EFFECTS OF NITROGEN FERTILIZER ON YIELD AND QUALITY OF INTRODUCED SUGARCANE (*Saccharum officinarum* L.) VARIETIES IN COMMERCIAL FIELDS AT KILOMBERO, MOROGORO REGION

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ABSTRACT

Nitrogen deficiency and planting low yielding varieties are common problems at Kilombero Estate mill area, and are known to be the major causes of yield decline. An experiment was laid out in split plot in a randomized complete block design (RCBD) with three replications to evaluate the effect of N- fertilizer on yield and quality of introduced varieties in the commercial farms at Kilombero sugar estate during the 2015/16 season. The main plots were varieties and the sub plots were N-fertilizer rates. Tested varieties were N41 (at first ratoon crop), R 579 (at third ratoon crop) and N25 (at fourth ratoon crop). Each variety was applied with different N-fertilizer rates as urea fertilizer. The compared rates were 0, 150, 200, 250, 300, 350, 400 and 450 kg N/ha. Results indicated that N had an effect on yields of cane and sugar (t/ha) quality except purity, pol % and sucrose %. There was an increase in yield of cane and sugar, plant leaf nutrients concentration and plant nutrients uptake with increased N-rates. Variety N 41R1 had highest N utilization efficiency, nutrient removed, yield and quality followed by R 579 R3 and finally N 25 R4. Highest average yields of cane and sugar (t/ha) were found with 400 kg N/ha followed by 350 and 300 kg N/ha, then declined at 450 kg N/ha. Effect of N application was significant ($P < 0.001$) on cane and sugar yields. Differences were not significant between N-rates on quality parameters of pol, sucrose and purity percentage cane. The interaction of N41R1 x N fertilizer rates of T7, T6, T5, T4 and R 579 R3T7 had higher yields of cane and sugar followed by interaction of R 579 R3 x N -fertilizer rates of T6 and T5, while the least yield was with N25 R4 x N fertilizer rates of T7, T6 and T5. Development of soil specific nutrient management guidelines for the Kilombero farms is vital so as to recommend optimum fertilizer application levels on introduced sugarcane varieties to ensure profitability, net benefits, cane (t/ha), total benefit and total variable costs were significantly and positively correlated among themselves. The benefit cost ratio was negatively correlated with the other economic variables but significantly so with all except net benefit. Most of the cane yield components and nutrients removal were significantly and positively associated. It is concluded that N-fertilizer rates of 300-400kgn/ha should be used for sugarcane production at Kilombero. A combination of N41 RI was superior in most of sugarcane quality and yield variables. The interactions between variety-ratoon with N-fertilizer rates suggest that N-rates have differential effects of variety-ratoon combination. The highest benefit cost ratio was not necessarily associated with higher net benefit.

Keywords: Nitrogen fertilizer, sugarcane ratoon crop, variety, yield and quality.

DECLARATION

I, George Mwasinga, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other Institution.

George Mwasinga   Date
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The above declaration is confirmed by;

Prof. S.W.O.M. Reuben   Date
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Prof. A.J.P. Tarimo   Date
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ABBREVIATIONS AND SYMBOLS

EASDP	East African Sugar Development Project
IPNI	International Plant Nutrition Institute
K	Potassium
KSC	Kilombero Sugar Company
N	Nitrogen
OECD	Organization for Economic Co-operation and Development
P	Phosphorous
SBT	Sugar Board of Tanzania
TCH	Tons of cane per hectare
Tsh	Tanzania shillings
TSH	Tons of sugar per hectare
VAT	Value added tax

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Sugar is an important dietary ingredient in Tanzania. Its consumption is becoming more and more popular in rural areas where most people live, as compared to the past when it was consumed mainly in urban areas (SBT, 2015). Official estimates by the Sugar Board of Tanzania (SBT, 2006) gave a total demand by 2015/16 as 831 000 tons and per capita consumption of 20.5 kg per annum. Sugar is one of the most valuable products of the plant worldwide. It is a necessary food for human and provides energy (Saleem *et al.*, 2012).

Sugar is also used in the manufacture of alcoholic beverages, soft drinks, ice-creams, chocolates, canning industry, etc. Other sugar processing industry products such as molasses and bagasse are very important. Molasses is an important byproduct of the sugarcane industry, which is used as a livestock feed, and preparation of rum, industrial alcohol, vinegar and glycerol (Hogarth and Allsopp, 2000). The molasses are also used in cooking and candy making, and sometimes used as manure. Bagasse is used as fuel in sugar mills. It is also used for paper making and as an ingredient of fiber boards (EASDP, 2013).

The major problem facing the sugar industry in the country is the gradual decline in the sugar yield due to low cane yield per unit area. This is linked to lack of proper fertilizer management practices and planting low yielding varieties in sugarcane commercial farms (Maro, 2004). The current fertilization practices does not take into consideration the potential of the native soil in supplying mineral N, the varietal differences in N-fertilizer use efficiency and percentage recovery of the nutrients harvested in sugarcane crops (Isa, 2004).

1.2 Sugarcane Production at Kilombero Sugar Company

Sugarcane is the only crop grown by the Kilombero Sugar Company. Total area under cane production is 23 000 ha, with Kilombero Sugar Company farming 10 000 hectares, 65 % of which is under irrigation program (KSC, 2015). The out-growers handle the remaining 13 000 hectares (SBT, 2016). Total cane production for both independent out growers and estates in the 2012/13 crop season, was around 1.3 million tones, almost ten times of the 150 000 tons at privatization in 1998. The company records high production of 725 000 tons, while sugar production in the 2012/13 season reached the record low of 130 000 tons (KSC, 2015).

Among the strategies advocated for improving sugar yield include the use of better sugar varieties, improvement of soil fertility in general and in particular the efficient use of N-fertilizers (SBT, 2014). Nitrogen is inadequate and imbalanced in commercial fields at Kilombero due to intensive cropping system, exhaustive crop rotation and the introduced high-yielding varieties with high-nutrient requirements (Maro, 2004). Improved sugarcane varieties requires higher rates of fertilizer than recommended rates with better N-fertilizers use efficiency by optimizing the rates and timing of N-fertilizer application (Isa, 2004). However, N is still the most limiting nutrient in all farms at Kilombero estate (SBT, 2016).

1.3 Problem Identification and Justification

1.3.1 Africa sugarcane production

In terms of production shares, 50.16% of African sugar is produced in South Africa, 14.48% in East Africa, 9.96% in Central Africa and 25.4% in North Africa (SBT, 2016). Global annual sugar consumption was running at about 170 556 million tons during 2015/2016 season and is increasing at a rate of the about 16.6 million tons per annum.

However, most sugar is consumed within the country of production and only approximately 25% is traded internationally (SBT, 2015).

1.3.2 Sugar production in Tanzania

Tanzania lies in the tropics where sugarcane is grown with a total annual average sugar production of 300 000 tons, while domestic sugar import is more than 15 tons, industrial sugar import is more than 101 528 tons, sugar export is about 9 000 tons and local consumption is more than 511 379 tons (EASDP, 2013). Sugar domestic demand for sugar for direct consumption stands at 400 000 tons annually against the domestic production capacity of 320 000 tons, giving a deficit of 80 000 tons. Industrial users in Tanzania also require 80 000 tons of refined sugar. Tanzania's sugar demand exceeds the sugar currently supplied domestically (SBT, 2016).

Sugar production in Tanzania is low due to low production per unit area of the crop, inadequate utilization of appropriate agronomic technologies (SBT, 2006). Sugarcane is a tropical plant and requires warm, humid climate for good growth, it is grown in a wide variety of soil types ranging from sandy loam to heavy clay (Hogarth and Allsopp, 2000). A number of factors are responsible for low yield of sugarcane in Tanzania including low soil fertility, use of low yielding varieties, use of poor agronomic practices, insufficient irrigation water, higher cost of farm establishment, disease and pests infestations (Azzazy and El-Geddawy, 2003).

1.3.3 Sugarcane production at Kilombero Sugar Company

Kilombero Sugar Company in the season 2015/16, had an average yield of 78 cane tons per hectare which was still low under irrigated fields which had the average yields of 100 to 150 t/ha (SBT, 2016) resulting to low total yields as shown in Fig.1. A number of factors were responsible for low yields of sugarcane and sugar production at Kilombero, but the major factor of yield decline is inability of newly introduced commercial varieties to maintain original yield levels after a few years which is associated with low soil fertility in commercial farms (Maro, 2004).

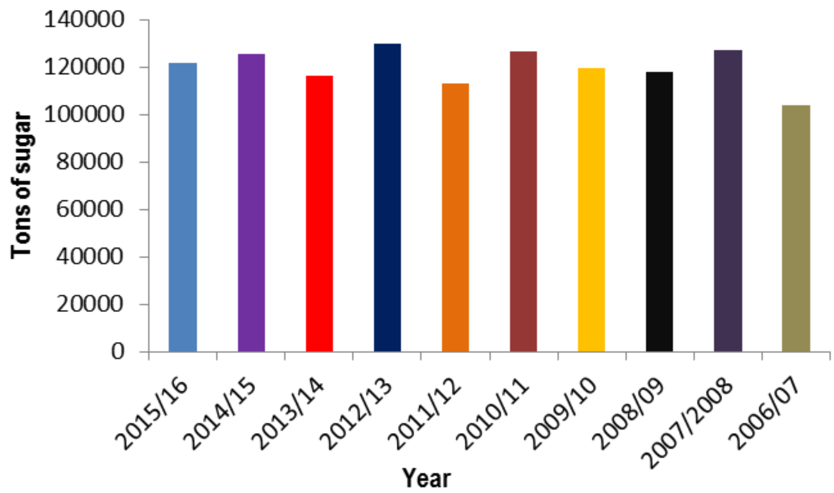

Figure 1: Sugar production trend at Kilombero from 2006/07 to 2015/16

Source: SBT (2016)

1.3.4 Sugarcane production constraints at Kilombero Sugar Company

The major problems facing sugar production at Kilombero are mainly declined soil fertility, planting low yielding sugarcane varieties, use of poor agronomic practices, prevalence of pests and climatic factors (Maro, 2004). The decline in sucrose content of cane is the major complaint at Kilombero Sugar Company (EASDP, 2013). Sugarcane variety sucrose content is regularly recorded below the level of benchmark of ten percent, which negatively affects their price, as the producer price is adjusted for sucrose content (KSC, 2015).

Sugarcane is a long duration crop that requires a high quantity of nutrients. Continuous planting of sugarcane in the same field depletes the soil nutrients (Jagtap, 2006). Among these elements, N is the primary nutrient limiting sugarcane production in commercial fields (Lashmi *et al.*, 2003). The longer span of sugarcane growth and introduction of high yielding varieties in commercial fields with high-nutrient requirements presents different challenges for efficient N-fertilizers use (Hogarth and Allsopp, 2000). A crop having a yield of 100 t/ha removes 207 kg N, 30 kg P_20_5 and 233 kg K_20 from the soil (Jagtap, 2006). These elements must be added in adequate quantities to the crop in order to obtain higher yields (Saleem *et al.*, 2012). This study was initiated to investigate the effect of nitrogen application on cane yield and quality of introduced sugarcane varieties at Kilombero.

1.4 Objectives

1.4.1 Overall objective

To identify optimum N- fertilizer rates for the introduced sugarcane varieties at Kilombero Sugar Company Farms.

1.4.2 Specific objectives

i. To determine components of sugar yield and quality variations among the selected varieties in the commercial farms.

ii. To determine the interaction effects of varieties and N-fertilizer on yield and yield components, including sugar quality.

iii. To determine economic benefits of N-fertilizer application in sugarcane production in the commercial farms.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Yield Decline in Sugarcane Commercial Fields

Yield decline is an issue that has plagued sugarcane production systems in Tanzania for many years. Initially, yield decline was regarded as an apparent decline in the productive capacity of cane varieties due to genetic deterioration (Garside *et al.,* 2003). In recent years, however yield decline has been clearly associated with soil fertility decline caused by the long-term monoculture of sugarcane production (Isa, 2004). Maro (2004) reported that factors such as long-term monoculture, uncontrolled traffic from heavy machinery and excessive tillage along with practices that deplete organic matter contents contribute to yield decline.

Soils at Kilombero Sugar Company have low organic matter content of 1-2 % leading to deficiencies of nitrogen and other nutrient elements (KSC, 2015). Earlier studies revealed that, nitrogen is the most limiting nutrient for sugarcane production at estate fields as the land has been under sugarcane monoculture and heavily mechanized using irrigation for most of the growing period (Maro, 2004).

2.2 Nitrogen Fertilizer Application in Sugarcane Crop

Sugarcane consumes more nutrients than inherent nutrients present in the soil. Thus, fertilizer application is very important for better production of cane and sugar yields (Horgath and Allsopp, 2000). Nitrogen is usually applied on the cane stools three months after planting or emergence on both planted cane and ratoon crops. In cultivated ratoons, fertilizers are subsurface (buried) applied in the soil in a band on each of side of the cane row in blocks that are mechanically cultivated after burnt harvest to overcome volatilization losses (Isa, 2004).

2.3 Influence of Nitrogen Fertilizer on Cane and Sugar Yield

Nitrogen is a building block of plant proteins. It is an integral part of chlorophyll and is a component of amino acids, nucleic acids and coenzymes (Hogarth and Allsopp, 2000). Most nitrogen in the soil is tied up in organic matter. The plant available forms of nitrogen are ammonium-N (NH_4-N) and nitrate-N (NO_3-N) (Isa, 2004). Soil concentrations of NO_3-N and NH_4-N depend on many factors including organic matter content, soil pH, biological activity and therefore fluctuate with changes in soil conditions such as temperature and moisture. Nitrate is easily leached from the soil with high rainfall or excessive irrigation (Saleem *et al*., 2012).

Nitrogen is the most essential element having direct effect on cane growth, sugarcane yield, and juice quality. Nitrogen increases the quantity of green tops (Garside *et al*., 2003), yield components, and yield of cane and sugar (Azzazy and Elgadaway, 2003). However, nitrogen application at rates exceeding (sugarcane) plant utilization has adverse effect on cane quality (Isa, 2004). Due to the introduction of high yielding varieties with high nutrient requirements, sugarcane requires higher rates of fertilizer than the currently recommended rates (Garside *et al.*, 2003).

Only about one third of the nitrogen applied as fertilizer to sugarcane crop is utilized by crop in the year of application. This nitrogen is supplied in the annual fertilizer application and by the mineralization of organic nitrogen reserves, including the nitrogen in crop residues (Isa, 2004).

Recommended nitrogen rates based on farm yield variations to the broad recommendations takes into account yield expectations, soil properties, vigorous sugarcane varieties and irrigation (George *et al*., 2015). High nitrogen rates applied towards the end of the grand period of growth normally result in lower sucrose contents which will then promote diversion of dry matter to growth rather than to storage (Isa, 2004).

The most profitable type and amount of fertilizer to use depends on crop, soil, climate, economic and management factors (Yousef *et al.,* 2000). The actual amount of N applied depends on these factors plus the personal experiences or knowledge of the farmer. It is important to establish the fertilization regimes that optimize growth with minimum nutrient leaching. These involve adjusting fertilizer application rates and frequencies to maximize N uptake while minimizing N leaching from the rooting zone (Isa, 2004).

