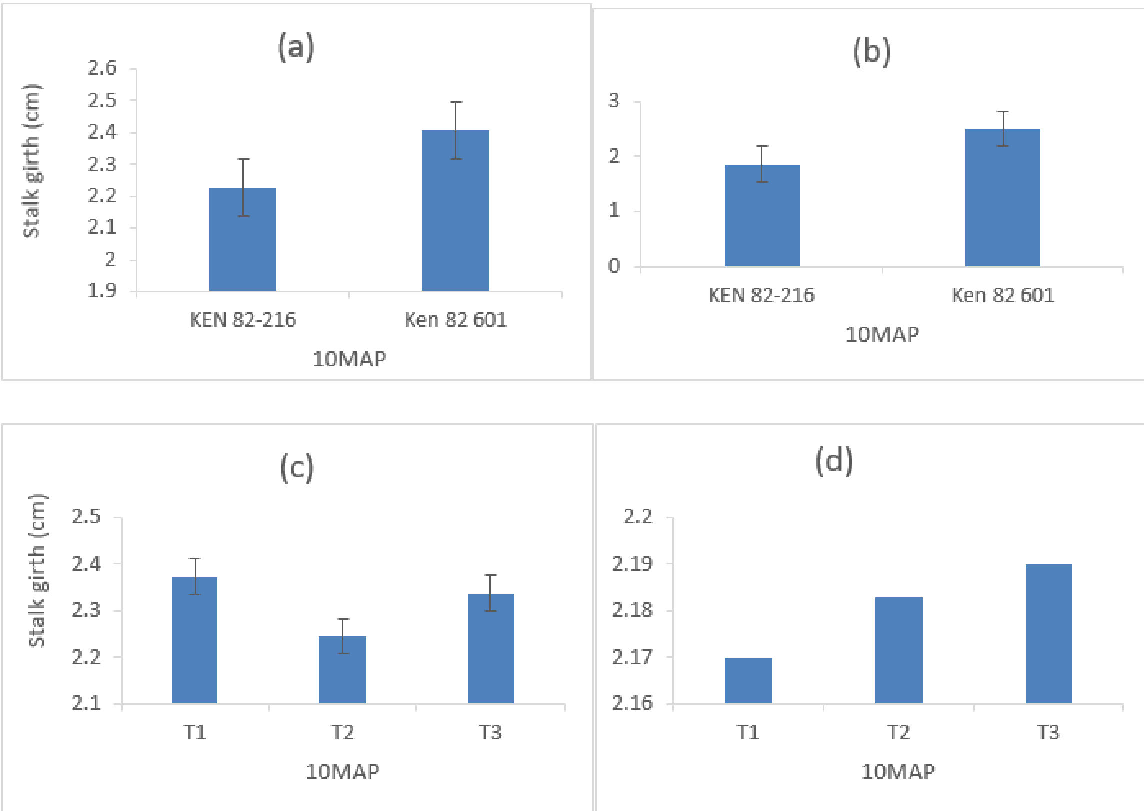

Figure 12. Average stem girth (cm) for variety KEN82-601 and KEN82-216 at Kibos (a) and Mumias (b), and effect of time of N rate on stem girth (cm) at Kibos (c) and Mumias (d). Bars are standard errors of means; T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

Table 23. Time of nitrogen (N) and verieties interaction effects on stem girth (cm) in Kibos and Mumias

	Kibos			Mumias		
Variety	T1	T2	T3	T1	T2	T3
KEN 82-216	2.2	2.1	2.3	1.8	1.9	1.9
KEN 82-601	2.5	2.4	2.4	2.5	2.5	2.5
$LSD_{\leq 0.05}$	0.4			0.4		
P-value	0.7			0.9		

N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

4.6.7 Effect of time of nitrogen application on plant height (cm) of selected seedcane varieties

Significant variations ($P \leq 0.05$) in plant height between the varieties were recorded in the 5th and 6th months at Mumias while varieties grown at Kibos did not record significant variations (Figure13a and b),time of N-rate application had significant effect on plant height in the 4th month at Kibos while at Mumias, no significant effect recorded. Varieties recorded a progressive increase in plant height across the growing period with a maximum average height of 162.9 cm and 168.3 cm recorded in the 10th month at Kibos and Mumias respectively (Figure13c and d). Mumias recorded a higher non-significant average plant height of 87 cm than Kibos that recorded 87 cm, plant height in response to time of N-rate application ranged from 82 cm at T1 to 94 cm at T3 at Kibos and 84 cm at T1 to 89 cm at T3 in Mumias. Generally, a higher average plant height was recorded at T3 (N-rate application 6 months after planting) in Kibos (95 cm) and Mumias (89 cm). Interactions between variety and time of N-rate application had significant effect on plant height in the 10th month at Mumias while in Kibos there were no significant interactions between varieties and time of N-rate application (Table 24).

