# INFLUENCE OF CULTIVARS AND NITROGEN FERTILIZER RATES AND APPLICATION MODE ON YIELDS AND QUALITY PARAMETERS OF RATOON SUGARCANE IN WESTERN KENYA

**Abstract**

Productivity of sugarcane in Kenya has declined despite use of recommended production practices including introduction of elite high yielding and early maturing sugarcane varieties. Farmers continue to use recommended agronomic inputs for the old low yielding and late maturing varieties on these elite varieties. Nitrogen fertilizer rates in single or split doses for old varieties are still in use yet their appropriateness on new varieties remains untested culminating to decline in sugarcane productivity in Kenya. Currently, cane payment is based on delivered milling cane weight. The industry plans to change payment to a combination of quality and yields. Influence of agronomic inputs and timing of harvesting period on proposed mode of payment is unknown. Harvesting age in western Kenya remains 18-20 months after ratooning (MAR). However, optimal age that combines quality and yields is not documented. Influence of these agronomic practices on quality, yields and optimal harvesting age of ratoon crop of new (D8484) and old (CO421) varieties were evaluated in 2x4x3 split-split-plot design replicated three times. Four rates of nitrogen as urea, all applied at 3 MAR, split once (50-50%) and applied at 3 and 6 MAR or split three times (40-30-30%) applied at 3, 6 and 9 MAR were evaluated. Yields and quality parameters were monitored from $10^{th}$-$24^{th}$ MAR. Variety D8484 out-yielded ($p \leq 0.05$) CO421 throughout demonstrating its superiority. Yields reached maximum at 20 and 19 MAR for CO421 and D8484, respectively. Maximum pol and brix were attained at 18 and 15 MAR for CO421 and D8484, respectively while commercial cane sugar (CS) was maximum at 18 and 17 MAR for CO421 and D8484, respectively. Results demonstrated that for high returns, D8484 should be harvested between 15-18 MAR while CO421 between 17-19 MAR.

The 60 kg N/ha, that produced higher ($p \leq 0.05$) output in both varieties, from 16th MAR is recommended for both varieties. Split fertilizer application did not affect productivity.

**Keywords:** Sugarcane, Ratoon, Varieties, Nitrogen fertilizer application, Yields, Harvesting time

# 1. INTRODUCTION

Sugarcane (*Saccharum officinarum L.*) is commercially grown in for sugar production in climates ranging from hot dry locations near sea level to cool and moist locations at high elevations (Plaut, Meinzer, & Federman 2000). The plant produces sugar as the main product and other co-products such as ethanol used by pharmaceutical industry and as fuel, bagasse for paper and chip board manufacture and press mud as a rich source of organic nutrients for crop production (Lingle, Wiedenfeld, & Irvine 2000). In Kenya, sugar is exclusively produced from sugarcane and the industry is a major employer and contributor to the national economy, supporting approximately 250,000 small-scale farmers that supply 92% of cane (KSB, 2010). Area under sugarcane in Kenya increased between 1997 and 2010 from approximately 128,000 ha to 157,000 ha with 54,621 ha harvested annually. Despite the increase in area under cane, sugar production has either stagnated or declined (Wawire, Kahora, Wachira, & Kipruto 2006) over the years, culminating in need for efforts to increase productivity.

The efforts to increase productivity have included development and release of new sugarcane varieties to Kenya sugar industry that are high yielding and early maturing (Wawire et al. 2006). Early maturing varieties are defined as those maturing at 8-10 months in India (Blackburn, 1984), 10-11 months in Indonesia (Gonzales & Galvez 1998), 9-10 months in Mauritius (Hunsigi, 1993) and 15-19 months in western Kenya (Jamoza 2005; Wawire et al. 2006). It was hoped these new released varieties would improve productivity. However, despite the introduction of the new varieties, declining/stagnating production levels of sugar has persisted.