The nutrient uptake of sugarcane per ton of cane yield are: 0.7 – 1.2 kg N, 0.4 – 0.8 kg P_2O_5 and 1.8 – 2.5 kg K_2O, while the optimum leaf nutrient concentration levels are: 2–2.30% N, 0.2–0.24% P, 1.1–1.3% K, 0.2–0.3% Mg, 0.8–1.0% Ca, 0.25–0.30% S, 9–30 ppm B, 8–10 ppm Cu,100–250 ppm Mn, 200–500 ppm Fe and 25–50 ppm Zn (IPNI, 2016). Common types of single inorganic fertilizers with their nutrient composition used in crop production are: Nitrogenous fertilizers which are Ammonium nitrate (34%), Ammonium sulphate nitrate (26%N), Calcium ammonium nitrate (26 %N), Calcium nitrate (16%N), anhydrous ammonia (82 % N), Sodium nitrate (16 % N) and Urea (46 %N). Phosphate fertilizers are Single superphosphate (18 % P_20_5) and triple superphosphate (46% P_2O_5), Potassium fertilizers are Potassium chloride or Muriate of potash (60-62 % KCl), Potassium nitrate (44-46% KNO_3) and Potassium sulphate (50-53% K_2SO_4) (Isa, 2004).

Under different environments, sugarcane recommended nutrient dose of 250-300 kg N + 80-100kg P_2O_5 + 125-250kg K_2O per ha, can yield cane ranging from 100 to 250 t/ ha with sugar yield ranging from 10 to 25 t/ ha. Plant cane crop applied with 300:100:200 kg N, P_2O_5 and K_2O per ha had a cane yield ranging from 70 to 135 t/ ha, with sugar yield ranging from 7 to 13.5 t/ ha, while ratoon crop applied with 300 + 25% extra N: 100:200 (kg N,) P_2O_5 and K_2O per ha had a cane yield ranging from 135 to 300 t/ ha, with sugar yield ranging from 13.5 to 30 t/ ha (IPNI, 2016).

2.4 Influence of Soil Water on Nitrogen Requirement in Sugarcane Production

Nitrogen nutritional needs of the cane crop are typically met by the application of N-fertilizer and water that plays important role in enhancing yield and quality (Muchovej and Newman, 2004). Environmental factors such as moisture availability do influence the amount of soil N utilized by sugarcane. Availability of water is an important factor causing variation in sugarcane yield and juice quality (KSC, 2015).

Water is the key to sugarcane growth, development and subsequent conversion of recoverable sugar to sucrose. The amount of water utilized by cane plant has a linear relationship to total dry matter produced (Yahaya *et al.*, 2008). A favorable soil water condition during cane growth also has a significant effect on the yield and quality response of sugarcane to nitrogen fertilization (Yousef and Taha, 2003). Sugarcane also shows high response to N application, it can utilize 4 to 7 kg N /ha per day during its rapid growth period (Hogarth and Allsopp, 2000). A substantial amount of N fertilizer is necessary for commercial sugarcane production due to large biomass produced by the crop. However, as harvest time approaches it is desirable to have much of the soil N depleted (Isa, 2004). In addition, juice quality may be reduced by excess N application (Saleem *et al.*, 2012). Higher N levels coupled with adequate water causes more vegetative growth which result in the conversion of sucrose to simple sugars and use them for growth compared with lower N rates (EASDP, 2007). N application can provide the highest Water Use Efficiency (WUE) and would increase yield. If such options are implemented, sugarcane production costs could be lowered and water loss to the environment through evaporation, runoff, and drainage could be minimized. Isa (2004) reported that both cane and sugar yields significantly increased with increased water and N application levels.

Meeting the nutrient and water requirements of sugarcane effectively makes the crop flourish and yields profitably (Fig. 2, Appendix 10). Irrigated sugarcane is usually dried off prior to harvesting (Yahaya *et al*., 2008). This practice generally results in increased sucrose content in the cane stalks. However, it is essential that sucrose percentage dry matter should be used for monitoring ripening during the drying off period to ensure that that increase of sucrose content is not solely attributed to desiccations (Azzazy *et al*., 2000). The young sugarcane plant, given excessive N and water, induce vigorous vegetative growth but stores little sugar. After vegetative growth stage, the growth rate subsides and more sugar is stored in the stalks (Yousef and Taha, 2003). As sugarcane approaches its normal harvesting period, its moisture and N level drops its reducing sugar are converted to sucrose. Too much water and N at this stage have detrimental effects, in such that it delays maturity of sugarcane, affect the quality of cane juice and sometimes causes lodging of the crop (Isa, 2004).

Figure 2: Sugarcane under irrigation at Kilombero by the use of drag line

Source: KSC (2015)

2.5 Importance of Nitrogen Evaluation at Growth stages

Nitrogen increase sugar yield, but has to be balanced to ensure good plant growth without leading to excessive uptake which delays maturity, reduces sugar levels and resulting in off-white sugar color (Hogarth and Allsopp, 2000). Nitrogen requirement for sugarcane is higher at grand growth stage. This is required for adequate cane stalks formation and canopy development (Tarimo and Takamura, 1998). Tillering of sugarcane commences around 30 to 45 days after planting (OECD, 2016). Therefore, adequate N-fertilizer supply should be available to the crop in the soil from formative phase (Fig. 3), because crop requirement for N-fertilizer is higher in early grand growth period (IPNI, 2016). This enhances cane formation and promotes better cane growth and development (McCray and Mylavarapu, 2013). Application of more N-fertilizer at active crop growth period not only promotes late cane stalks formation, but also affects sugar recovery due to reduced sucrose percentage, increase in soluble N-fertilizer in juice, water and side shoots formation (Hogarth and Allsopp, 2000).

Nitrogen evaluation is mostly done at three to six months of plant growth and development to check if it is insufficient or sufficient (Rice *et al.,* 2010). The optimum time of N-fertilizer application is during initial stages of crop growth. Therefore, sufficient N-fertilizer must be made available in the soil during grand growth stage (OECD, 2012).

Cane maturity is usually determined by monitoring sugar yield parameters such as pol and brix cane percentage (EASDP, 2007). However, most cane growers focus their evaluation on pol cane percentage and its value ranged from 10-17. In milling operations, the preferred varieties are those with pol cane and brix cane percentage values nearly equal at maturity, and a pol value of 16 or greater and purity of 80 % or greater are commercially acceptable (Hogarth and Allsopp, 2000).

Optimum productivity of sugarcane cropping system depends on an adequate supply of the essential and beneficial plant nutrients from the soil or growth medium. When the soil is not capable of supplying sufficient amounts of N nutrient for normal plant growth and development, application of supplemental nutrients to the soil in the form of inorganic is mandatory (Hogarth and Allsopp, 2000). The amount of supplemental nutrients to be applied to the soil is determined by the nutrients requirement by the sugarcane crop cycles and the nutrient supply power (nutrient contents and availability) of the soil (Isa, 2004). Diagnostic techniques that are used to determine and assess the nutrient supply of the soil includes the identification of the plant nutrient deficiency symptoms, plant material (tissue) analysis, soil analysis (tests) and the extent of growth of sugarcane crop (McCray and Mylavarapu, 2013).

Soil fertility evaluation involves the assessment of the ability and capacity of a soil to supply the nutrients required by plants for optimum growth and development. The evaluation is based on the qualitative and quantitative data and information generated by the aforementioned diagnostic techniques (Hogarth and Allsopp, 2000).

Figure 3: Sugarcane at grand growth stage

Source: KSC (2015).

2.6 Complexity of Nitrogen Availability to Sugarcane Crop

Nitrogen fertilizer recovery by sugarcane is comparatively low and ranges from 20 to 40% with up to 65% of applied N-fertilizer lost from the sugarcane soil system. These losses occur via several pathways including nitrate leaching, ammonia volatilization, and gaseous emissions through microbial conversion of ammonium and nitrate (Isa, 2004). Nitrate is 5 to 10 times more mobile in soils than alternative N sources like ammonium and amino acids (IPNI, 2016). Nitrification rates are generally high in sugarcane commercial farms (EASDP, 2007). Sugarcane has a preference for ammonium and a low capacity to use nitrate during periods of high N availability, and that discrimination against nitrate contributes to the pronounced accumulation of nitrate in the soil and subsequent N losses (Hogarth and Allsopp, 2000).

Nitrogen fertilizer uptake by sugarcane is a key constituent of the global N cycle, as N-fertilizer captured by roots has a markedly different fate than N-fertilizer remaining in the soil (Hogarth and Allsopp, 2000). The success or failure of sugarcane to capture N-fertilizer in the root zone has implications not only for crop growth and yield but also for losses of reactive N-fertilizers from agro-ecosystems through leaching, runoff and emission as nitrogenous gases (Saleem *et al.,* 2012).

The N- fertilizers are applied annually to sugarcane crops, which are either captured or remain in the soil or lost to the environment. This inefficiency is of global concern, and requires innovation based on improved understanding of how N-fertilizers are transformed in soils and how N transformations affect N-fertilizers uptake by crops (IPNI, 2016).

Nitrogen fertilizers are considered to be the main N source for sugarcane, largely due to their prevalence in agricultural soils. The quantitative importance of organic N to the plant and N utilization has not been established in improved varieties at Kilombero (EASDP, 2013). Determining which N forms are available for and ultimately taken up by crops remains a challenge. Matching soil N- fertilizer supply to the crop demand is required for improving the nutrient use efficiency of introduced varieties in commercial fields at Kilombero (Maro, 2004).

The release of organic N to plant available forms (R-NH_4 → NH_4^+ → NO^-_3), is favored by high concentrations of NH_4^+ in the soil. Retention of soil NH_4^+ may be limited due to low cation exchange capacity and low organic matter allowing movement of the cation with soil water. NO_3^- is free to move with soil water because of its anionic charge. Soil water movement may be upward during warm dry sunny weather or downward during rainfall events (Isa, 2004). The most challenging aspect of nitrogen control is the regulation of the soluble forms of this element after it enters the soil (Saleem *et al.,* 2012). Availability at the proper time and in adequate amounts, with a minimum loss, is more ideal. Plant roots take up nitrogen from the soil solution principally as NO_3^- and NH_4^+ ions (Isa, 2004).

Although sugarcane grows best when provided with mainly one or the other of these forms, a relatively equal mixture of the two ions gives the best results with most sugarcane varieties (Hogarth and Allsopp, 2000). These two ions differ in their effect on the pH. Nitrate anions (negatively charged ions) move easily to the root with the flow of soil water and exchange at the root surface with HCO_3^- or OH^- ions (Isa, 2004). Even where commercial fertilizers are used to supply much of the nitrogen, maintaining an adequate but not excessive quantity of available nitrogen is not an easy task. Saleem *et al.* (2012) reported that split applications of nitrogen fertilizer is one way of solving the problem.

This method involves the splitting of nitrogen application into several doses as the crop growing continues (Hogarth and Allsopp, 2000).

2.7 Response of Varieties to Nitrogen Fertilizer

The response to N fertilization occurs more in sugarcane ratoon crops than in planted-cane crops. Isa (2004) demonstrated that the depletion of plant-available soil N over time in sugarcane fields justifies the need for split application of the yearly total N-fertilizer rate. Sugarcane is capable of rapidly depleting the soil of mineral elements, particularly N and P. A high yielding irrigated crop like varieties N 25, 41 and R 579 can remove more than 250 kg N/ha, 30kg P and 650 kg K/ha, depending on crop stage and cycle (EASDP, 2013). Improved cane varieties alone contribute as much as 30-35% to the general cane and sugar yields, while better fertilization and soil management practices contribute 35-40 % of the total yields of cane and sugar (SBT, 2016). Fertilizer can be hardly profitable unless the crop responds to it. Some varieties of sugarcane needs relatively large amount of certain nutrients. The crop variety also makes a difference. Much work in plant breeding has been aimed at producing varieties that respond well to fertilizers (Maro, 2004). These varieties will produce much higher yields than other varieties if adequate plant nutrients were available. A good variety can only produce high yields that it is expected of it when the grower at the same time follows good farming practices (Hogarth and Allsopp, 2000).

A high-yielding variety, producing 100 kg or more of cane per ha, will require more N nutrients. The new varieties may do poorly when they are not adequately supplied with enough amounts of N-fertilizers (Hogarth and Allsopp, 2000). Application of the recommended rate of N-fertilizer per ha benefited the crop so that more millable canes were produced at harvest which ultimately resulted into increased cane and sugar yields (Lakshmi *et al*., 2003). Application of N in high amount increases the fertilizer cost, but its use is justified by increased sugar yield. The depletion of plant-available soil N over time justifies the need for high application of N rates (Hogarth and Allsopp, 2000). Increasing nitrogen applications increases both cane and sugar yields per ha until a level is reached where cane tonnage gradually drops. Sugar-per-unit area drops more or less sharply as the optimum N-rates are exceeded (Rice *et al.,* 2010).

The presence of unused nitrogen, caused by excessive or delayed nitrogen applications enhances continued vegetative growth as harvest approaches, implying higher moisture level within the cane, higher reducing sugars and lower sucrose at harvest (Yahaya *et al.,* 2008). As harvest approaches it is imperative that the level of nitrogen in the plants is low enough to reduce the rate of vegetative growth and force the conversion of reducing sugars to recoverable sucrose (Dirou, 2000). In practice the nitrogen application on sugarcane varies from less than 50 to more than 500kgN/ha in many sugarcane growing areas (IPNI, 2016).

There is little information on what the optimum N rate should be for commercial sugarcane varieties in Tanzania. Continued application of the same 200 kgN/ha rate on ratoon crops as used on plant cane crops results in lower N-use efficiency on yield and quality parameters in promising varieties of sugarcane (SBT, 2016). Cane production is the first stage in the sugar value chain and it has strong bearings on costs and the availability of sugar in subsequent stages in the sugar value chain (EASDP, 2013).

Variety plays a key role in both increasing and decreasing sugar yield per unit area and use quality of cane as experienced at Kilombero (KSC, 2015). The solution of low cane yield and sugar recovery problem lies in the planting of improved cane varieties with high N use efficiency (Maro, 2004). In Tanzania efforts are being made to increase cane production by introducing high yielding varieties with good responses to N-uptake and adoption of improved crop production techniques (EASDP, 2013). More than 400 varieties have been introduced in the country (SBT, 2016). Success of variety depends upon its adaptability to agro-climatic conditions of the area and response to N nutrients. Most of high yielding varieties have a good ability in N utilization. Selection of a proper variety to be sown in a particular agro-ecological zone is a primary requisite to explore its yield and sugar recovery potential. Ratoons are important for overall profitability of sugarcane cultivation as they save about 30% in the operational cost (Horgarth and Allsopp, 2000). The inherent potential of a variety to give better yields in plant and ratoon crops is of paramount importance for sustaining high productivity (Isa, 2004). Acceptance of a variety by the farmers depends very much on its ratooning potential which requires more than 300 to 500kgN/ha (EASDP, 2013). Sugarcane varieties, which show good response to N utilization and good performance in plant and ratoon crops are promoted for commercial cultivation (SBT, 2016).

2.8 Factors Affecting Soil quality and Limiting Nitrogen Uptake in Sugarcane Commercial Fields

Soil quality is the capacity of a soil to function for specific land uses or within ecosystem boundaries. Soil quality in agricultural production is the capacity of soil to support the growth of plants on a sustained basis, yielding quantities of expected products that are close to the known potential. Such productive capacity requires the provision of adequate amounts of N nutrients to ensure proper growth of the plants with other favorable soil factors to promote proper N uptake, and therefore good growth, production and yields (Maro, 2004). Some of these are soil moisture and temperature, aeration, water holding capacity, a pH that should be near neutral, an absence of hardpans that would inhibit root growth, adequate organic matter, and other conditions that promote the growth of soil micro-organisms (Hogarth and Allsopp, 2000).