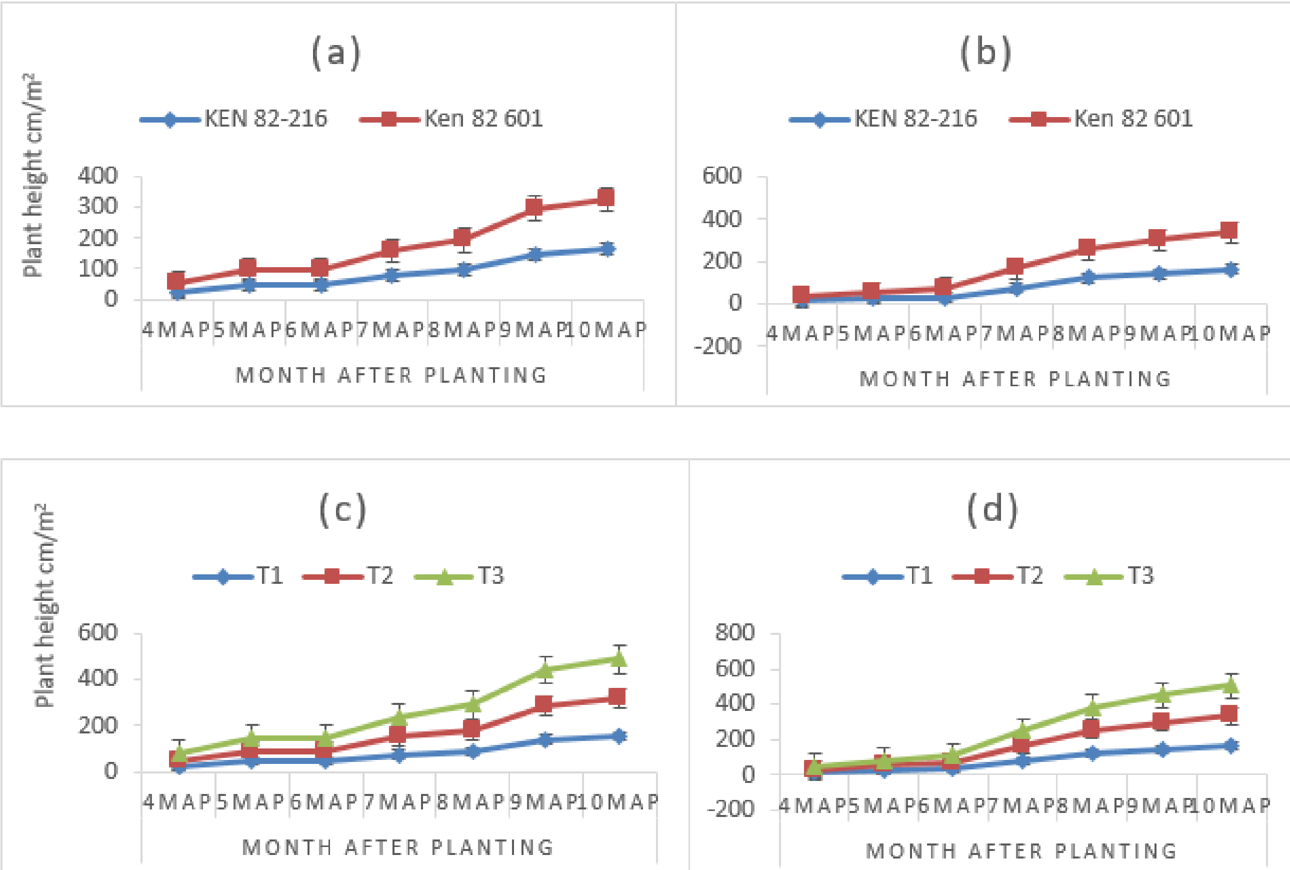

Figure 13. Average plant height (cm) at Kibos (a) and Mumias (b), and effect of time of N rate on height (cm) at Kibos (c) and Mumias (d). Bars are standard error of mean, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting.

Table 24. Time and nitrogen (N) interaction effects on plant hieght(cm) at different months after planting (MAP) in Kibos and Mumias

		Kibos				Mumias			
MAP and Time		KEN 82-216	KEN 82-601	LSD	Pvalue	KEN 82-216	KEN 82-601	LSD	Pvalue
	T1	22.0	26.6	8.2	0.35	13.4	17.8	4.8	0.97
4 MAP	T2	23.1	21.9			13.9	18.7		
	T3	31.6	29.6			14.0	19.0		
	T1	40.6	50.1	21.6	0.34	21.4	30.3	8.4	0.83
5 MAP	T2	49.9	39.0			21.7	34.2		
	T3	49.6	60.1			22.6	32.6		
	T1	44.3	51.7	22.9	0.28	29.8	42.8	11.2	0.55
6 MAP	T2	47.9	35.9			26.5	45.6		
	T3	47.8	62.6			33.3	44.8		
	T1	70.3	77.3	28.0	0.56	73.7	87.3	20.6	0.84
7 MAP	T3	88.5	75.5			74.6	94.2		
	T3	79.3	86.7			76.7	92.3		
	T1	92.3	87.1	46.4	0.57	118.5	122.6	25.9	0.44
8 MAP	T2	100.1	81.7			122.7	142.7		
	T3	100.5	119.1			123.1	140.4		
	T1	139.6	143.3	61.2	0.87	129.4	155.3	29.9	0.62
9 MAP	T2	146.7	142.3			144.0	164.7		
	T3	149.2	165.7			148.3	161.3		
	T1	158.7	151.2	54.6	0.75	163.3	163.3	27.0	0.05
10MAP	T2	171.7	153.5			158.8	184.5		
	T3	165.3	177.0			166.3	173.5		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

4.6.8 Effect of time of nitrogen application on number of tillers of selected seedcane varieties

Varieties showed significant variations ($P \leq 0.05$) in number of tillers at Kibos and Mumias accept for the 5th and 1st month after planting for Kibos and Mumias respectively (Table 25). Variety KEN 82-216 recorded a significant higher average number of tillers of 146 at Mumias and 42 tillers at Kibos compared to KEN 82-601 which recorded an average of 106 tillers and 26 tillers at Mumias and Kibos respectively. Mumias recorded a higher significant average number of tillers of 126 than Kibos which recorded an average of 34 tillers (Table 25). Varieties recorded a high average number of tillers were recorded in the 5th month (51 tillers) and in the 6th month (151 tillers) at Kibos and Mumias respectively. Time of N-rate application had significant effect on number of tillers on the 4th month at Mumias and 5th and 8th month at Kibos. Time of N-rate application recorded a high significant average number of tillers at Mumias (126 tillers) compared to Kibos that recorded an average of 34 tillers. The highest number of tillers of 151 were recorded in the 6th month at Mumias. Interactions between varieties and time of N-rate application had non-significant in number of tillers in Kibos and Mumias (Table 26).