The national sugarcane yields have continued to decline to as low as an average of 53.62 TCH in 2013 (KSB 2013), which is below the potential for the varieties that have achieved up to 100 TCH under rain fed conditions (Ochola, Owuor, Abayo, & Manguro 2014; Wawire et al. 2006). These new early maturing sugarcane varieties were, however, released without development of specific agronomic technologies suitable for their high production. Consequently**,** these new varieties are being subjected to same agronomic inputs as the old late maturing varieties. It is not tested if these technologies are appropriate for these new varieties.

In North America, early maturing varieties require different fertilizer rates from late maturing varieties (Snyder & Bruulsema 2007). Nitrogen is considered an important nutrient for sugarcane and yield responses usually accrue from its application (Ochola et al. 2014; Ong'injo & Olweny 2011). Nitrogen fertilizer application in sugarcane farming is therefore mandatory (Sreewarome, Seansupo, Prammanee, & Weerathworn 2007). The range of nitrogen fertilizer rates currently in use is 100-120 kg N/ha applied in a single dose. These rates were developed and recommended in 1980s for plant and ratoon crops of the old and late maturing varieties (Anonymous 1985). The new cane varieties produced in Kenya may require different rates from the old late maturing varieties. Again, poor nitrogen fertilizer use such as inappropriate rate, application age from ratooning and placement method may reduce crop performance. Studies have reported that sugarcane producing areas exhibiting mineral soils and very low organic matter content, nitrogen must be supplied in split fertilizer applications (Mabry McCray et al. 2017). Moreover, for soils that are low in nitrogen, like sugarcane growing soils in Kenya, split nitrogen fertilizer application is recommended since it may improve yields (Wiedenfeld 1997). Péné & Coulibaly-Ouattara (2019) reported no significant difference in sugar yields between N rates applied at once in first ratoon. The research further showed that in ratoon sugarcane, at N-rates higher than 100 to 110 kg/ha, sugar yield increase was negligible and concluded that the observation was not the case for the return cost of any additional N-rate applied. It is important to note that the choice of single application of nitrogen fertilizer in the study was informed by findings obtained under farming conditions in the study area where two applications of N-fertilizer at planting and tillering stage did not significantly affect cane and sugar yields compared with a single application (Péné et al. 2018). Long-term effects of different nitrogen levels on growth, yield, and quality in sugarcane were assessed and the findings suggested that 300 kg/ha urea application was suitable for the plant and first ratoon crops, and 150 kg/ha urea application was suitable for the second and third ratoon crops (Zeng et al. 2020). This study evaluated the influence of nitrogen fertilizer rates and splitting application on crop productivity.

The Kenya Sugar Industry pays farmers based on delivered milling cane weight. This method does not consider the quality of the delivered cane; consequently, either millers or farmers lose. An objective payment system should be based on both cane yields and quality (Anonymous 2001). Agronomic practices and varieties have been documented to influence quality of sugarcane juice (Mengistu 2013). The implementation of the Sugar Act (Anonymous 2001) that intended to incorporate cane quality in paying sugarcane farmers has been difficult since it was introduced before evaluation of how its implementation will affect the industry and how the agronomic inputs recommended in sugarcane production influence the payment system.

Variety CO421 is an old and late maturing variety while D8484 is a new high yielding early maturing variety released in 2007. Both varieties are widely cultivated in western Kenya. The two varieties were used to evaluate if old and new varieties respond differently to nitrogen fertilizer application and how their ratoon crop yields, harvesting age, quality and productivity vary.

## 2. MATERIALS AND METHODS

### 2.1. Study site and experimental design

The experiment (on ratoon crop) was a continuation of a trial on plant crop conducted in Opapo sub-station of Kenya Sugar Research Institute, 25 km west of Rongo town at latitude $0^{o}$ 30' S, longitude $34^{o}$ 30' E and altitude 1351 m above mean sea level. The experimental design was 2x4x3 split split-plot in randomized complete block arrangement, where the sugarcane varieties CO421 and D8484 were the main treatments while nitrogen (N) rates and number of splits were the split and sub split-split treatments, respectively. The treatments were replicated three times. Each sub-plot comprised of 7 rows of sugarcane and measured 1.2 m wide x 10 m long (84 $m^2$). Fertilizer nitrogen (urea) was applied in each plot depending on the assigned levels and splitting schedule. The levels were 0, 60, 120 and 180 kg N/ha which were applied once at the third month after ratooning (MAR), split into two halves and each half applied at the third and sixth MAR and split in the ratio of 4:3:3 and applied at the third, sixth and ninth MAR respectively.