This capacity is an inherent characteristic of a soil and varies from soil to soil. Soil indicators such as organic-matter content, salinity, tilth, compaction, available nutrients, and rooting depth helps to measure the health or condition of the soil quality in any given place (Isa, 2004). Dynamic soil quality is how the soil changes depending on how it is managed. Management choices affect the amount of soil organic matter, soil structure, soil depth, water and nutrient holding capacity (Hogarth and Allsopp, 2000). Soils respond differently to management depending on the inherent properties of the soil and the surrounding landscape. Soil type, crop rotation and management practices associated with tillage, stubble retention and fertiliser application can influence the diversity of microbial populations, and along with their environment they affect biological processes involved in nitrogen fixation, mineralization, availability and losses (Yousef *et al.*, 2000). All of these processes and the associated microorganisms can be manipulated to optimise N-use efficiency both by improving the supply of N-fertilizer to organic N and decreasing the losses via denitrification and leaching (IPNI, 2016).

Sugarcane cultivation contributes to soil fertile and yield decline due to the use of intensive agricultural practices, no N recycling of organic residues with no legume breaks, and uncontrolled field traffic that leads to soil compaction, which is a threat to soils in commercial fields (Garside *et al.*, 2003). Soil quality has been shown in studies in Tanzania to be adversely affected by the wrong management practices (Maro, 2004).

Low uptake of N- fertilizers due to crusting, soil loss through erosion, low available moisture capacity, loss of soil organic matter, acidification and water logging during wet seasons limits the availability of N-fertilizers to sugarcane crops (Yousef *et al*., 2000). A number of ratoon crops management practices currently in use, such as burning of crop residues at harvest, harvesting under wet conditions and using heavy infield transport, degrades the physical, chemical and biological properties of soils (Yousef and Taha, 2003).

Hogarth and Allsopp (2000) reported a decline of N and reduced biological activities in soils where sugarcane was grown for a long time under rain fed and monoculture conditions. Sugarcane depletes heavily the nutrient reserve as it removes a lot of soil nutrients at harvest (Yousef *et al.,* 2000). Nitrogen is the most limiting nutrient in tropical areas, due to the low levels of organic matter, and therefore, its conversion into N through mineralization is low (Saleem *et al.,* 2012). Inorganic and organic N-fertilizers are usually applied in tropical soils to supplement N requirement by the crop (Isa, 2004). Although the N response on sugarcane differs with the soil type, the effect is more significantly influenced by climate and particularly more by the amount of sunlight and temperature in winter and in spring when the plants take up most of their nitrogen (Hogarth and Allsopp, 2000). The highest nitrogen response is obtained under conditions of relatively high temperatures and much sunshine (Yousef and Taha, 2003).

Numerous studies have shown that responses of sugarcane to N are not consistent (Lakshmi *et al*., 2003), even though it has been observed that the management of the previous crop affects the yield and quality of the cane. The highest yields of cane and sugar are obtained with the highest amounts of N applied although too much N has adverse effects on cane quality as reported by Isa (2004).

Factors affecting soil quality and limit N uptake includes directly and indirectly from organic materials and mineral fertilizers when applied to the soil (Maro, 2004). Some of the major processes through which N is lost from the plant soil system include denitification, This refers to nitrate reduction to gaseous nitric oxide (NO), nitrous oxide

(N_2O) or nitrogen gas (N_2), this mainly takes place under anaerobic conditions through several bacteria resulting in a net loss from system. These N gas losses can be better reduced through soil and fertilizer management (Yousef and Taha, 2003). The effect of soil pH has an important influence on the response to fertilizers to most of sugarcane crops. A pH value below 5.0 usually leads to little or no response to N in the majority of soils this being attributed to aluminium toxicity, restricted root development and chemical fixation. A pH of 5.0 and below, about 0.004% of the N is present as free NH_3, but that fraction increases approximately 10-fold with unit increase in pH. Thus at pH 9.0, about 40 % of the total N available in form of NH_3 is volatilized (Isa, 2004). Denitrification, volatilization, leaching, crop harvesting and run off have been noted to be the principal ways through which about 89% of the N fertilizers applied in the soil is lost. Sugarcane is capable of recovering only about 20-50% N nutrients applied in the soil (EASDP, 2007). There is little chance of getting N-fertilizers response with soil organic matter content above 3.5 %, the response can be expected as organic matter fall below 3.3 % (Hogarth and Allsopp, 2000). Length of day season and presence of wet and dry periods during the rainfall season affects the amount of N made available for plant through mineralization of organic matter. The N nutrients flushes become more pronounced the longer the dry season and more wet periods (IPNI, 2016). Leaching of bases and the use of acidifying fertilizers has led to the development acidic conditions. This limits the availability of N nutrients in the soil, leading to reduced productivity of the soils (Isa, 2004).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location and Duration

The research was conducted in the commercial fields of Kilombero Sugar Company Ltd, which is located in Kilombero District, Morogoro Region, Tanzania. Kilombero Sugar Company Ltd, lies between 7^o30” and 7^o50” Southern latitude, and between 36^o00” and 37^o10” Eastern longitude. Its immediate neighbors include Mikumi Town and National Park to the north, Seleous game reserve to the south and east, and Udzungwa mountain ranges to the west. Field experiments were conducted in 2015/16 season (Appendix 11).

3.2 Climate

The climate of Kilombero is tropical, with annual rainfall varying between 800 mm and 1700 mm and a well-defined dry spell. Main rains peak is between March and April, while short rains which starts in November and end in January. The types of soils are sandy loam (light), loam (medium) and clay loams (heavy) (Appendices 7, 8 and 9).

3.3 Materials

The experiment comprised eight treatments of N- fertilizer applied in the form of urea (46% N) including three promising candidate sugarcane varieties, R 579 from Reunion, N 25 and N 41 from South Africa.

3.4 Experimental Layout Design and Treatments

The experiment was laid out in split plots arranged in a randomized complete block design (RCBD) replicated three times. Main plots were varieties and sub plots were N- fertilizer rates. The main plots consisted of sugarcane varieties with different ratoon levels as follows: N41-ratoon 1, R 579- ratoon 3 and N25-ratoon 4. In each of the main plots; 8 N-fertilizer rates as sub plots as follows; (T1=0 kgN/ha, T2=150 kgN/ha, T3=200 kgN/ha, T4=250 kgN/ha, T5=300 kgN/ha, T6=350 kgN/ha, T7=400 kgN/ha and T8=450 kgN/ha).

3.5 Sub Plot Treatments

N -fertilizer was applied 3 months after ratooning along the rows by broadcast method on t cane stools after tillering. Phosphorous and potassium were not applied but used as residual effect fertilizers, which were applied at planting during establishment of the crop. The net plot size was 180m^2. The spacing used was 1.5m x1.5m with 8 rows per plot and a length of 10m width. Recommended agronomic practices were followed throughout the growth and development period as described by KSC (2015).

3.6 Soil and Leaf Sampling

3.6.1 Soil sampling

A total of ten soil samples were taken along cane row of equal length on the side of the cane rows from 0-30 cm depth from a mining soil pit. The sampling was divided into uniform field areas of 3 to 10 ha. A slice of about 5cm thick was cut vertically down the soil surfaces along the clean side length. After harvest the soils were collected from each plot according to N-fertilizer rate treatments arrangement in the experimental field layout applied. The soil samples were mixed well in a clean plastic bucket filled in a sample bag. One kilogram of soil was taken from each of 0-30 cm and sent to laboratory (ARI-Mlingano, Tanga) for soil analysis.

3.6.2 Leaf sampling

Leaf samples of 25 leaves (third leaves from the apex), were taken from primary shoots or stalks in each plot (not from tillers or suckers), and leaves were plucked from the sampled plants. Leaf sampling took place during the grand stage periods (3 to 6 month) of sugarcane to maturity stage (9 to12 months). Care was taken to avoid diseased plants or leaves with insect or herbicide damage since these conditions may affect N contents. During the entire sampling process, the leaves were kept as clean as possible and were never placed directly on the ground. The leaf samples were enclosed in paper bag, labeled, and kept out of the sun to prevent excessive moisture loss after removing midribs from leaf blades. Leaf blades were rinsed in distilled water to remove soil and dust particles that might contaminate the samples. Rinsed leaf samples were placed in dry labeled sample bags dried in the oven at 70°C for 12 hours and sent to laboratory (ARI-Mlingano, Tanga) for leaf analysis.

3.6.3 Data analysis for soil and leaf samples

Soil and leaf sample analysis was done using standard analytical method for soil and leaf N as described by Kjeldahl method (Bremner and Mulvaney"s, 1982).

3.7 Data Collection

3.7.1 Nutrients removed

Nutrients removed are the amount of nutrients utilized by the crop from the soil during growth and development. Nutrient uptake by crop was determined by yield of cane (tone/ha) at harvest x standard soil nutrient uptake by sugarcane crop (kg/ton). The standard nutrient uptake of N is 1.2 kg/ton, P is 0.8 kg/ton, and K is 2.5 kg/ton. The maintenance of nutrient in the soil at growth phase was the application of removed kg N/ha, kg P/ha and kg K/ha (OECD, 2016).

3.7.2 Quality data

Observations were recorded for important quality characters, which were: brix %, pol %, fiber %, purity %. Ten cane stalks were randomly sampled from eight stools for each net plot to determine sugar content. The stalks were crushed with a Jafco-cutter grinder to extract the juice which was determined with Brix hydrometer. Polarity (sucrose concentration) was measured using Lomb polarimeter.

3.7.3 Purity percentage cane

This is the percentage apparent sucrose content in the cane juice. Purity % cane = (P/B) x100, where P = Pol % cane and B = Brix % cane (Hogarth and Allsopp, 2000).

3.7.4 Brix percentage cane

Brix percentage is equivalent to the proportion of the total soluble solids derived from the diluted brix. This was measured in the laboratory according to the following formula:

$$\text{Brix cane } (\%) = Dilutedbrix \times [4.04 - \frac{\text{Fiber \% cane}}{100}] \quad \text{..............................(1)}$$

3.7.5 Pol percentage cane

This is the percentage apparent sucrose content in cane juice. This was determined by using a polarimeter during plant growth (Hogarth and Allsopp, 2000).

3.7.6 Fiber percentage cane

This is the water insoluble matter of cane and bagasse from which the brix-free water is removed by drying.

Fibre % cane = (100-M-3b)/(1-0.0125b)

Where:

M= moisture % cane

b= brix % extract (Hogarth and Allsopp, 2000).

3.7.7 Yield data

At maturity stage**,** 5 cane stalks were randomly selected from each plot for height determination, which was measured from the base (ground level) to the top (highest node) and then average stalks height per plot was obtained. Plant height was measured using measuring poll. Data on various growth and yield parameters of the crop were recorded such as number of millable canes, weight of 10 stalks per plot at growth and weight of cane at harvest per plot (kg). Eight rows from each plot (Net plot) were harvested manually for yield data as described by Japtap (2006).

3.7.8 Cane yield

Cane yield fresh weight was taken from net plots at harvest and extrapolated in tons per hectare and calculated as shown in the formula below:

$$\text{Cane yield (t/ha)} = \left(\frac{\text{Plots yield (kg)}}{120\ \text{m}^2 \times 1000\ \text{kg}}\right) \times 10000\ \text{m}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

(Hogarth and Allsopp, 2000).

3.7.9 Sugar yield

Yield of sugar was obtained by the following formula:

Yield of sugar/ha= (tons of cane/ha x sucrose %) /100)…………………..……………… (3)

(Hogarth and Allsopp, 2000).

3.7.10 Cost Benefit Ratio

Cost benefit ratio was obtained by calculating:

Total net benefit (net present value (NPV) =Total benefit –Total cost (NPV=B –C)… (4)

Benefit /Cost Ratio =Total benefit divide by Total cost (B/C)………………………… (5)

If, B/C > 1, then do not implement it.

If, B/C > 2 or 3, then implement it (Dutton, 2016).

3.8 Data Analysis

Data collected from the experiment were subjected to analysis of variance (ANOVA) using GenStat software (14^{th} edition). The following Statistical Model was used:

$Y_{ijkl} = \mu + R_i + V_j + E_a + F_k + VF_{(jk)} + E_b + Eijkl$……………………………..…..……… (6)

Whereas:

- Y_{ijkl}=observation in the i^{th} rep , j^{th} fertilizer, and K^{th} plots
- μ=Overall mean
- Ri=i^{th} rep effect;
- Vj= effect due to j^{th} variety;
- Ea = Error (a)
- Fk = effect due to fertilizer rate
- VF(jk) = variety and fertilizer interaction
- Eb = Error (b)
- Eijkl= random error associated with i^{th} rep, j^{th} varieties and k^{th} fertilizer rates

Where significant difference existed, mean comparison among treatments was done using Duncan's New Multiple Range Test (DNMR) at 5 % probability level.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of N-fertilizer on Yield and Quality of Sugarcane at Kilombero Sugar Company Farm

4.1.1 Analysis of soil prior N-fertilizer application

A result on analysis of soil before N-fertilizer was applied is shown in Table 1. Low total N levels in the soil were observed before N-fertilizer was applied. Soil analysis for N was found with lower nitrogen content at a range of 1.33-1.45%, while P and K was found with sufficient nutrient content at a range of 26-45 ppm observed for P and at a range of 246-318 ppm for K. Soil pH was at a range of 5.18-6.50 before N fertilizer was applied. Results from soil analysis showed that, the soils were slightly acidic on sugarcane production but was with the range of sugarcane cultivation.

Table 1: Soil nutrient content before N-fertilizer was applied at Kilombero Sugar Company Farm

Soil parameters	Soil pH	Total N (%)	P (ppm)	K (ppm)
Range	5.18-6.50	1.33-1.45	26-45	246-318

4.1.2 ANOVA summary for the variables

4.1.2.1 ANOVA summary of means of squares for leaf nutrients concentration at growth and maturity

Analysis of variance results for the leaf nutrients concentration is shown in Table 2**.** Variety-ratoon crops were tested to determine the effect of different rates of N-fertilizer on leaf nutrients concentrations. Results indicated highly significant ($P<0.001$) difference among varieties tested with different N-fertilizer rates at both grand growth and maturity stages (Table 2). On the other hand, there was no significant ($P\leq0.05$) effect regarding interactions between varieties and fertilizer rates and between N-fertilizer rates.

Table 2: Nutrient concentrations (%) in leaves at grand growth and maturity stages

Sources of variation	Degree of freedom	Grand growth stage (means of sum of squares)			Maturity stage (means of sum squares)		
		N	**P**	**K**	**N**	**P**	**K**
Reps	2	0.029	0.0001	0.002	0.014	0.287	0.010
Varieties-ratoon	2	4.824***	0.012***	0.190**	1.950***	4.546***	0.181***
Error (b)	4	0.089	0.0001	0.058	0.012	0.058	0.011
N- fertilizer rates	7	0.014^{NS}	0.0002^{NS}	0.006^{NS}	0.022^{NS}	0.042^{NS}	0.0003^{NS}
Varieties x N- fertilizer rates	14	0.028^{NS}	0.0002^{NS}	0.013^{NS}	0.012^{NS}	0.106^{NS}	0.0002^{NS}
Error (b)	42	0.017	0.0003	0.018	0.029	0.080	0.0003
Total	**71**						

Highly significant (P<0.001): **Significant (P<0.01): *Significant (P<0.05): Non significant (NS)

4.1.2.2 ANOVA summary for nutrients removed

Analysis of variance for nutrients removed from the soil is as presented in Table 3. Results showed that there were highly significant (P<0.001) differences among varieties tested for different N amounts removed from the soil. Alternatively, fertilizer rates and variety-fertilizer rate interactions had no effect (P≤0.05) on nutrient removed from the soil.