Table 25. Time and nitrogen (N) effects on number of tillers (cm) at different months after planting (MAP) in Kibos and Mumias

	Kibos					Mumias				
Variety	KEN 82-216	KEN 82-601	Mean	LSD	P-value	KEN 82-216	KEN 82-601	Mean	LSD	P-value
3 MAP	38.8	16.2	27.5	9.0*	0.008	84.2	73.7	79.0	45.0	0.419
4 MAP	51.2	27.6	39.4	4.2*	0.002	113.0	94.4	103.7	15.0*	0.042
5 MAP	57.6	44.4	51.0	29.8	0.196	158.9	109.7	134.3	50.1*	0.052
6 MAP	40.6	24.2	32.4	9.8*	0.019	184.2	118.3	151.3	51.5*	0.031
7 MAP	31.6	22.3	27.0	6.5*	0.026	171.1	122.1	146.6	25.7*	0.015
8 MAP	30.2	22.6	26.4	35.1*	0.044	163.3	117.1	140.2	26.4*	0.017
Mean	41.7	26.2	34.0			145.8	105.9	125.9		

	Mumias						Kibos					
N rate	T1	T2	T3	Mean	LSD	P-value	T1	T2	T3	Mean	LSD	P-value
3 MAP	74.3	68.2	94.3	79	25.45	0.102	27	20	35.6	27.5	15.5	0.123
4 MAP	99.3	115.2	96.7	103.7	13.25*	0.025	38.8	36.4	42.8	39.3	11.58	0.476
5 MAP	126.7	146.7	129.5	134.3	20.65	0.111	61.8	41.2	50	51	13.94*	0.026
6 MAP	146.3	166.2	141.3	151.3	22.67	0.078	33.14	28.8	35.36	32.4	6.706	0.132
7 MAP	137.7	152	150.2	146.6	13.61	0.081	26.96	24.66	29.14	26.9	4.766	0.159
8 MAP	135.2	147	138.5	140.3	15.22	0.241	26.44	23.2	29.56	26.4	4.314*	0.028
Mean	120	132.6	125.1	125.9			35.7	29	37.1	33.9		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting, * is significant

Table 26. Time of nitrogen (N) and variety interaction effects on number of tillers at different months after planting (MAP) in Kibos and Mumias

MAP and Time		Kibos KEN 82-216	Kibos KEN 82- 601	Mean	LSD	P-value	Variety		Mumias KEN 82-216	Mumias KEN 82-601	Mean	LSD	P-value
3 MAP	T1	39.4	14.6	27.0	18.2	0.738	3MAP	T1	82.7	66.0	74.4	38.0	0.881
	T2	28.2	11.6	19.9				T2	71.0	65.3	68.2		
	T3	49.0	22.4	35.7				T3	99.0	89.7	94.4		
4 MAP	T1	53.0	24.8	38.9	13.8	0.684	4MAP	T1	113.3	85.3	99.3	17.3	0.36
	T2	48.0	24.8	36.4				T2	123.7	106.7	115.2		
	T3	52.4	33.2	42.8				T3	102.0	91.3	96.7		
5 MAP	T1	64.2	59.6	61.9	23.7	0.483	5MAP	T1	154.7	98.7	126.7	38.9	0.505
	T2	50.4	31.8	41.1				T2	165.0	128.3	146.7		
	T3	58.4	41.8	50.1				T3	157.0	102.0	129.5		
6 MAP	T1	43.0	23.3	33.1	9.1	0.47	6MAP	T1	178.7	114.0	146.4	40.3	0.994
	T2	37.3	20.3	28.8				T2	199.3	133.0	166.2		
	T3	41.5	29.2	35.4				T3	174.7	108.0	141.4		
7 MAP	T1	32.0	21.9	27.0	6.3	0.495	7MAP	T1	158.3	117.0	137.7	21.2	0.524
	T3	30.3	19.0	24.7				T3	177.3	126.7	152.0		
	T3	32.3	25.9	29.1				T3	177.7	122.7	150.2		
8 MAP	T1	31.0	21.9	26.4	6.2	0.612	8MAP	T1	154.7	115.7	135.2	22.5	0.577
	T2	27.2	19.2	23.2				T2	173.7	120.3	147.0		
	T3	32.3	26.9	29.6				T3	161.7	115.3	138.5		
Mean		41.7	26.2	33.9					145.8	105.9	125.9		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

4.6.9 Effect of time of nitrogen application on the number of plants/ha of selected seedcane varieties

Varieties did not show significant variations ($P \leq 0.05$), time of N-rate application had significant effect on plant population on varieties grown at Kibos while in Mumias (Figure 14a and b), time of N-rate application had significant effect on stalk population. N-rate application in the 6th month after planting (T3) recorded a higher number of plants of 10151 at Kibos while at Mumias N-rate application in split (at 3rd and 6th month after planting) recorded the highest plant population of 8567. Kibos recorded a higher average plant population of 8764 compared to Mumias that recorded an average plant population of 8174 (Figure 14c and d). Interaction between variety and time of N-rate application did not have significant effect in plant population at Kibos and Mumias (Table 27). Variety KEN 82-216, recorded a higher average plant population of 9225 than variety KEN 82-601 that recorded an average of 7714 plants per hectre.