Table 3: ANOVA Summary (means of squares) for amount of nutrients removed from soil by sugarcane crop

Source of variation	**Degree of freedom**	**N (kg/ha)**	**P (kg/ha)**	**K (kg/ha)**
Reps	2	506.40	225.10	2198.00
Varieties-ratoon	2	31462.50***	13983.30***	136556.00**
Error (a)	4	998.90	444.00	4336.00
N -fertilizer rates	7	16624.90^{NS}	7388.80^{NS}	72157.00^{NS}
Varieties x N- fertilizer rates	14	738.30^{NS}	328.10^{NS}	3204.00^{NS}
Error (b)	42	620.20	275.60	2692.00
Total	**71**			

4.1.2.3 Effects of N-fertilizer rates on cane yields and quality parameters

Analysis of variance for cane yields and quality parameters is shown in Table 4. Varieties were tested to determine the effect of N-fertilizer rates on yields and quality. Results showed that varieties had highly significant (P<0.001) effects on brix, pol, sucrose content and sugar yield. Also, varieties had significant (P<0.01) effects on purity and cane yield. On the other hand, fertilizer rates had highly significant (P<0.001) effects on cane and sugar yields. While there was significant (P≤ 0.05) effect on brix due to N rates, no effects were observed for pol, purity and sucrose content. With regard to interaction between varieties and N rates, there was no effect (P≤ 0.05) on the studied parameters except sugar yield which was significant at P≤ 0.05.

Table 4: Effects of nitrogen on yield and quality parameters on sugarcane crop

N fertilizer rates (kgN/ha)	Degree of freedom	Brix (%)	Pol (%)	Purity (%)	Cane (t/ha)	Sucrose (%)	Sugar (t/ha)
Reps	2	0.210	0.709	0.655	351.600	0.436	11.941
Varieties-ratoon	2	127.851***	136.872***	160.414**	21849.000**	72.506***	770.476***
Error (b)	4	0.203	0.083	4.113	693.700	0.199	13.363
N -fertilizer rates	7	1.267*	1.238^{NS}	3.055^{NS}	11545.000***	0.918^{NS}	219.592***
Varieties x N –fertilizer rates	14	0.378^{NS}	0.749^{NS}	3.410^{NS}	512.700^{NS}	0.500^{NS}	15.535*
Error (b)	42	0.531	0.771	2.830	430.700	0.451	7.933
Total	**71**						

*** Highly significant (P<0.001): **Significant (P<0.01): *Significant (P≤ 0.05): Non significant (NS)

4.2 Main Plot Effects (Variety – Ratoons)

4.2.1 The effects of variety-ratoons on leaf nutrient concentrations

The effects of variety-ratoons on nutrient concentrations in leaves at grand growth and maturity stage are shown in Table 5. Results showed no significant ($P \leq 0.05$) differences for variety-ratoons on N leaf nutrient concentration at grand growth. Similarly, variety-ratoons were not significantly ($P \leq 0.05$) different for N at grand growth and K at maturity stage but were significantly ($P \leq 0.05$) different for P and K at grand growth and N and P at maturity stage. The highest leaf N concentration at grand growth for N-fertilizer was for variety N25 R4 (1.52%) but statistically similar to variety R579 R3 (1.43%) and the lowest N content was observed for variety N41 R1 (0.99%). For P, variety N25 R4 had the highest concentration (2.78%) followed by variety R 579 R3 (2.42%) and the lowest was found in variety N41 R1 (1.91%). For K, R579 R3 had the highest concentration (0.20%) followed by variety N25 R4 (0.8%) and the lowest was observed in variety N41 R1 (0.03%).

The highest leaf N concentrations at maturity stage was in variety N25 R4 (2.09%) followed by variety R 579 R3 (1.34%) and the lowest was observed in variety N41 R1 (1.30%). Likewise, variety N25 R4, had the highest P concentration (0.21%), while variety R 579 R3 and N41 R1 had similar concentration of 0.17%. Potassium (K) concentration was highest in R579 R 3 (1.61%) followed by N41 R1 (1.60%) and the lowest was observed with variety N25 R4 (1.45%) however, these were statistically similar.

Table 5: Mean effects of variety-ratoons for leaf nutrients concentration at grand growth and maturity stage

Variety-ratoons	Grand growth stage			Maturity stage		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
N 41 R1	0.99	1.91	0.03	1.30	0.17	1.60
R 579 R3	1.43	2.42	0.20	1.34	0.17	1.61
N 25 R4	1.52	2.78	0.08	2.09	0.21	1.45
Mean	**1.32**	**2.37**	**0.10**	**1.58**	**0.18**	**1.55**
SED (±)	**0.14**	**0.22**	**0.03**	**0.13**	**0.01**	**0.12**
CV (%)	**13.10**	**12**	**18.70**	**8.70**	**9.70**	**8.70**
LSD (P ≤ 0.05)	**0.27**	**0.45**	**0.08**	**0.27**	**0.03**	**025**

Key: R1 = first ratoon crop, R3= third ratoon crop and R4=fourth ratoon crop

4.2.2 Effects of variety-ratoons on nutrients removed from soil

The main effects of variety – ratoons on nutrients removed from the soil are shown in Table 6. Results showed significant (P≤ 0.05) difference for variety-ratoons with nutrient removed among the varieties tested. The treatment with highest N-fertilizer removed 161.90 kg N/ha variety N41 R1 followed by 152.60 kg N/ha variety R579 R3 and the lowest was 95.1kgN/ha observed in variety N25 R4. The highest P removed was 107.90 kg P/ha with N41 R1 followed by 101.70 kg P/ha with variety R579 R3 and the lowest recorded was 63.40kgN/ha with variety N25 R4. Similarly, the highest K removed was 337.30 kg K/ha with variety N41 R1 followed by 317.90 kg K/ha with variety R579 R3 and the lowest was 198.1kgK/ha with variety N25 R4.

Table 6: Mean effects variety-ratoons on nutrient removed from soil

Variety-ratoons	N (kg/ha)	P (kg /ha)	K (kg/ha)
N41 R_1	161.90	107.90	337.30
R579 R_3	152.60	101.70	317.90
N25 R_4	95.10	63.40	198.10
Mean	**136.50**	**91.00**	**284.40**
SED (±)	**21.10**	**14.06**	**43.95**
CV(%)	**18.20**	**18.20**	**18.20**
LSD (P ≤ 0.05)	**42.61**	**28.41**	**88.77**

Key: R1 = first ratoon crop, R3= third ratoon crop and R4=fourth ratoon crop

4.2.3 Main effects of variety-ratoons on yields and quality variables

The effects of variety-ratoons on yields and quality variables are shown in Table 7. Results showed significant (P≤ 0.05) difference on quality variables viz. brix percentage, pol percentage, purity percentage and sucrose percentage among the tested varieties with different ratoons. Similarly, test varieties differed significantly on TCH and TSH. The highest TCH was 134.90 t/ha (N41 R1) and TSH of 19.68 t/ha (N41 R1) followed by 127.20 t/ha (R579 R3) and 17.03 t/ha (R579 R 3). The lowest was 79.20 t/ha (N25 R4) and TSH of 8.81 t/ha (N25 R4).

Table 7: Mean effects of varieties on yields and quality variables

Variety-ratoons	Brix (%)	Pol (%)	Purity (%)	Cane (t/ha)	Sucrose (%)	Sugar (t/ha)
N41 R_1	23.03	21.26	91.84	134.90	14.51	19.68
R 579 R_3	20.39	19.20	94.50	127.20	13.31	17.03
N25 R_4	18.43	16.50	89.33	79.20	11.09	8.81
Mean	**20.61**	**18.98**	**91.89**	**17.58**	**12.97**	**15.17**
SED (±)	**0.57**	**0.67**	**1.41**	**35.51**	**0.53**	**2.39**
CV (%)	**3.50**	**4.60**	**1.80**	**17.58**	**5.20**	**18.60**
LSD (P ≤ 0.05)	**1.15**	**1.36**	**2.80**	**35.10**	**1.06**	**4.84**

Key: R1, R3 and R4 are first, third and fourth ratoon crop, respectively.

4.3 Sub Plots Effects (N- Fertilizer Rates)

4.3.1 Sugarcane leaf nutrient concentration at grand growth and maturity stages

The concentrations of N nutrients in the leaves were not significantly (P≤0.05) different among the N-fertilizer treatments (Table 8 and Appendices 1 and 10). Nitrogen concentration in sugarcane plants at grand growth stage ranged from 1.53% to 1.64%. Phosphorous ranged from 0.18-0.19% and potassium from 1.51-1.59 %. At maturity, leaf nutrients concentrations ranged from 1.23-1.39%, 0.09-0.11% and 2.28-2.49% for nitrogen, phosphorous and potassium, respectively. Nitrogen concentration in leaves was highest at a rate of 400 kg N/ha (1.64%) at grand growth and 150 kg N/ha (1.39%) at maturity stage (Table 8). According to Rice *et al.* (2010), values for N ranked very deficient except for 400 N-fertilizer at grand growth stage; while for P it was deficient to marginal at grand growth stage and very deficient at maturity. With K the levels were sufficient plus at grand stage and high for maturity stage (Appendices 1 and 2). Generally, N and P levels were higher at grand growth stage while K was higher at maturity stage. The variations of rainfall and irrigation water affected the leaf nutrient concentrations (Appendices 7 and 10).

Table 8: Sugarcane leaf nutrient concentrations at grand growth and maturity stages

N- fertilizer rates	**Grand growth stage**			**Maturity stage**		
(kg N/ha)	**N%**	**P%**	**K%**	**N%**	**P%**	**K%**
0	1.54a	0.18a	1.54a	1.27a	0.10a	2.31a
150	1.58a	0.18a	1.55a	1.39a	0.10a	2.39a
200	1.54a	0.18a	1.58a	1.33a	0.10a	2.49a
250	1.55a	0.19a	1.59a	1.34a	0.09a	2.42a
300	1.53a	0.18a	1.51a	1.23a	0.11a	2.28a
350	1.63a	0.18a	1.54a	1.31a	0.10a	2.32a
400	1.64a	0.19a	1.57a	1.31a	0.10a	2.28a
450	1.59a	0.19a	1.54a	1.31a	0.10a	2.34a
Mean	**1.58**	**0.18**	**1.55**	**1.32**	**0.10**	**2.37**
SED (±)	**0.13**	**0.014**	**0.124**	**0.14**	**0.04**	**0.23**
CV (%)	**8.30**	**9.70**	**8.70**	**13.10**	**18.70**	**12.00**
($P \leq 0.05$)	**0.11**	**0.69**	**0.74**	**0.96**	**0.72**	**0.24**

Means followed by the same letter within a column are not statistically ($P<0.05$) different according to Duncan's New Multiple Range Test

4.3.2 Nutrients removed from soil by the sugarcane crop

Results on nutrient removed from the soil are as presented in Table 9. Nutrients removed from the soil increased with increasing fertilizer rates and sugarcane yields except for highest rate (450kgN/ha) of N-fertilizer applied. N removed by the plants increased from 41.10 kg N/ha to 181.40 kg N/ha (Appendix 3). The lowest and highest nutrient removed were for 0 and 400 kg N/ha, respectively (Table 9).

The N, P and K removed by sugarcane were significantly (P< 0.001) different among N-fertilizer rates. The lowest nutrients removed was in 0 kg N/ha. The lowest N was 41.10 kg N/ha, P was 27.41 kg P/ha and K was 85.70 kg K/ha, while the highest nitrogen removed was 181.40 kg N/ha, P was 120.92 kg P/ha and K was 377.90 kg K/ha. The total amount of nutrients removed was associated positively with yields of cane and sugar at harvest. Nutrient leaf concentrations and removal trend demonstrated indicators of crop nutrient use efficiency associated with total inputs of N-fertilizer rates applied. Nutrient removed showed the ability of soils to supply nutrients. At 400kgN/ha was reached maximum of N-nutrients required by the crop, while at 450kgN/ha the N-nutrient removal value was greater than the critical value, indicated that no additional nutrient inputs were needed to achieve maximum yields.

Table 9: Amount of nutrients removed from soil by sugarcane crop

N- fertilizer rates (kg /ha)	N (kg /ha)	P (kg /ha)	K (kg /ha)
0	41.10d	27.41d	85.70d
150	118.20c	78.77c	246.20c
200	138.60bc	92.43bc	288.80bc
250	150.20b	100.15b	313.00b
300	160.00ab	106.65ab	333.30ab
350	163.50ab	109.03ab	340.70ab
400	181.40.a	120.92a	377.90a
450	139.20bc	92.81bc	290.00bc
Mean	**136.50**	**91.00**	**284.4**
SED (±)	**21.10**	**14.00**	**43.95**
CV (%)	**18.20**	**18.20**	**18.20**
(P ≤ 0.05)	**0.001**	**0.001**	**0.01**

Means followed by the same letters within a column are not statistically (P<0.05) different according to Duncan’s New Multiple Range Test.

4.3.3 Effect of nitrogen fertilizer on yield and quality parameters

Mean values of different levels of N-fertilizer for pol percentage and purity percentage were not significantly different (Table 10). Minimum brix percentage and sucrose percentage was with 250kgN /ha while the control had lowest pol percentage, cane (t/ha) and sugar (t/ha). Maximum levels of quality attributes were attained at 400kgN/ha while maximum brix percentage was observed in 350 kg N/ha which was not statistically different from 400kgN/ha. The effects of N–fertilizer rates on brix percentage from 250 to 450 kg N/ha were not significantly different.

Cane yield increased from 34.30 t/ha to 151.10 t/ha (Table 10, Appendix 4). Analysis of variance showed highly significant (P<0.001) differences among fertilizer rates for cane and sugar yields (Table 4). The 400 kg N/ha produced highest cane yields but statistically similar to 350 and 300 kg N/ha. The lowest cane yield was (34.3 t/ha) was observed in control plots (0 kg N/ha). Maximum sugar yield (t/ha) was obtained with 400 kg N/ha followed by 350 and 300 kg N/ha. At 400kgN/ha the soil was reached the maximum to supply the N-nutrients required by the crop, while at 450kgN/ha the soil N-nutrients value was greater than the critical value, indicated that no additional nutrient inputs were needed to achieve maximum yields.

Table 10: Effect of nitrogen on yield and quality parameters on sugarcane crop

N- fertilizer rates (kgN/ha)	Brix (%)	Pol (%)	Purity (%)	Cane (t/ha)	Sucrose (%)	Sugar (t/ha)
0	20.28ab	18.49a	92.05a	34.30d	12.60b	4.42e
150	20.37ab	18.65a	91.12a	98.50c	12.68ab	12.75d
200	20.56ab	19.00a	92.23a	115.50bc	12.95ab	15.41cd
250	19.99b	18.56a	91.36a	125.20b	12.58b	16.27bc
300	20.78a	19.32a	92.75a	133.30ab	13.31ab	18.22abc
350	21.03a	19.35a	91.82a	136.30ab	13.25ab	18.53ab
400	20.97a	19.39a	92.46a	151.10a	13.35a	20.41a
450	20.93a	19.12a	91.35a	116.00bc	13.05ab	15.37cd
Mean	**20.62**	**18.98**	**91.89**	**113.80**	**12.97**	**15.17**
SED (±)	**0.34**	**0.41**	**0.79**	**9.78**	**0.32**	**1.33**
CV (%)	**3.50**	**4.60**	**1.80**	**18.20**	**5.20**	**18.60**
(P ≤ 0.05)	**0.03**	**0.16**	**0.39**	**0.001**	**0.07**	**0.001**

Means followed by the same letter within a column are not statistically (P ≤ 0.05) different according to Duncan's New Multiple Range Test.

4.3.4 Interaction of variety-ratoons x N-fertilizer rates

The interactions of variety x N-fertilizer rates for leaf nutrient concentrations are shown in Table 11. A leaf nutrient concentration between varieties and N-fertilizer rates was not significant ($P \leq 0.05$) except for N at grand growth. At maturity, the interaction was significant for N and K. The combinations N25 R4T6, N25 R4T3, N25 R4T2, N25 R4T5 and N25 R4T4 resulted in highest N-fertilizer nutrient concentrations at grand growth stage. The lowest combinations on N concentrations were R 579 R3T4 followed by R579 R3T6, T1, T2 and T3. The N leaf nutrient concentrations at maturity were highest with the combinations of N25 R4T6, N25 R4T4, N25 R4T2, N25 R4T5, N25 R4T8, N25 R4T3 and N25 R4T6 followed by R 579 R3T7, R579 R3T6 and R579 R3T3. The leaf N-nutrient concentration was lowest with combination of R579 R3T4 and N41 R1T3.The highest leaf K concentration nutrient was in N25 R4T4 and N25 R4T3 while the lowest was in N41 R1T5 and N41 R1T7. Results indicated that at grand growth stage sugarcane crops requires higher N than at maturity stage, although were not consistent statistically significant interaction has been shown to exist between varieties and N-fertilizer rates.

Table 11: Interaction of variety x N fertilizer rates for leaf nutrient concentration at grand growth and maturity

Treatment combinations	Grand growth stage N (%)	P (%)	K (%)	Maturity stage N (%)	P (%)	K (%)
N41 R1T1	0.88	0.03	1.82	1.27	0.16	2.31
N41 R1T2	1.11	0.04	2.11	1.32	0.17	2.39
N41 R1T3	1.01	0.03	1.88	1.20	0.17	2.49
N41 R1T4	1.04	0.03	1.98	1.28	0.17	2.42
N41 R1T5	0.95	0.03	1.98	1.27	0.17	2.28
N41 R1T6	0.91	0.03	1.82	1.27	0.17	2.32
N41 R1T7	1.02	0.04	1.87	1.46	0.18	2.28
N41 R1T8	1.00	0.03	1.91	1.35	0.16	2.34
R579 R3 T1	0.20	0.20	1.58	1.39	0.18	2.51
R579 R3 T2	0.20	0.20	1.67	1.28	0.18	2.48
R579 R3 T3	0.20	0.20	1.60	1.43	0.18	2.41
R579 R 3 T4	0.19	0.19	1.59	1.23	0.18	2.41
R579 R 3 T5	0.21	0.21	1.53	1.20	0.17	2.51
R579 R3T6	0.20	0.20	1.67	1.44	0.16	2.58
R579 R3T7	0.21	0.21	1.58	1.47	0.17	2.54
R579 R3 T8	1.43	0.20	1.56	1.29	0.18	2.41
N25 R4 T1	1.46	0.08	1.54	1.98	0.20	2.61
N25 R4 T2	1.54	0.07	1.53	2.15	0.21	2.61
N25 R4 T3	1.56	0.08	1.65	2.01	0.21	3.20
N25 R4 T4	1.52	0.07	1.62	2.16	0.23	3.87
N25 R4 T5	1.52	0.12	1.64	2.14	0.21	2.57
N25 R4 T6	1.59	0.07	1.61	2.19	0.20	2.58
N25 R4 T7	1.49	0.08	1.67	2.00	0.21	2.81
N25 R4 T8	1.51	0.07	1.63	2.14	0.22	2.81
Mean	**1.32**	**0.10**	**1.56**	**1.58**	**0.19**	**2.37**
SED (±)	**0.08**	**0.01**	**0.06**	**0.06**	**0.01**	**0.13**
CV (%)	**13.10**	**18.70**	**8.70**	**8.30**	**9.70**	**12.00**
LSD ($P \leq 0.05$)	**0.16**	**0.02**	**0.12**	**0.12**	**0.01**	**0.27**

Key: R1 = first ratoon crop, R3= third ratoon crop and R4=fourth ratoon crop and T=Treatment

4.3.5 Interaction of variety x N- fertilizer rates on nutrients removed and production by the sugarcane crop

Interaction between variety and N-fertilizer rates on nutrients removed by the sugarcane crop, cane and sugar production are shown in Table 12. Nutrient removed and cane yield differed significantly ($P \leq 0.05$). There was an increase in cane yields (t/ha) with increasing N nutrient removal. The combinations N41 R1T7, N41 R1T6, N41 R1T5, N41 R1T4, R579 R3T7, R579 R3T6 and R579 R3T5 resulted in higher cane and sugar yields. The N-fertilizers removed by crops showed significantly increase on yields of cane and sugar associated with the increase of N-rates were applied in the soil, whereby the interaction of variety x N-fertilizer rates from 250 kg N/ha up to 400 kg N/ha showed higher cane and sugar yields.

Table 12: Interaction of Variety x N-fertilizer rates on nutrients removed and production by the sugarcane crop

Treatment combinations	Nutrient removed N (kg/ha)	P (kg/ha)	K (kg/ha)	Yield Cane (t/ha)	Sucrose (%)	Sugar (t/ha)
N41 R1T1	58.50	39.00	121.80	48.70	14.04	6.81
N41 R1T2	127.00	84.70	264.60	105.80	13.84	14.74
N41 R1T3	170.80	113.90	355.90	142.40	14.92	21.28
N41 R1T4	192.30	128.20	400.70	160.30	14.35	22.98
N41 R1T5	195.30	130.20	406.80	162.70	15.06	24.49
N41 R1T6	197.30	131.50	411.00	164.40	14.60	23.98
N41 R1T7	199.60	133.10	427.00	166.30	15.07	24.83
N41 R1T8	154.60	103.10	342.60	128.80	14.23	18.34
R579 R3 T1	34.90	23.30	72.70	29.10	12.53	3.64
R579 R3 T2	136.00	90.60	283.20	113.30	13.64	15.46
R579 R3 T3	152.10	101.40	316.80	126.70	13.04	16.51
R579 R 3 T4	162.00	108.00	337.40	135.00	13.19	17.62
R579 R 3 T5	180.40	120.30	375.80	150.30	13.49	20.29
R579 R3T6	186.20	124.10	387.90	155.20	13.85	21.52
R579 R3T7	205.00	133.10	415.90	170.80	13.43	22.94
R579 R3 T8	164.40	103.10	342.60	137.00	13.29	18.22
N25 R4 T1	30.00	20.00	62.50	25.00	11.23	2.81
N25 R4 T2	91.50	61.00	190.60	76.20	10.54	8.04
N25 R4 T3	93.00	62.00	193.90	77.50	10.89	8.45
N 25 R4 T4	96.40	64.30	200.80	80.30	10.21	8.20
N 25 R 4 T5	104.30	69.50	217.20	86.90	11.37	9.89
N 25 R4 T6	107.20	71.50	223.30	89.30	11.28	10.09
N 25 R4 T7	139.60	93.00	415.90	116.30	11.56	13.47
N 25 R4 T8	98.60	65.70	322.10	82.20	11.63	9.56
Mean	**136.50**	**91.00**	**284.40**	**113.80**	**12.97**	**15.17**
SED (±)	**11.74**	**7.83**	**24.46**	**9.78**	**0.31**	**1.32**
CV (%)	**18.20**	**18.20**	**18.20**	**18.20**	**5.20**	**18.60**
LSD ($P \leq 0.05$)	**23.69**	**15.79**	**49.36**	**19.74**	**0.63**	**2.68**

Key: R1 = first ratoon crop, R3= third ratoon crop, R4=fourth ratoon crop and T=Treatment

4.3.6 Correlation coefficients in among sugarcane variables

Correlations among the 12 variables are presented in Table 13. One-sided test of correlations greater than zero was used. A perfect positive fit highly significant (P<0.001) correlation was found among N, P, K and tons of cane per ha.

Highly significant (P<0.001) correlations were found among characters contributing to cane yield, which are tons of cane, stalk population, millable cane and stalk weight of 10 stalks/plot. Stalk weight/plot was found with significant (P<0.01) correlations with fertilizers and characters contributing to cane yield. Similar correlations were observed for brix percentage.

Table 13: Correlation coefficient of sugar yield, nutrients removed, effect of nitrogen fertilizer, cane yield components and cane quality

		Nutrients removed										
Parameters	**Brix % Lab**	**kg K/ha**	**kg N/ha**	**kg P/ha**	**Pol (%)**	**Pop (t/ha)**	**Purity (%)**	**Stalk weight /plot(kg)**	**Cane (t/ha)**	**Sucrose (%)**	**Millable cane/ha (t/ha)**	**10stalkweight /plot (kg)**
Brix % lab	-											
kg K/ha	0.1419***	-										
kg N/ha	0.1419***	1***	-									
kg P/ha	0.1419***	1***	1***	-								
Pol (%)	0.6808***	0.2112***	0.2112***	0.2112***								
Pop/ha	0.2187***	0.7506***	0.7506***	0.7506***	0.4035**	-						
Purity (%)	0.1411**	-0.025	-0.0251	-0.0251	-0.3847	-0.0488	-					
Stalk weight/plot(kg)	0.2321***	0.1378**	0.1378**	0.1378**	0.4459***	0.7426***	-0.0204	-				
Cane (t/ha)	0.1419***	1***	1***	1***	0.2112***	0.7506***	-0.0251	0.1378**	-			
Sucrose (%)	0.7066***	0.2065***	0.2065***	0.2065***	0.8497***	0.4109***	0.1355**	0.4828***	0.2065***		-	
Millable cane (t/ha)	0.2187***	0.7506***	0.7506***	0.7506***	0.4035***	1***	-0.0488	0.7426***	0.7506***	0.7678***		-
10 stalks weight/plot (kg)	0.3624***	0.6162***	0.6162***	0.6162***	0.4499***	0.6892***	-0.0317	0.5146***	0.6162***	0.6493***	0.4562***	

***Highly significant (P<0.001): **Significant (P<0.01): *Significant (P<0.05): Non significant (NS)

4.3.7 Relationships among N-fertilizer, tons of cane, tons of sugar and sucrose content

The linear relationships between pairs of variables are presented in Figures 4-9. The relationship for N-fertilizer rates with cane yield was linear and positive (r=0.766) with moderate coefficient of determination (R^2 = 0.587) suggesting that an increase in one variable has a positive increase on the other (Fig. 4). A similar relationship was observed for tons cane per ha and sucrose content with a linear relationship (r=0.714) with moderate coefficient of determination (R^2 = 0.510) (Fig. 5). Moreover, a strong positive linear relationships was observed for tons cane per ha and tons of sugar with high coefficient of determination (R^2 =0.994) (Fig. 6). A positive linear relationship (r =0.754) with moderate coefficient of determination (R^2 = 0.568) was observed for N-fertilizer rates and tons of sugar per ha (Fig. 7), Further, a weak linear relationships (r=0.471) with low coefficient of determination (R^2 = 0.222) was observed for N-fertilizer rates and sucrose content (Fig. 8). Finally, a positive and linear relationship (r=0.764) with moderate coefficient of determination (R^2 = 0.583) was observed for sucrose and tons of sugar (Fig. 9).