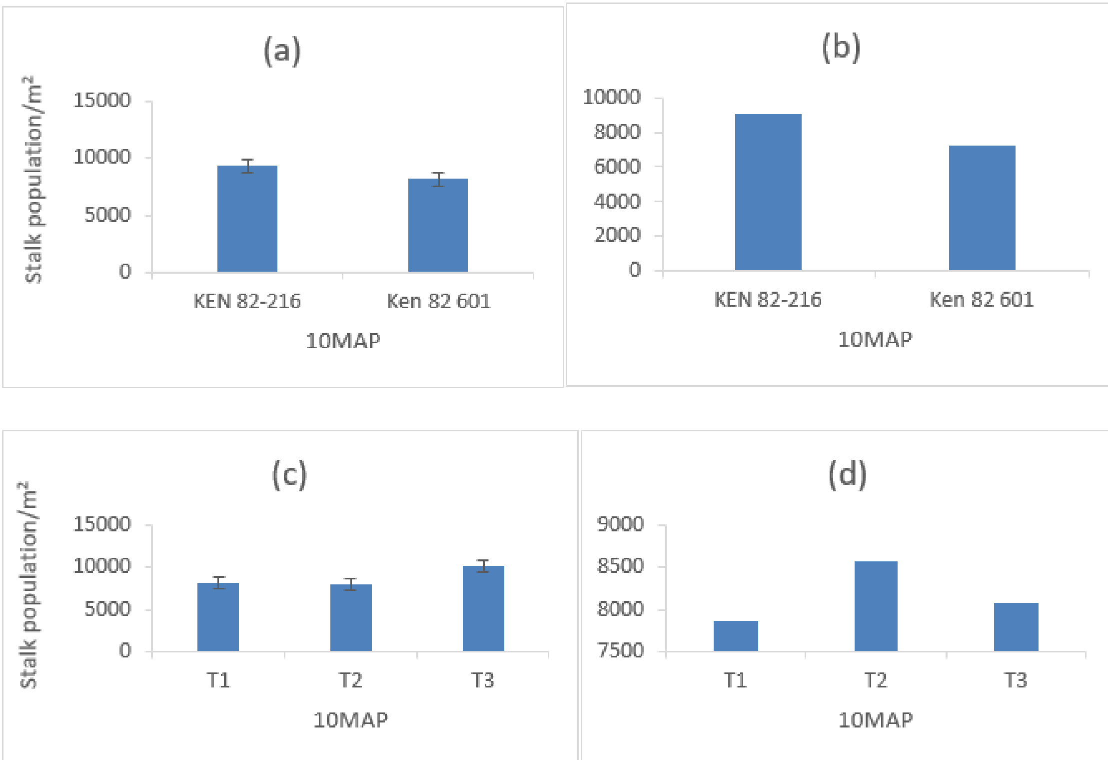

Figure 14. Average dry weight (w/m^2) at Kibos (a) and Mumias (b) and effect of time of N rate on dry weight (w/m^2) at Kibos (c) and Mumias (d) on the varieties. Bars are standard errors of means; T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

Table 27. Time of nitrogen (N) and variety interaction effects on number of tillers in 10^{th} month in Kibos and Mumias

	Kibos			Mumias		
Variety	T1	T2	T3	T1	T2	T3
KEN 82-216	43195.0	46278.0	50820.0	44555.0	46111.0	45778.0
KEN 82- 601	38333.0	33611.0	50694.0	34111.0	39556.0	35111.0
$LSD_{\leq 0.05}$	11147.4			32105.7		
P-value	0.29			0.74		

T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

4.6.10 Effect of time of nitrogen application on dry weight per plant of selected seedcane varieties

Varieties recorded significant variations (P≤0.05) in dry weight in the 10th month at Kibos and 8th and 10th month at Mumias (Figure 15a and b), interactions between variety and time of N-rate application significantly affected dry weight on the 7th month at Mumias while non-significant interactions were recorded at Kibos (Table 28). Varieties at Mumias recorded an average higher dry weight of 448 w/m^2 than varieties at Kibos which recorded an average dry weight of 425w/m^2. Average dry weight increased progressively during the experimental period in both sites recording an average maximum dry weight of 774 w/m^2 at Mumias, variety KEN 82-601 recorded the highest average dry weight of 460 w/m^2 and 501w/m^2 at Kibos and Mumias respectively (Figure 15c and d). N-rate application at T3 (6 months after planting) recorded the highest dry weight of 467w/m^2 at Mumias.