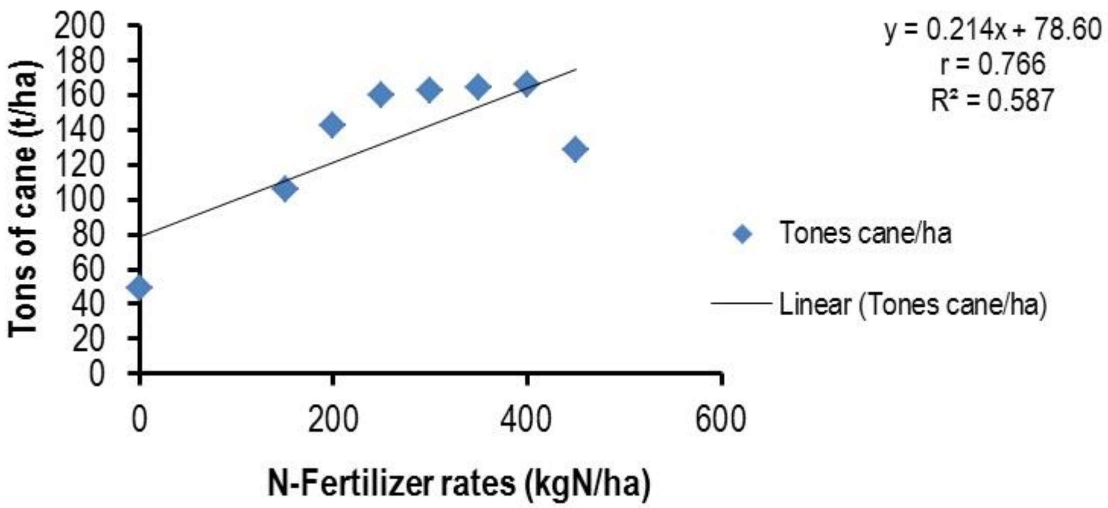

Figure 4: Relationship between N- fertilizer rates and tons of cane

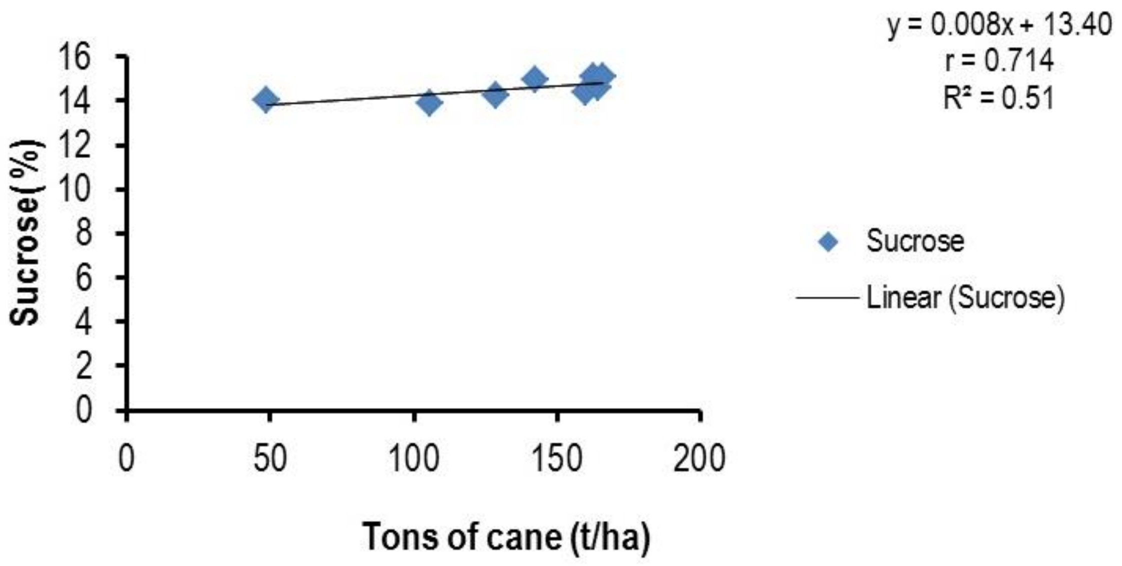

Figure 5: Relationship between tons of cane and sucrose

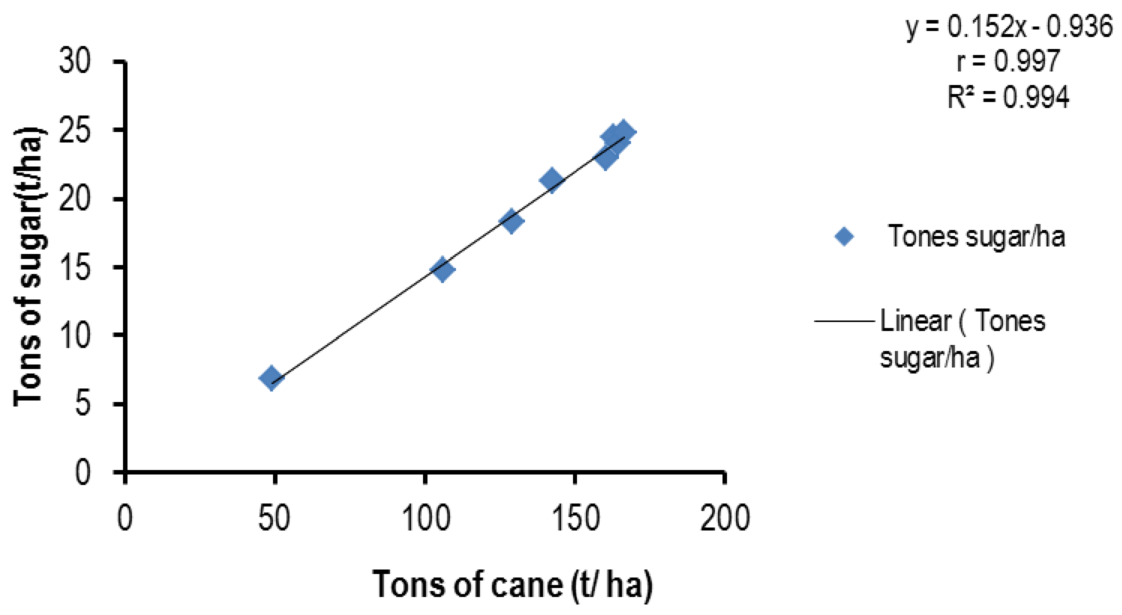

Figure 6: Relationship between tons of cane and sugar

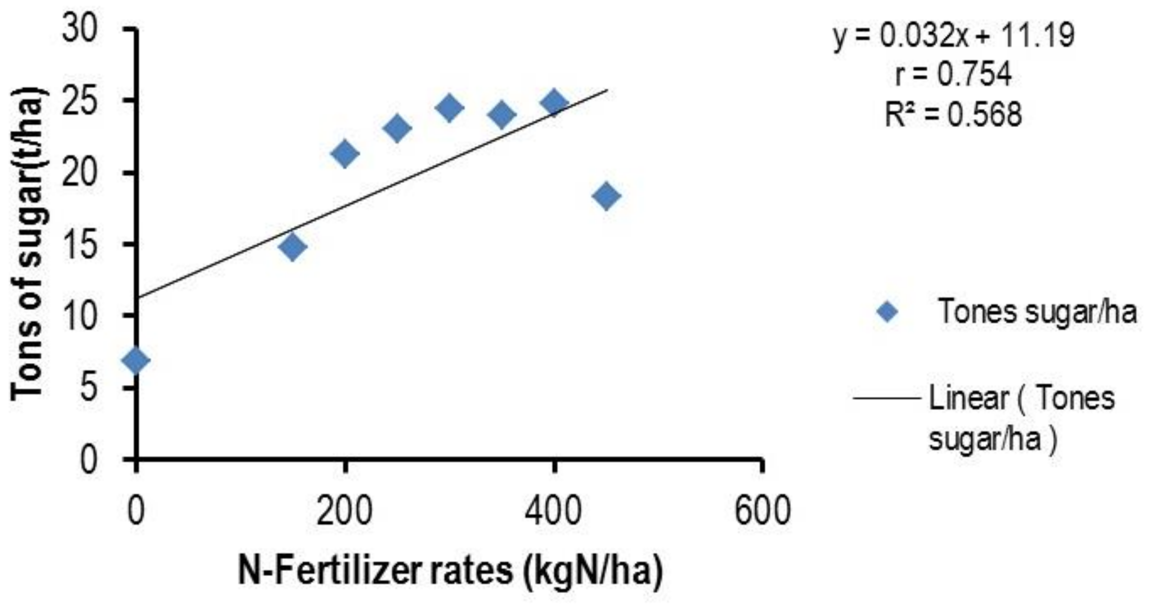

Figure 7: Relationship between N- fertilizer rates and tons of sugar

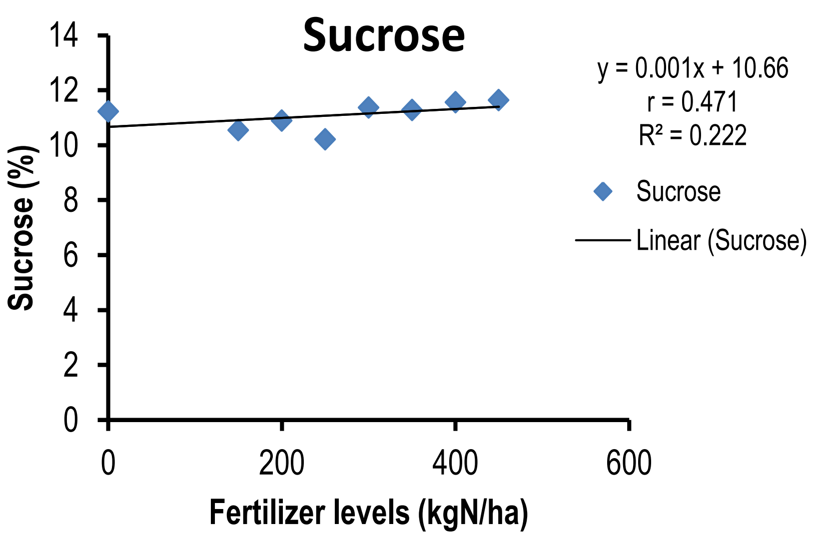

Figure 8: Relationship between N- fertilizer rates and sucrose

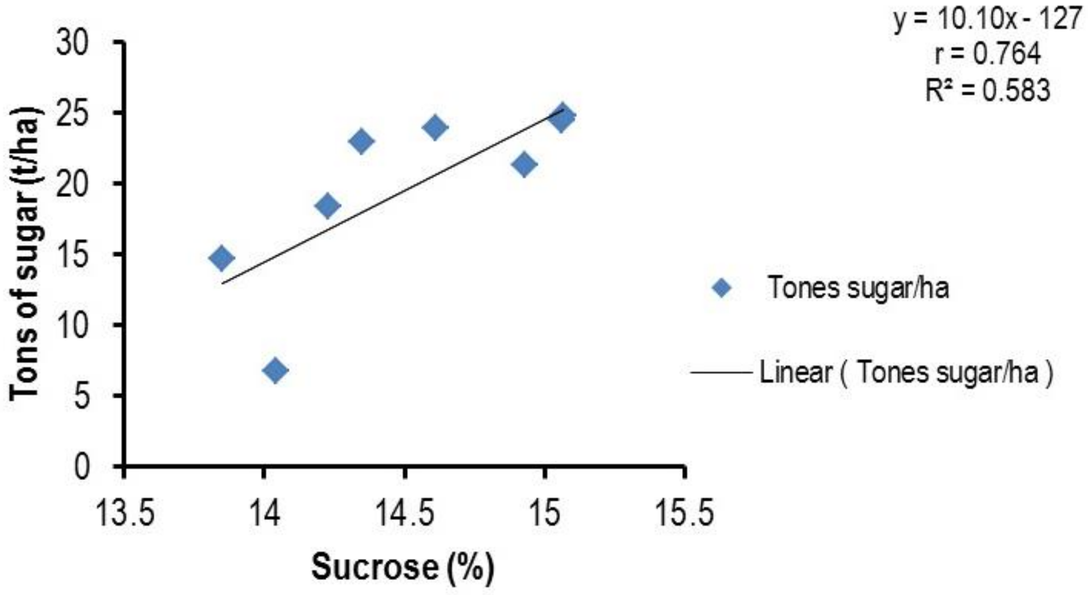

Figure 9: Relationship between tons of sugar and sucrose

CHAPTER FIVE

5.0 DETERMINATION OF BENEFIT COST RATIO FOR RATOON CROP

Area =one hectare

Cane price per ton= TSH 78 000

5.1 Cost Components

Cost components (Table14) were used to determine productivity and profit of farms. Cost components were fixed per harvesting season of sugarcane and used in all farms, but they can be changed depending on income and profit of farms per season.

Table 14: Cost components for the experiment of 1 ha

Item	Unit	Price (TSH)	Cost (TSH)
Urea	50kgN	1 200	60 000
Herbicides; (Acetochlor 900 EC)	3 liters	9 000	27 000
Volmetra 500SC 4liters	4 liters	7 000	28 000
Harvesting 5 tons per person	5 tons	1 000	5 000
Transport cost	1ton	4 000	4 000
Herbicide application	2 man days	5 000	10 000
Fertilizer application	2 man days	5 000	10 000
Total			**144 000**

5.2 Economic Analysis on N-Fertilizer Application in Sugarcane Farm during 2015/16

The study revealed that the highest benefit-cost ratio was in the control plot (6.56), followed by 400kg N/ha (2.86) and 350kgN/ha (2.61) (Table 15). On the other hand, the lowest benefit-cost ratio was observed for rate of 150 kg N/ha followed by 450 and 200 kgN/ha with the ratios of 2.02, 2.28 and 2.28, respectively (Table 15).

Table 15: Economic analysis on N-Fertilizer application in sugarcane in farm during 2015/16 cropping season

N-Fertilizer rate (kg N/ha)	Tons of cane (t/ha)	Rank	Total benefit (TSH)	Rank	Total variable costs (TSH)	Rank	Net benefit (TSH)	Rank	Benefit cost ratio	Rank
0	34.3	8	3368393	8	516,190	1	2852203	8	6.56	1
150	98.5	7	7680140	7	3757306	2	3893650	7	2.02	8
200	115.5	5	9013420	5	3929540	3	5083880	6	2.28	6
250	125.2	4	9764820	4	3970790	5	5794030	4	2.43	5
300	133.3	3	10387260	3	3999740	6	6387520	3	2.57	4
350	136.3	2	10630360	2	4100573	7	6604087	2	2.61	3
400	151.1	1	11789440	1	5462681	8	7688867	1	2.86	2
450	116.0	6	9046700	6	3931423	4	5115277	5	2.28	7
Mean	**113.8**		**8874580**		**3913723**		**4960857**		**2.25**	

5.3 Relationship between Independent Variables and Benefits Accrued

Influence of independent variables on benefits accrued is shown in Figures 10, 11, 12 and 13. The highest percentage of determination of 100 % was observed in the relationship of total benefit against tons of cane (Fig. 10) followed by total net benefit against tons of cane per ha (R^2 = 0.935) (Fig. 12), then total benefit versus total variable costs (R^2 = 0.803) (Fig. 13) and lastly tons of cane per ha versus total variable costs (Fig. 11). (R^2 =0.802).

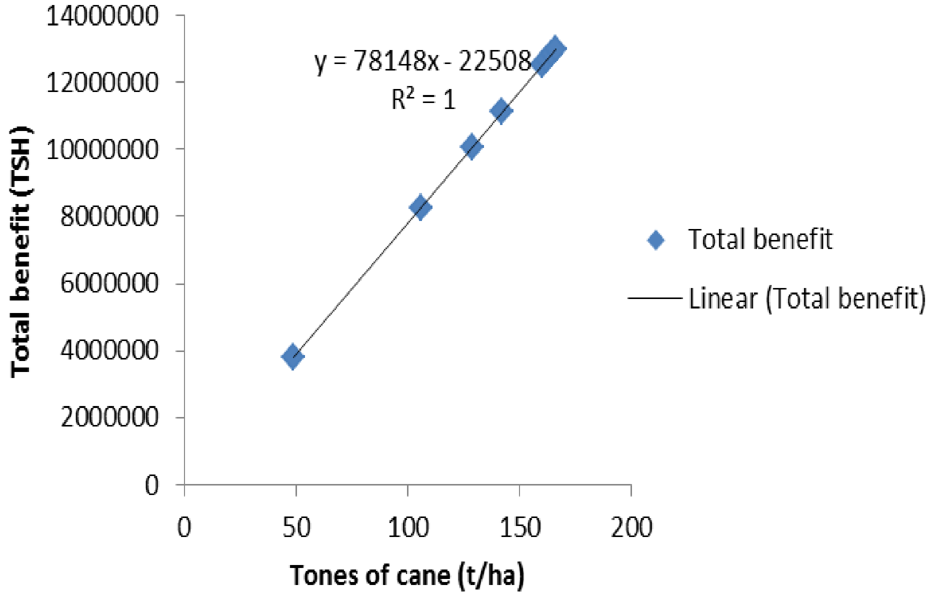

Figure 10: Relationship between tons of cane and total benefit

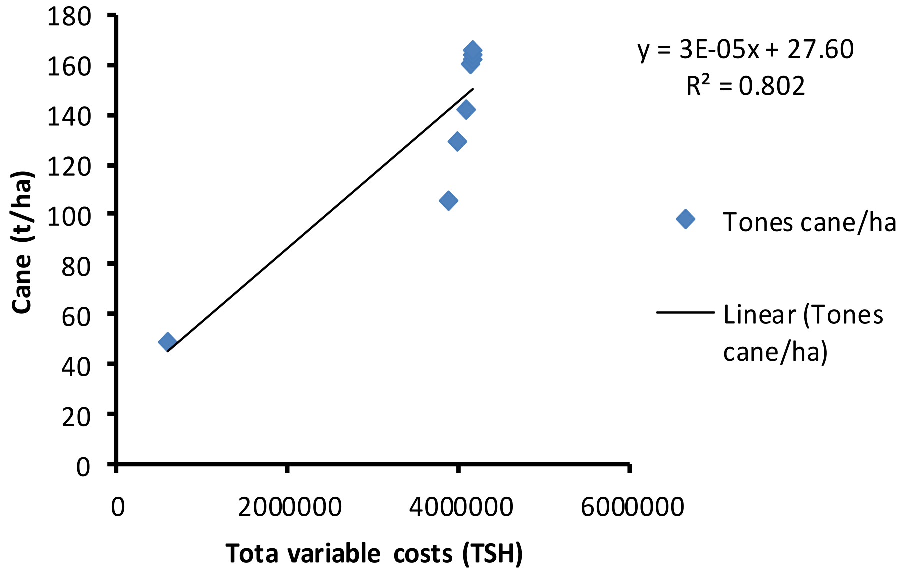

Figure 11: Relationship between total variable costs and tons of cane

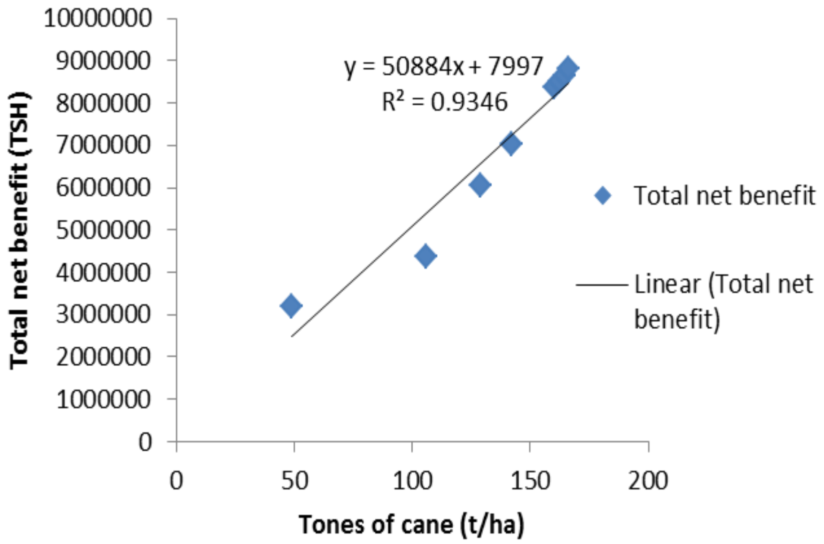

Figure 12: Relationship between tons of cane and total net benefit

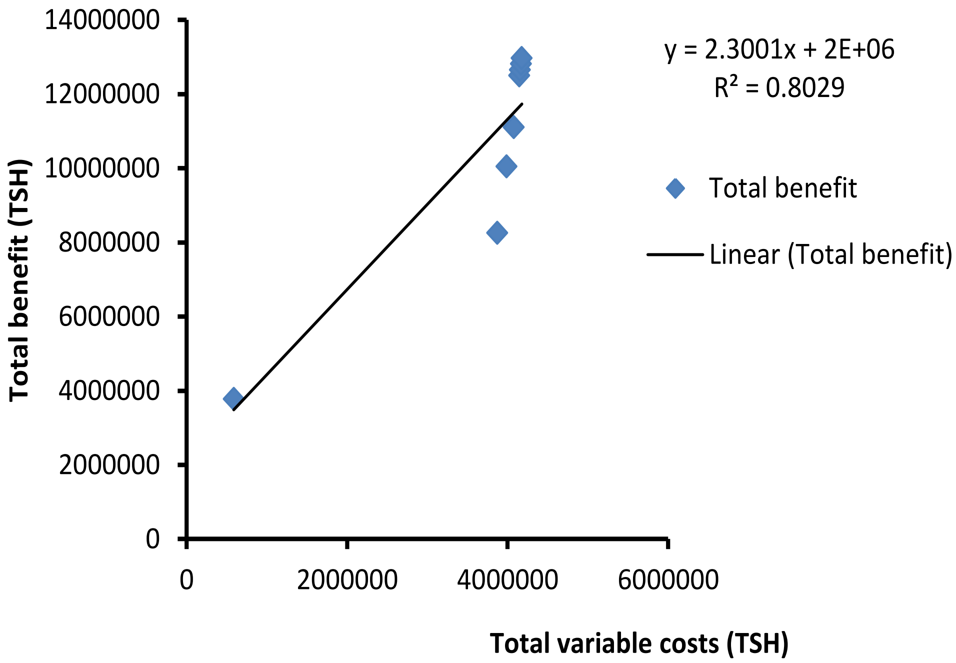

Figure 13: Relationship between total benefit and total variable costs

5.4 Correlation Coefficients among Economic Variables

Correlation coefficients between pairs of economic variables on sugar yield are presented in Table 16. Highly significant ($P<0.001$) and positive correlations were observed for tons of cane per ha with net benefit, total benefit with net benefit and tons of cane per ha with total benefits. Also, a highly significant (P<0.01) and positive correlation was observed for total variable cost with net benefit, total variable cost with tons of cane per ha and total variable cost with total benefit (Table 16). Benefit cost ratio was negatively correlated with net benefit, tons of cane/ha, total benefits and total variable costs. However, it was not significantly with net benefit while other relations were significantly and negatively correlated.

Table 16: Correlation coefficient analysis of economic variables on N- fertilizer application in sugarcane, during 2015/16 cropping season

	1	**2**	**3**	**4**	**5**
1.Benefit Cost Ratio	-				
2.Net benefit	-0.4852	-			
3.Tons of cane/ ha	-0.6927*	0.9668***	-		
4.Total benefits	-0.6935*	0.9665***	1.000***	-	
5.Total variable cost	-0.9412***	0.7522**	0.8955**	0.8961**	-

***Highly significant (P<0.001): **Significant (P<0.01): *Significant (P ≤ 0.05): Non significant (NS)

CHAPTER SIX

6.0 Discussion

All the three varieties showed differences in demand of N at grand growth and maturity phases. These might be attributed to differences among varieties in N uptake, utilization efficiency and crop cycles (Hogarth and Allsopp, 2000). Variety response to fertilizer application depends not only on the level of available plant nutrients in the soil but also related to crop physiology and morphology (Isa, 2004).

According to results obtained from this study, variety N41 in first ratoon (R1) had highest N utilization efficiency, nutrients removed, yield and quality except for purity percentage though it was statistically similar with R 579, the best in purity. This was followed by R579 in third ratoon (R3) and N25 in fourth ratoon (R4) and this could be attributed to the capacity of the variety to grow and yield on nutrient-deficient soils with specific physiological mechanisms that allow it to gain access to sufficient quantities of nutrients and utilize them efficiently (Saleem *et al*., 2012). Plant growth characteristics including roots and leaves morphology are considered to be among the physiological mechanisms which cause differences in leaf nutrients concentration and nutrients removal. Higher yielding varieties respond most readily to fertilizers (IPNI, 2016).

Results from the experiment indicated that nitrogen content in the soil was deficient. Such low levels of this essential nutrient indicated that there is a need for application of this nutrient in the soils. McCray and Mylavarapu (2013) reported that high amounts of N in soils resulted to higher total nitrogen in the leaf increasing the concentration of chlorophyll molecules and photosynthetic capacity of leaf, better growth and development of cane stalks. Similar observations were made in this study as applied N fertilizer increased leaf nutrient concentration and plant N uptake resulted into more stalks, vigorous growth and development (Fig. 3). Phosphorous and potassium contents in the soil were at sufficient levels. Such levels of these essential nutrients indicated that there was no need for application of these nutrients in the soil (IPNI, 2016).

Hogarth and Allsopp (2000) reported that leaf nutrient concentrations increased with time during the grand growth and maturity but decreased with time at harvesting. The different patterns of leaf nutrient concentrations may be due to differences on availability of irrigation water, as well as rainfall and other climatic conditions (Yousef *et al*., 2000). At grand growth, sugarcane crop showed high requirements for N-fertilizer, which was deficient in leaf at concentration range of 1.53-1.64 % and 1.27-1.39 % (Table 8) indicating that sugarcane requires more nutrients in these soils for growth and development.

Sugarcane has a higher ability to remove N (41.10 kgN/ha) in plots with no application of fertilizer and produced reasonable tons of cane per ha (34.30 t/ha) (Table 10). The highest N removed in the soil (181.40 kgN/ha) produced the highest cane weight of 151.10 t/ha (Table 9). Thus, it shows that sugarcane is more efficient in utilizing N-fertilizers for higher cane yields and that N is important in cane production. When sugarcane reaches maturity, the N and P nutrient requirements are reduced and the uptake becomes low, however, that of K increases (Table 8). The increase in cane yield appeared to reach a peak at 400kg N/ha and start to decline at 450kg N/ha because the crop demand was reached at critical level where N nutrient was sufficient, no additional nutrient inputs were needed to achieve maximum yields.

The increase in cane and sugar yields also increased with increasing rates of N-fertilizer. The N uptake by sugarcane crop was interrelated and correlated with cane and sugar yields (Table 10). Results indicated that with N-fertilizer application, cane and sugar yield increased and there were no significant effects of brix, pol and purity percentages. These suggested that quality attributes have lower soil N requirement than once applied in this study. Sugarcane quality improved at higher rates of N-fertilizer rates. An increased sugar yield with increasing N-fertilizer rate was also reported by Muchovej and Newman (2004). In the current investigation, the N-fertilizer rates had positive effect on cane and sugar yields up to 400 kg N/ha beyond which, there was a decline. Since cane, sucrose and sugar yields were statistically similar at 300-400kg N/ha with higher net benefits, application of 300 kg N/ha can also give higher cane and sugar yields at Kilombero.

This study showed that the response of N-fertilizer to variety- ratoons contributed strongly in determining the number of millable stalks, which has large influence on final cane and sugar yields where by the relatively higher yields were from 133.30 (300 kg N/ha) – 151.10 t/ha (400 kg N/ha) with 18.22-20.41 t/ha respectively. The data associated with cane yield suggested that, nitrogen affected significantly growth and development of sugarcane crop and consequently number of millable stalks which is the most important yield component of cane and sugar. Similar findings were reported by Hogarth and Allsopp (2000). Nitrogen application promotes tillering in cane crop with consequent increased production of millable stalks. It is also important in early growth stage mostly for vegetative development. The positive and significant effect of nitrogen on number and length of millable stalks was also reported by Azzazy and El-Geddawy (2003). The findings indicated that the significant response of yield attributes to N-fertilizer could be due to its effects on crop growth. Saleem *et al*. (2012) reported that, N-fertilizer had a great influence on cane stalks development at early growth, cane and sugar yields.

In this study, cane and sugar yields generally increased with N-fertilizer rates, although the quality parameters were not statistically different. N-fertilizer does not bring consistence on quality parameters depending on weather conditions as reported by KSC (2015). For instance Azzazy *et al.* (2000) obtained higher yields of cane and sugar with increased higher rates of N as results of this study indicate, but obtained improved quality parameters at higher rates of N-fertilizers. Saleem *et al*. (2012) also reported non-significant differences on quality parameters in commercial fields at varied levels of nitrogen fertilizer. Significant increase in cane yield in response to higher rates of N was also reported by Jagtap (2006). Differences in cane yield might be attributed by special features, including the morphological characteristics of plants, soil types, the ratios of shoots to roots, characteristics of root development, specific nutrient requirements and nutrient dynamics (Isa, 2004). Hogarth and Allsopp (2000) reported that, despite clear differences among varieties in ion uptake characteristics, the rate of nutrient uptake by a variety depends on individual variety demand and external nutrient concentration, soil moisture, soil type and agronomic practices.

In this study, N and P levels were higher at grand growth stages and dropped at maturity, However, K increased from grand growth to maturity. Hogarth and Allsopp (2000) found that when sugarcane attains full maturity, its moisture and N levels drop and reducing sugars are converted into sucrose. Yousef and Taha (2003) reported that cane yield responded positively and significantly to nitrogen with the availability of balanced nutrition at the time of cane formation resulting in better crop growth. Higher number of millable canes per unit area with increasing rate of N was also reported by Yousef *et al*. (2000). Isa (2004) found that increase in stalk length with increasing N-fertilizer rates application were significant on total sugar yield, which is a cumulative effect of cane yield (ton/ha) and sucrose percentage.

The lower rate of N-fertilizer applied gave less sucrose percentage content, yield of cane and sugar. Rice *et al*. (2010) reported that cane yield and sucrose content were significantly interrelated with applied fertilizers. Differences in sugar yield in response to different fertilizer rates were also reported by Jagtap (2006).

The study suggests that N is not sufficient in commercial farms which might lead to low productivity regardless of soil type, variety and climatic conditions. According to Havlin (1999) plant cane at 3 months and ratoon cane at 2 months should contain 2.40% to 2.50% N. Similarly, plant cane at 5 months and ratoon cane at 3 months should contain 2.10% N. Plant cane at 6 months and ratoon cane at 4 months should contain 1.90 % N, if P and K are not limiting in the soil (Yahaya *et al.*, 2008). The current study indicated that only N was deficient probably due to soil fertility status but P and K were sufficient. Results explain for positive response on cane and sugar yields upon increased application of N rates.

The response of yields to applied N is strongly influenced by the ability of soils to mineralize N. The sugarcane crop depends on N soil supply and other environmental factors (Hogarth and Allsopp, 2000). The ratoon crop grows faster than the plant crop and the leaf canopy covers much earlier than plant crop. Ratoon crops tend to produce more stalks per hectare than plant crops. It is therefore evident that long term ratoon monoculture of sugarcane degrades the physical, chemical, and biological properties of the soil (Maro, 2004).

At Kilombero, soil degradation and sugarcane yield decline are amongst the major problems. Sugarcane is capable of rapidly depleting the soil of mineral elements, particularly N and K (Maro, 2004). A high yielding variety can remove up to 250 kgN/ha, 30kgP/ha and 650 kg K/ha depending on crop growth stage and cycle (IPNI, 2016). Results from this study have confirmed that high rates of N applications increase yields of cane and sugar. These results con-cur with the findings reported by Hogarth and Allsopp (2000). Under certain conditions, application of N-fertilizer by splitting may be beneficial on soils with restricted drainage and sandy soils (Yahaya *et al*., 2008).

There was no significant ($P \leq 0.05$) interaction between varieties and nitrogen rates for nutrients removed, cane and sugar yields and sucrose percentage but was significant ($P \leq 0.05$) for sugar yield (Table 4). There was a general increase in nutrients removed associated with increased cane and sugar yields. These could have been attributed to nutritional and physiological functions that promote yields. The combination of N41R1 x N fertilizer rates of T7, T6, T5 and T4 and R 579 R3T7 had highest yields of cane and sugar followed by R 579 R3 x N-fertilizer rates of T6 and T5 and the least yields were for N25 R4 x N-fertilizer rates of T7, T6 and T5. Thus, since the interaction between varieties and N-fertilizer rates was not statistically significant in most of the yields and quality attributes, combinations of variety x fertilizer rates followed a similar pattern as for mean effects of varieties (Tables 4 and 7).

Economic analysis performed to determine which N-fertilizer rates were economical for adopting by cane growers indicated that optimum rate of N-fertilizer is 400 kgN/ha after considering their effects on cane and on benefit cost ratio. However, the highest B/C ratio was for 0kg N/ha followed by 400kgN/ha. The N-fertilizer rates of 350 and 300kgN/ha, were also economical but had slightly lower B/C ratio. The B/C ratio supports these fertilizer rates with high net benefit, total benefits and tons of cane per ha. Similar results were reported by Dutton (2016). The existing profitability levels can be considerably improved with the use of required nitrogen rates as per crop demand (Hogarth and

Allsopp, 2000). However, 0 kg N/ha had the highest B/C ratio, yet had the least net benefit, total benefits, tons cane per ha and lowest total variable costs, yet not a recommended package because profit can only be improved by increasing income, a function of production and price or by reducing costs (overhead and variable costs). The 400 kgN/ha was beneficial on yields of cane and sugar. Similar scenario was reported by Dutton (2016), that benefit cost ratio is not a reliable parameter for increased yields and benefits.

Results on correlation suggest that higher investments are necessary for higher yields and benefits because the economic variables were significantly and positively correlated, and the use of higher N-rates had a positive relationship with yields of canes and sugar.

CHAPTER SEVEN

7.0 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Application of fertilizer rate at 400 kgN/ha resulted into higher cane and sugar yields at Kilombero followed by 350 and 300kgN/ha. Variety N41 R1 had highest N utilization efficiency, nutrient removal, yield and quality followed by R 579 R3 and N25 R4. This study indicated better responses on yield components and quality parameters of sugarcane crop with increased N-fertilizer rates application. Application of 400kgN/ha indicated economical productivity and profitability of the farm followed by 350 and 300 kg N/ha as shown by tons of cane, total benefits, net benefit and benefit cost ratio. The highest B/C ratio in 0kg/ha is offset by low revenue attained. The interaction of N41 R1 x N-fertilizer rates of T7, T6, T5, T4 and R 579 R3T7 had higher yields of cane and sugar followed by R579 R3 x N-fertilizer rates of T6 and T5, and N25 R4 x N-fertilizer rates of T7, T6 and T5. Perfect and positive correlations were observed between N removal with cane t/ha. Most of the cane yield components and nutrients removed were significantly and positive correlated. All the economic variables studied except benefit cost ratio were significantly and positively correlated among themselves. All of the economic variables were negatively correlated with benefit cost ratio and significantly so except with net benefit.

7.2 Recommendations

i. The optimum rate of 400 kg N/ha followed by 350 and 300 kg N/ha should be used for introduced sugarcane varieties in commercial fields at Kilombero.

ii. Combination of N41 R1T5 and 41 R1T7 should be used to maximize yields of cane, sugar and sucrose percentage at Kilombero.

iii. Research involving several seasons and sites (multilocational trials) should be done to confirm on specific combinations of variety x fertilizer rates that give maximum cane, sugar yields and sucrose percentage.

iv. Higher total variables costs and good crop management should be in place to maximize yields and benefits in sugar production at Kilombero.