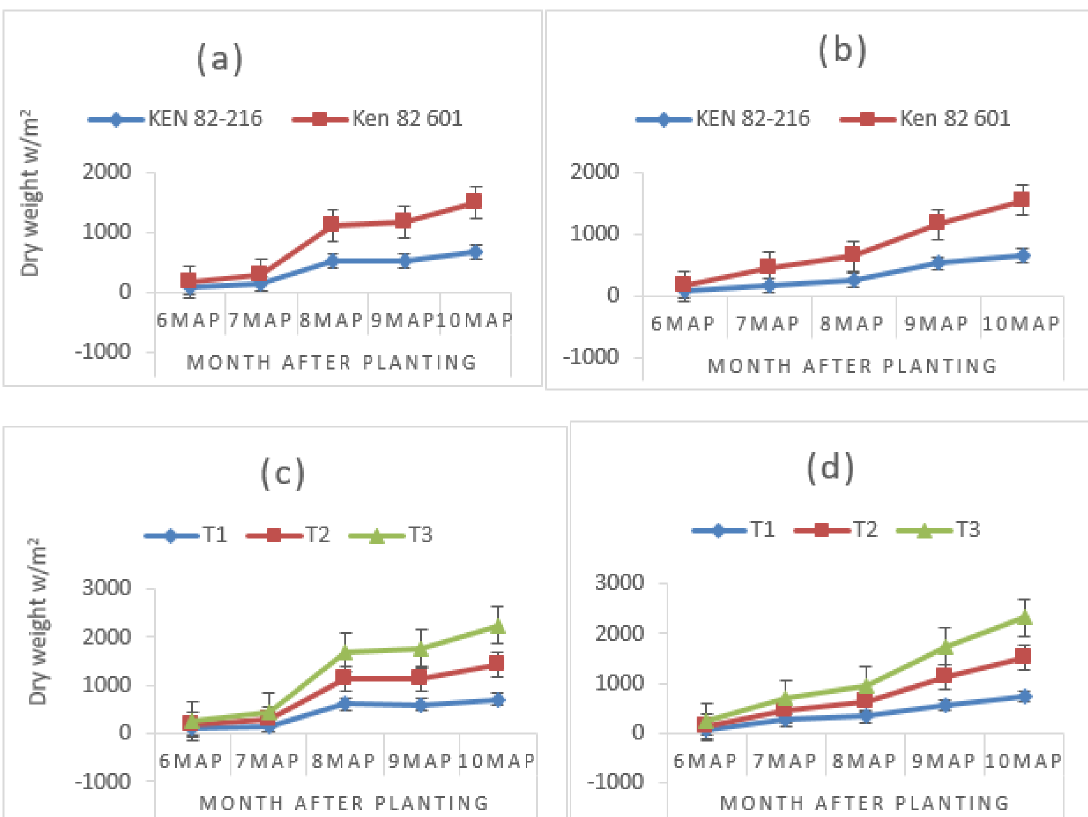

Figure 15. Average dry weight (w/m^2) at Kibos (a) and Mumias (b) and effect of time of N rate on dry weight (w/m^2) at Kibos (c) and Mumias (d) on the varieties. Bars are standard errors of means; T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three

months of planting and second split after six months of planting, T3 is N-rate application after six months of planting.

Table 28. Time of nitrogen (N) and variety interaction effects on dry weight (w/m^2) at different months after planting (MAP) in Kibos and Mumias

		Kibos				Mumias			
MAP and Time		KEN 82-216	KEN 82-601	$LSD_{\leq 0.05}$	P-value	KEN 82-216	KEN 82-601	$LSD_{\leq 0.05}$	P-value
	T1	102.3	82.5	50.7	0.43	67.2	77.6	37.5	0.86
6 MAP	T2	89.8	84.8			59.3	67.2		
	T3	73.7	83.2			95.8	92.9		
	T1	135.3	183.4	77.2	0.30	159.6	363.6	232.7*	0.01
7 MAP	T3	126.3	127.0			192.1	215.7		
	T3	117.3	189.5			165.2	275.7		
	T1	538.0	670.0	254.2	0.41	220.0	459.0	176.4	0.48
8 MAP	T2	571.0	470.0			268.0	347.0		
	T3	498.0	622.0			255.0	386.0		
	T1	517.0	659.0	340.5	0.60	435.0	690.0	240.9	0.21
9 MAP	T2	534.0	542.0			542.0	584.0		
	T3	549.0	723.0			601.0	627.0		
10MAP	T1	637.0	756.0	166.5	0.86	574.0	904.0	179.3	0.23
	T2	639.0	825.0			714.0	835.0		
	T3	746.0	882.0			660.0	960.0		

MAP is Months after planting, N is Nitrogen, T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting, * is significant

4.6.11 Effect of time of nitrogen application on sugarcane yield (t/ha) of selected sugarcane varieties

There were no significant variations (P≤0.05) between the varieties in sugarcane yield in both locations. Variety KEN 82-216 recorded a higher average non-significant sugarcane yield of 29.9 t/ha than variety KEN 82-601 which recorded an average of 25.9 t/ha (Figure 16a and b). Time of N-rate application had no significant effect on seedcane yield in both locations (Figure16c and d). Varieties grown at Mumias recorded a higher average seedcane yield of 33.3 t/ha than those grown at Kibos which recorded seedcane yield of 22.5 t/ha. Split application of N-rate at 3rd and 6th (T2) months after planting recorded a higher seedcane yield of 29.4 t/ha compared to T1 (25.8 t/ha) and T3 (28.6 t/ha). Interactions between varieties and time of N-rate application had no significant effect on seedcane yield in both locations (Table 29).