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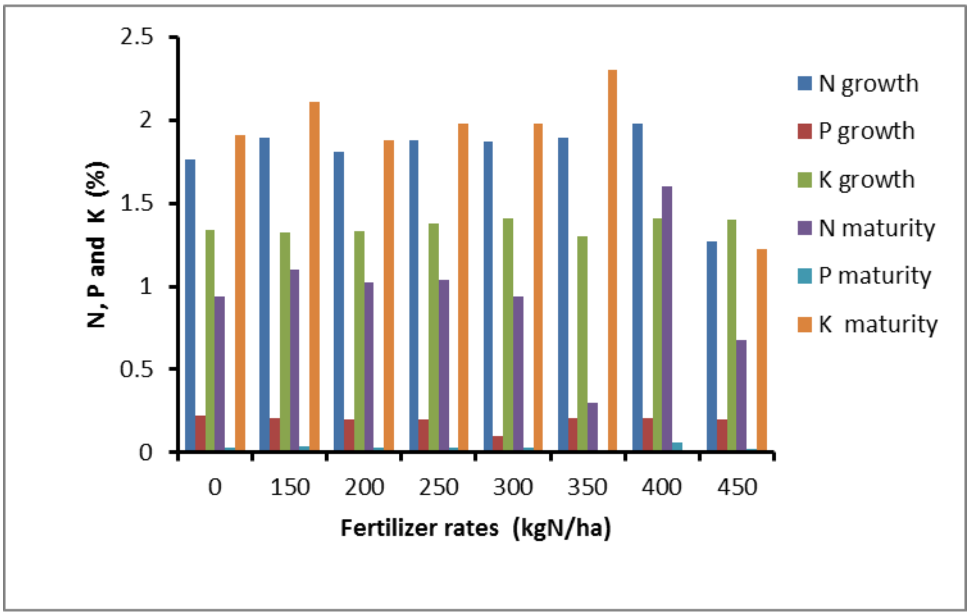
APPENDICES

Appendix 1: Nutrients concentration at varying phonological stages and fertilizer rates

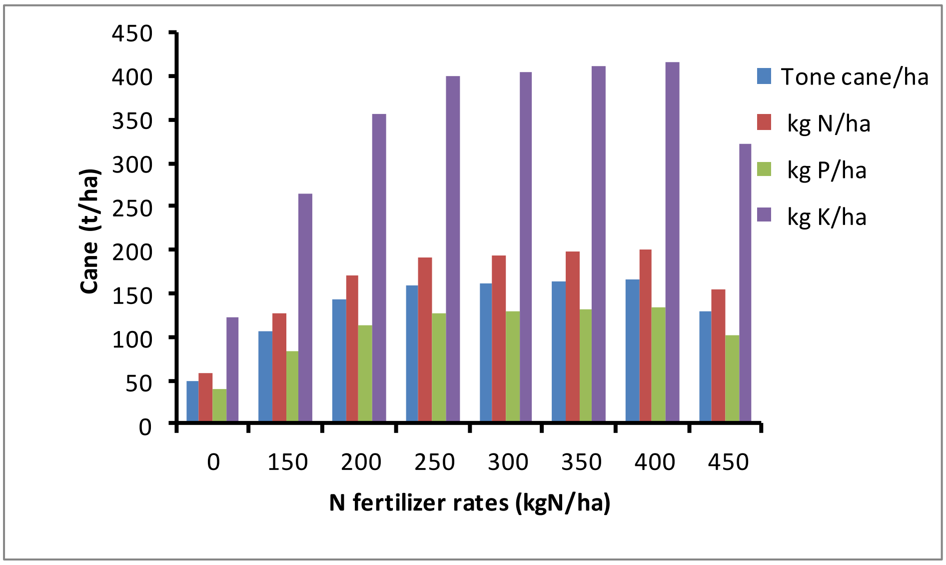


Appendix 2: Nutrient leaf concentration category ranges

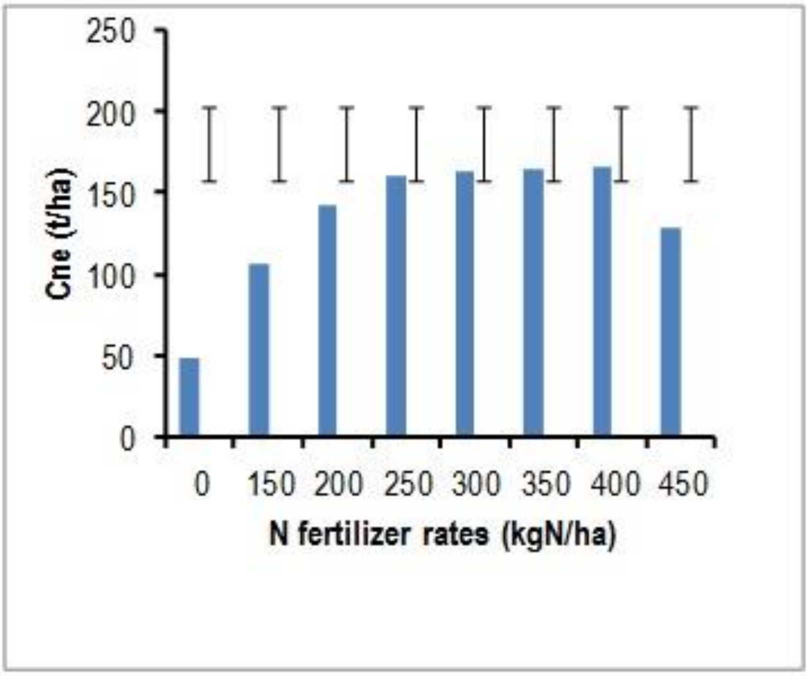
Category ranges	**N (%)**	**P (%)**	**K (%)**
Very deficient	<1.60	<0. 17	<0. 80%
deficient	1.6 –1.79	0.17–0.18	0.80–0.89
Marginal	1.8-1.99	0.19-0.21	0.90-0.99
Sufficient	2.00-2.30	0.22-0.26	1.00-1.30
Sufficient plus	2.31-2.60	0.27-0.30	1.31-1.60
high	2.31-2.60	= >0.30	>1.60

Source: Rice *et al.* (2010).

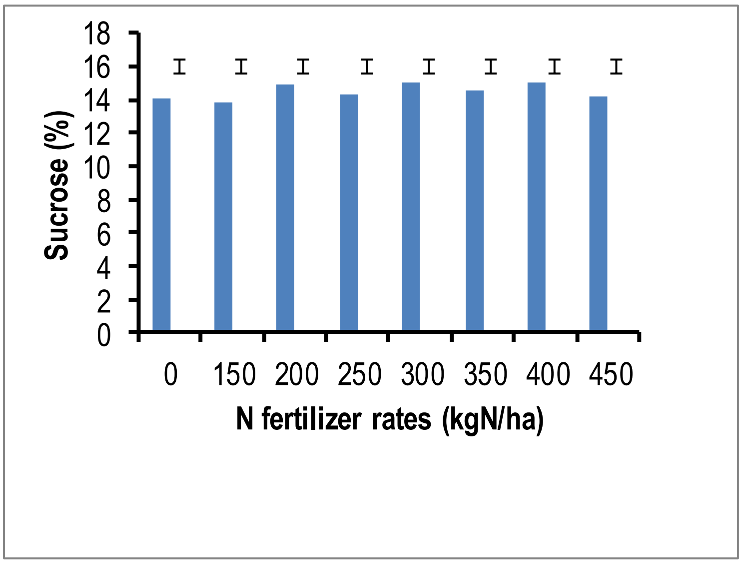
Appendix 3: Nutrients removal at varying rates of nitrogen fertilizer



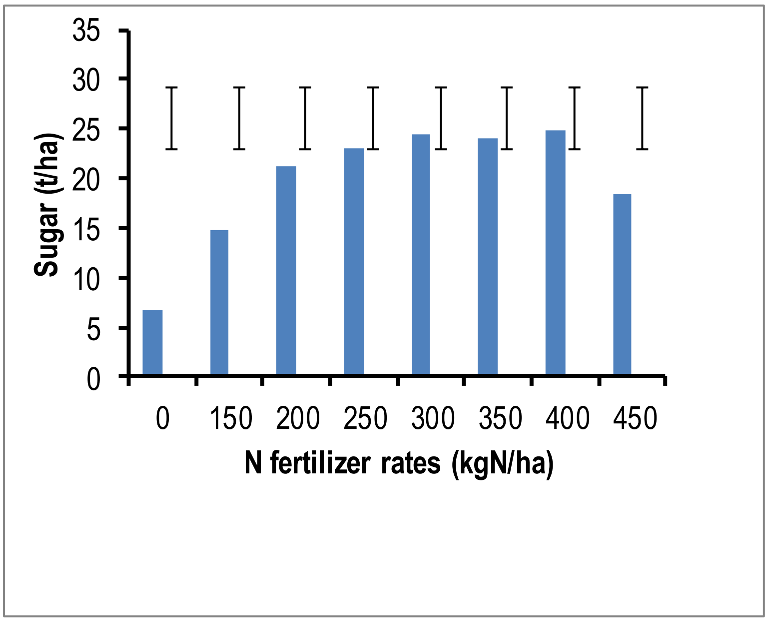
Appendix 4: Cane yield as affected by different rates of nitrogen fertilizer



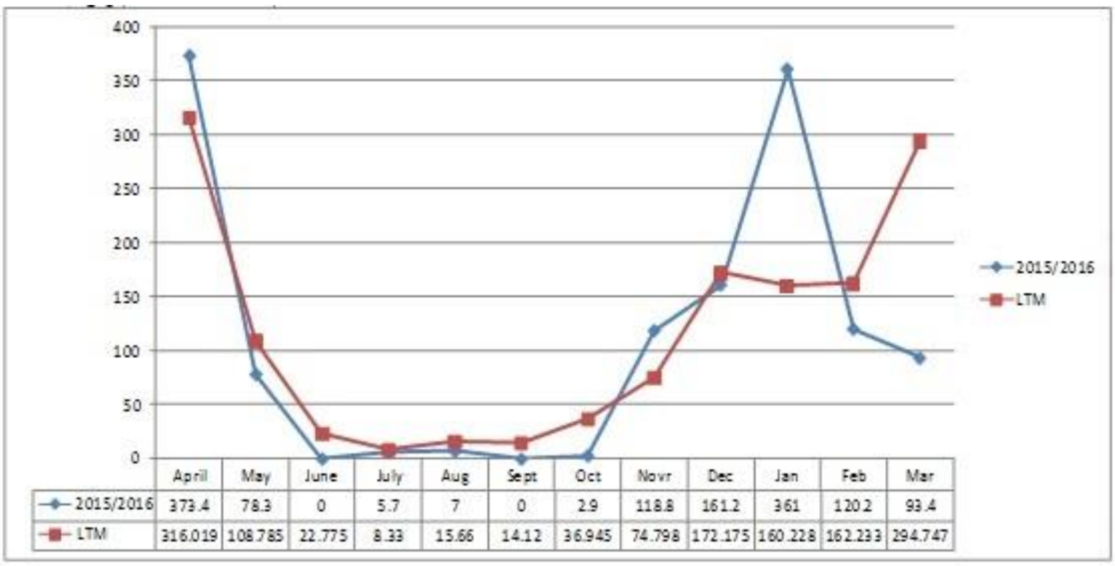
Appendix 5: Sucrose percentage at different rates of nitrogen fertilizer



Appendix 6: Sugar yield at different rates of nitrogen fertilizer



Appendix 7: Rainfall vs LTM 2015/2016 season at Kilombero Sugar Company Ltd



Appendix 8: Weather Data at Kilombero Sugar Company (2015)

Month	RAINFALL (mm) (MSOLWA)	RAINFALL (mm) (RUEMBE)	EVAPO. (mm)	MAX. TEMP.	MIN. TEMP.	MIN. REL. HUMIDITY (%)	MAX. REL HUM.	S/SHINE (HRS)	SOIL TEMP. 09.00 a.m)	WIND SPEED (KM/HR)
April	155.60	147.70	163.70	31.60	21.70	54.60	92.80	6.00	29.60	2.90
May	146.70	138.00	152.20	31.50	21.70	54.80	93.70	6.30	29.60	2.90
June	256.90	236.80	150.90	30.40	21.70	57.20	94.60	6.00	29.50	2.70
July	320.40	295.80	115.60	29.60	21.30	61.20	95.40	5.30	28.20	2.80
August	115.60	122.10	118.70	28.60	19.70	58.10	93.30	5.30	27.00	2.80
September	25.40	28.40	120.50	27.20	17.50	53.10	93.80	6.00	25.80	3.00
October	11.90	11.40	127.10	27.10	16.70	50.50	92.50	5.80	25.30	3.00
November	10.70	12.40	136.90	28.10	17.80	50.20	89.60	5.80	26.20	2.70
December	14.90	12.20	158.70	29.80	18.20	46.70	90.00	6.20	27.80	2.80
January	34.40	37.00	187.30	32.00	20.30	47.30	88.30	6.70	29.10	2.90
February	91.10	79.50	193.70	33.00	21.30	46.80	88.50	7.40	30.30	3.10
March	150.70	145.50	184.70	32.30	21.80	51.50	91.70	7.10	30.20	2.80
Mean	**111.20**	**105.60**	**150.80**	**30.10**	**20.00**	**52.70**	**92.00**	**6.20**	**28.20**	**2.90**

Appendix 9: Weather Data at Kilombero Sugar Company (2016)

Month	RAINFALL(mm) (MSOLWA)	RAINFALL(mm) (RUEMBE)	EVAPO. (mm)	MAX. TEMP	MIN. TEMP.	MIN. REL. HUMIDITY (%)	MAX. REL HUM.	S/SHINE (HRS)	SOIL TEMP. 09.00 a.m)	WIND SPEED (KM/HR)
April	160.30	152.70	162.70	31.60	21.70	54.80	92.80	6.00	29.60	2.90
May	144.10	134.80	149.50	30.90	21.30	53.80	92.00	6.20	28.90	2.70
June	252.30	231.30	148.10	29.80	21.30	56.20	92.90	5.90	28.70	2.50
July	314.70	288.90	113.40	29.10	20.90	60.10	93.60	5.20	27.50	2.70
August	113.50	119.30	116.60	28.10	19.40	57.00	91.60	5.20	26.30	2.70
September	25.00	27.70	118.30	26.70	17.20	52.20	92.10	5.90	25.10	2.80
October	11.70	11.10	124.80	26.60	16.40	49.60	90.80	5.70	24.70	2.80
November	10.50	12.10	134.40	27.60	17.50	49.30	88.00	5.70	25.50	2.60
December	14.60	11.90	155.80	29.20	17.90	45.90	88.30	6.10	27.10	2.70
January	33.80	36.20	183.90	31.40	19.90	46.40	86.60	6.60	28.40	2.70
February	89.50	77.60	190.20	32.40	21.00	45.90	86.90	7.20	29.50	2.90
March	148.00	142.10	181.40	31.70	21.40	50.50	90.00	7.00	29.40	2.70
Mean	**109.80**	**103.80**	**148.30**	**29.60**	**19.60**	**51.80**	**90.50**	**6.10**	**27.50**	**2.70**

Appendix 10: Irrigation scheduling at Kilombero Sugar Company (2015/16)

Hierarchy				Net Demand and Supply (mm)					Stress (days)							
	Potential Et (mm)	Actual Et (mm)	Measured Rainfall (mm)	Effective Rainfall (mm)	Net Irrigation (mm)	No. Irrig. Events	Area Irrigated (ha)	Cumulative Area Irrigated (ha)	Avg. Cycle Time (days)	Potential Et Prior to Dry-off (mm)	Actual Et Prior to Dry-off (mm)	Supply/Demand Index (%)	Prior to dry-off	During dry-off	Days Saturated
306	1244.80	1014.40	715.10	358.30	577.50	15.00	12.90	193.00	16.10	1059.50	916.80	87.70	22.30	10.90	42.00
234	1510.00	892.00	872.50	571.60	270.00	6.00	23.40	140.40	48.80	1328.40	795.80	60.10	107.30	13.00	38.00
142	225.90	225.90	438.00	158.10	0.00	0.00	17.00	0.00	36.90		36.90	150.50	0.00	0.00	33.00

Appendix 11: Sugarcane production areas in Tanzania

Source: SBT (2014)