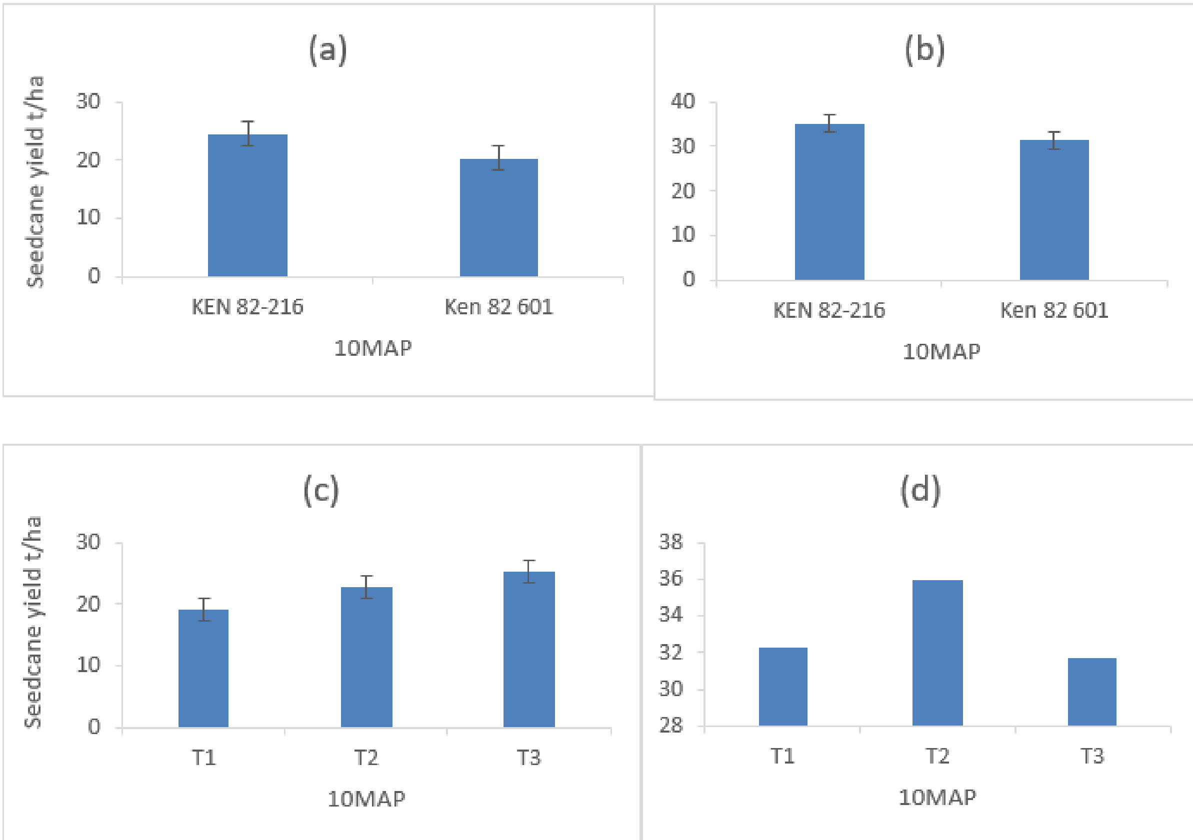

Figure 16. Average seedcane yield (t/ha) at Kibos (a) and Mumias (b) and effect of time of N rate on seedcane (t/ha) at Kibos (c) and Mumias (d) on the varieties. Bars are standard errors of means; T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting, MAP is month after planting

Table 29. Time of nitrogen (N) and variety interaction effects on seedcane yield (t/ha) 10th month in Kibos and Mumias

	Kibos			Mumias		
Variety	T1	T2	T3	T1	T2	T3
KEN 82-216	22.2	29.5	21.9	32.3	35.1	38.1
KEN 82-601	16.3	16.0	28.9	32.3	36.8	25.2
LSD	14.1			9.5		
P-value	0.09			0.14		

T1 is N-rate application after three months of planting, T2 is split application of N-rate, first split after three months of planting and second split after six months of planting, T3 is N-rate application after six months of planting

4.7 Discussion

4.7.1 Crop phenology and growth

Plant height increased gradually during the growing season, reaching a maximum average height of 163 cm and 168 cm in the 10th month at Kibos and Mumias, respectively. Interactions between variety and time of N-rate treatment had a substantial effect on plant height in the tenth month at Mumias, but not at Kibos. Gilbert *et al*., (2006) show that cane plant growth is controlled by a complex of internal and external influences. Soil moisture, temperature, light, soil condition, and nutrient content are the most important essential elements influencing growth. Temperature has a significant impact on sugarcane stem elongation and girth. Moisture and nutrient content, particularly nitrogen, are internal factors influencing sugarcane establishment and growth.

In Kibos, (T3) had a longer internode length than T1 and T2, whereas in Mumias, N-rate treatment in the third month after planting resulted in a greater average interno lenght of 17 cm compared to T2 (16.9 cm) and T3 (16 cm). Significantly longer sugarcane length in T3 at Mumias and T1 was a couse of increased nutrient availability, which increased crop growth rate, resulting in longer internodes and longer canes. Sugarcane plant height was affected by the rate and timing of N fertilizer treatment (Wiedenfeld and Enciso 2008).

The timing of N-rate application had no effect on stem girth in the two kinds, N-rate administration in the third month after planting (T1) resulted in a larger stem girth of 2.4 cm in Kibos compared to T2 (2.2 cm) and T3 (2.3 cm). Interactions between N-rate treatments and variety had no influence on stem girth in either experimental site. Maximum cane girth in T1 (3 months after planting) could be attributed to the availability of adequate nutrition during cane formation, resulting in a faster crop growth rate. Similar results were found by Bangar and Sharma (1992) and Shafshak *et al*. (2001), who acquired maximum cane girth at greater NPK doses administered early in growth.

4.7.2 Leaf area and leaf greenness

At Kibos, N-rate application at the sixth month (T3) resulted in a greater leaf area index of 5 cm^2 than N-rate treatment at T1 (three months after planting) and T2 (split application at 3rd and 6th months), after 3 months of planting, N-rate application resulted in a high leaf area of 6.4 cm^2 at Mumias, compared to T2 (6.2 cm^2) and T3 N-rate applications (6.1 cm^2). Kibos had a high leaf area index of 6.2 cm^2 in the ninth and tenth months and a low leaf area index in the third month, whereas Mumia had a high leaf area index of 9 cm^2 in the ninth and tenth months and a low leaf area index of 2.4 cm^2 in the third month. The leaf area index at Kibos in the fifth month was significantly affected by interactions between varieties and timing of N-rate application.

The timing of N-rate application altered chlorophyll content significantly in the 10th and 5th months at Kibos and Mumias, respectively, at Kibos and Mumias, N-rate treatment at the sixth (T3) and third (T1) stages resulted in significant chlorophyll content. Interactions between varieties and timing of N-rate application in the seventh month had a substantial effect on chlorophyll concentration at Kibos, but not at Mumias. This could account for the observed disparities in location, when compared to the split application of N-rate and application in the 6th month after planting, the N-rate treatment in the third month produced a high average number of leaves of 40 per plant.

4.7.3 Yield components and yield

Variety KEN 82-216 had 146 tillers on Mumias and 42 on Kibos, which was much more than KEN 82-601, which had 101 tillers on Mumias and 26 tillers on tillers, respectively. The application of N-rate had a substantial effect on the number of tillers in the fourth month at Mumias and the fifth and eighth months at Kibos. Mumias had a significantly higher average number of tillers at the time of N-rate application (126 tillers) than Kibos, which had an average of 34 tillers. These findings agree with those of Reghenzani *et al.,* (1996), they discovered that timing N treatment to coincide with conditions optimum for plant uptake can positively influence N uptake of the standing seed cane plant to store maximum food reserve for the following commercial crop performance measured in terms of stalk population. Although the quantity of developing tillers per stool varies with variety and growing conditions, inorganic fertilizer application is one of the most important elements influencing sugarcane tillering (Sundara, 2000).

N-rate application in the sixth month after planting (T3) resulted in a higher number of plants per hectre (10151) at Kibos, while N-rate application in split (at the third and sixth months after planting) resulted in the largest plant population (8567) at Mumias. The more millable canes with greater N levels may be owing to the availability of nutrients sufficient to meet the cane's requirements per unit area. Kolage *et al*., (2001) and Sinha *et al*., (2001) both found an increase in the number of millable canes per unit area

when the N dose increased (2005). Mengsitu (2013) discovered comparable results in sugarcane, recording a large number of stalks and a 51% rise in N-rate application in the fifth month.
Significant differences in dry weight were seen in the 10th month at Kibos and the 8th and 10th months at Mumias. Interactions between variety and time of N-rate administration had a substantial effect on dry weight on the seventh month at Mumias, but were non-significant at Kibos. During the testing period, average dry weight climbed steadily in both sites, with Mumias recording an average maximum dry weight of 774w/m^2. N-rate treatment at T3 (6 months after planting) resulted in the maximum dry weight of 467w/m^2 at Mumias.

Split N-rate treatment three and six months after planting led in a greater sugarcane production of 29 t/ha than T1 (26 t/ha) and T3 (28.6 t/ha), in either location, interactions between cultivars and timing of N-rate delivery had no effect on seedcane production. This finding agrees with Dereje *et al*., (2016), who found that timing of application and the interaction of blended fertilizer rate and time of application had no influence on sugarcane output. The fertilizer rate had a substantial influence on stalk girth and height but had no effect on sugarcane production, in agreement with this observation, Shrivastava (2006) said that cane yield is determined by around 70% of cane population, 27% of cane length, and a 3% of cane girth. According to Jiang (2004), sugarcane output per unit land is made up of sugarcane population and cane weight.

4.8 Conclusion

This study recorded non-significant interactions between time of N application and sugarcane varieties. Under the condition of the present study, split application of N-rate at 3rd and 6th (T2) months after planting recorded a higher seedcane yield of 29 t/ha compared to T1 (26 t/ha) and T3 (27 t/ha) is suitable for plant which could produce the highest sugar yield, variety KEN 82-216 recorded a higher average seedcane yield of 29.9 t/ha than variety KEN 82-601 which recorded an average of 26 t/ha, thus, variety KEN 82-216 can be adopted by farmers.

CHAPTER 5: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

The results on Chemical properties of soils from two experimental sites reports indicates that soils are strongly acidic and low in potassium (K), Carbon %C and deficiencies of N, leading to low and declining crop yields, they are indicators of low soil fertility which is a factor for declining sugarcane yields in Kenya as indicated by (Odendo *et al.,* 20110; Odhiambo, 1987), low soil fertility could be attributed to loss of nutrients through erosion and harvesting of crop without nutrient replenishment (Gachene *et al.,* 2000).Similler findings were also reported in the Australian sugar industry which show that yield decline is associated with soil degradation because of sugarcane monoculture (Bramley *et al.,* 1996).It is possible that the lower yields observed in the treatments were as a result of continuous monoculture.

The investigation from the study show that KEN 82-216 has better germination ability than KEN 82-601, depending on genetic differences. The most essential component of yield is the number of tillers per unit area the more tillers there are especially fruitful tillers the higher the yield the higher number of tillers, in this study could be linked to the availability of nitrogen which was essential for cell division. In general, the number of tillers grew as the N-rate increased, with the largest number recorded at 120 kg/ha N. From the third to the eighth MAP, there was a steady increase in chlorophyll content in both kinds, which was followed by a drop in the ninth and tenth MAP. The drop in SPAD value in the ninth and tenth months could be attributed to N transfer from leaf to stem. The leaf area index grew in the months coming up to maturity as N-rate application increased.

The increase in leaf count as a result of N-rates treatments might be related to appropriate N nutrition, which could be explained by an improvement in the plant's nutrient mining capability as a result of greater root development and enhanced carbohydrate translocation from source to growing sites in well-fertilized plots. N-rate treatments had no noticeable influence on plant height, the rise in plant height in response to N fertilizer application is most likely owing to increased nitrogen availability which increased leaf area resulting in higher photosynthetic rates and thus more dry matter accumulation. The response of each variety to N-rate application was time and site dependent due to the varying agro-ecological circumstances at each location and time.

The N-rate treatments had no influence on the internode length of the two types studied, internode length was not affected by interactions between variety and N-rate. The interaction of varieties and N-rates had little influence on stalk girth, drought that occurred throughout the manufacturing period may have contributed to the uniform effect reported at both sites. In Mumias, there was a considerable influence on the stalk population, however in Kibos, there was no significant effect, increased N-rate resulted in a high stalk population of 10151/m^2 at Mumias at 120 kg N/ha compared to 60 kg/ha N. A 120 kg/ha N N-rate resulted in a high cane yield of 25 t/ha at Mumias, compared to 19t/ha (control) and 22.8 t/ha (60 kg/ha N). Higher stripped cane yield at higher nitrogen levels, notably in Mumias, was ascribed to greater cane length, cane girth, and cane stalk number.

The best N rates and times to apply it depend on the soil, weather, and cropping techniques, in crop plants, leaves are the principal sites of photosynthesis and a result one can suppose that the more leaves a crop has the greater the interception of sunlight and the larger the plant production. After 3 months of planting a high N-rate application resulted in a high leaf area of 6.4 cm^2 compared to N-rate applications at T2 (6.2 cm^2) and T3 (6.1 cm^2). The chlorophyll concentration was high in the N-rate applications at 6th (T3) and 3rd (T1), the interaction of cultivars and the timing of N-rate application in the seventh month had a substantial effect on chlorophyll concentration at Kibos. A crossover interaction occurs when cultivar ranks vary from one environment to another, resulting in a variable response of cultivars to multiple settings and this could account for the observed disparities in location. Significantly longer cane length in T3 at Mumias and T1 was attributable to increased nutrient availability, which increased crop growth rate, resulting in longer internodes and longer canes. When compared to the split application of N-rate and application in the 6th month after planting, the N-rate treatment in the third month produced a high average number of leaves of 40 per plant. The interactions between N-rate treatments and varietals had little influence on stem girth, maximum cane girth in T1 (3 months after planting) could be attributed to the availability of adequate nutrition during cane formation hence resulting in a faster crop growth rate.

Plant height is an important factor in growth and yield, plant height increased gradually across the growth season with a maximum average height of 166 cm observed in the tenth month. Tiller density or population as well as biomass output are essential crop factors used to estimate final cane stalk population and sucrose yields, it is the most critical component determining overall crop stand and as a result in cane production. The timing of N-rate application had a substantial impact on the quantity of tillers in the fourth month at Mumias as well as the fifth and eighth months at Kibos. N-rate application in the sixth month after planting (T3) resulted in a higher plants per hactre of (10151) at Kibos, while N-rate application in split (at the third and sixth months after planting) resulted in the largest plants per hactre of (8567) at Mumias. The more millable canes with greater N levels may be owing to the availability of nutrients sufficient to meet the cane's requirements per unit area. Sugarcane yield was 29.4 t/ha when N-rate was administered at the third and sixth (T2) months after planting which was greater than T1 (25.8 t/ha) and T3 (28.6 t/ha). The fertilizer rate had a substantial effect on stalk girth and height but not on time of application, indicating that it had made a major difference in cane output. As a result, cane yield was determined by cane population, cane length, and cane girth.

5.2 Conclusions

Appropriate and timely application of nitrogen fertilizer promotes the growth and sugarcane yield. Under the condition of the present study, split application of N-rate at 3rd and 6th (T2) months after planting at a rate of 120 kg/ha recorded a higher sugarcane yield of 29.4 t/ha compared to T1 (25.8 t/ha) and T3 (28.6 t/ha) is suitable for plant which could produce the highest sugar yield. Variety KEN 82-216 recorded a higher average sugarcane yield of 29.9 t/ha than variety KEN 82-601 which recorded an average of 25.9 t/ha, thus, variety KEN 82-216 can be adopted by farmers.

5.3 Recommendations

1. Variety KEN 82-216 that recorded a high agronomic performance and cane yield could be recommended for adoption by small scale and large scale farmers.

2. Further research is required on variety KEN 82-216 to establish its adaptability to acidic conditions which are known to arise due to intensive use of nitrogenous fertilizers during its production.

3. Evaluation of the sucrose quality is required to identify the impact of nitrogen on the sucrose quality of the variety.

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APPENDICES

Appendix: Pictures

Picture 1

Counting the number of stalks

Measuring the leaf height

Picture 2

Leaf area index length and width of the leaf

Picture 3

Identified cane stalk for taking parameters per net raw

Picture 4

Calbrated tins for Fertilizer application at 3MAP and the application process

Picture 5

Chlorphyll reading

Picture 6

Sample collected, wet weighted, oven dried and weighted foe dry mass

Picture 7

Harvesting and weighing of net plots for t/ha