### 2.2. Crop management

The plant crop was harvested in February 2010, de-trashed and the trash spread on the plots. Two weeks after harvesting the plant crop left over sugarcane trash were aligned in alternative inter-row spaces, followed by inter-row cultivation to suppress emerging weeds and break possible hard pans, as is the normal practice. Weeds that emerged after three months were controlled by manual hand weeding at an interval of one hand weeding per month or when the weeds appeared. At 5 MAR, the sugarcane crop had formed sufficient canopy cover to smother any subsequent emerging weeds. However, due to exposure, the borders of the experimental fields were kept weed free by hand weeding throughout the experimental period.

Sugarcane smut disease is the most common, and deleterious, in the Kenya sugar industry (Nzioki, Jamoza, Olweny, & Rono 2010). Sugarcane varieties vary in their reaction to its infection with some being susceptible while others are tolerant (Nzioki et al. 2010). During the study period, the disease was monitored using the whip-like deformed stalk symptoms for identification. Identified diseased stalks were rouged at early stages to control the disease from maturing and spreading the shoot-like spores in neighbouring cane plots.

### 2.3. Sugarcane yield and quality parameters determination

Sugarcane dry matter was determined from $10^{th}$ to $24^{th}$ MAR by de-trashing and weighing freshly harvested (cut at the base) cane stalks per 30 cm plot length of the destructive sampling row (either $2^{nd}$ or $6^{th}$ row) of the net sub-subplot. The fresh stalk weight in the 30 cm row length was divided into two equal halves and one half weighed again assuming it to now have come from 15 cm row length. This sub-sample fresh weight was therefore extrapolated to per ha basis as follows:

Fresh weight (Tons cane (TC) $Ha^{-1}$) = sub-sample fresh weight x 10000 $m^2$/(0.15m x 1.2m) at 10, 12, 14, 16, 18, 20, 22 and 24 MAR. The 1.2 m was the inter-row spacing.

Cane quality was estimated using pol and brix levels. Pol measured the sucrose content while brix determined the total dissolved solids in the cane juice. From these two parameters commercial cane sugar (CCS) was determined and from yields and CCS, tons of sugar (TS) was determined. The other half of the fresh cane was used to determine the quality parameters. The quality parameters (pol and brix) were measured from the cane stalks starting from $10^{th}$ to $24^{th}$ MAR. Ten randomly sampled sugarcane stalks were harvested and de-trashed then crushed on a roller mill to extract cane juice. Analysis of pol and brix were done according to ICUMSA (1994) methods, using a polarimeter and refractometer, respectively. Percent commercial cane sugar (CCS %) was calculated as:-

- CCS% = pol%-{(brix%-pol%)}/2

Tons sugar per hectare (TS/ha)) was calculated as follows:

- TSS/Ha= (CCS %) x (TC/Ha)/100

## 2.4. Data analysis

The generated data were subjected to analysis of variance (ANOVA)  (Statistical Analysis System (SAS) Version 9.2 (SAS Inc., 2002)) as a 2x4x3 split-split plot design using general linear models procedure on the various parameters to determine any significant treatment effects at $p \leq 0.05$ confidence level. A quadratic model was used to estimate the responses in yields and quality with time and determine optimal harvesting time.

## 3. RESULTS AND DISCUSSION

### 3.1. Variations in yields

The sugarcane yields (in TC/Ha) two the varieties are presented Figure 1. The yields realized were generally high and above those realized by the industry. Similar such high yields have been recorded in another fertilizer trial (Ochola et al. 2014). These results demonstrate that with proper management, it is possible to increase sugarcane productivity in Kenya.

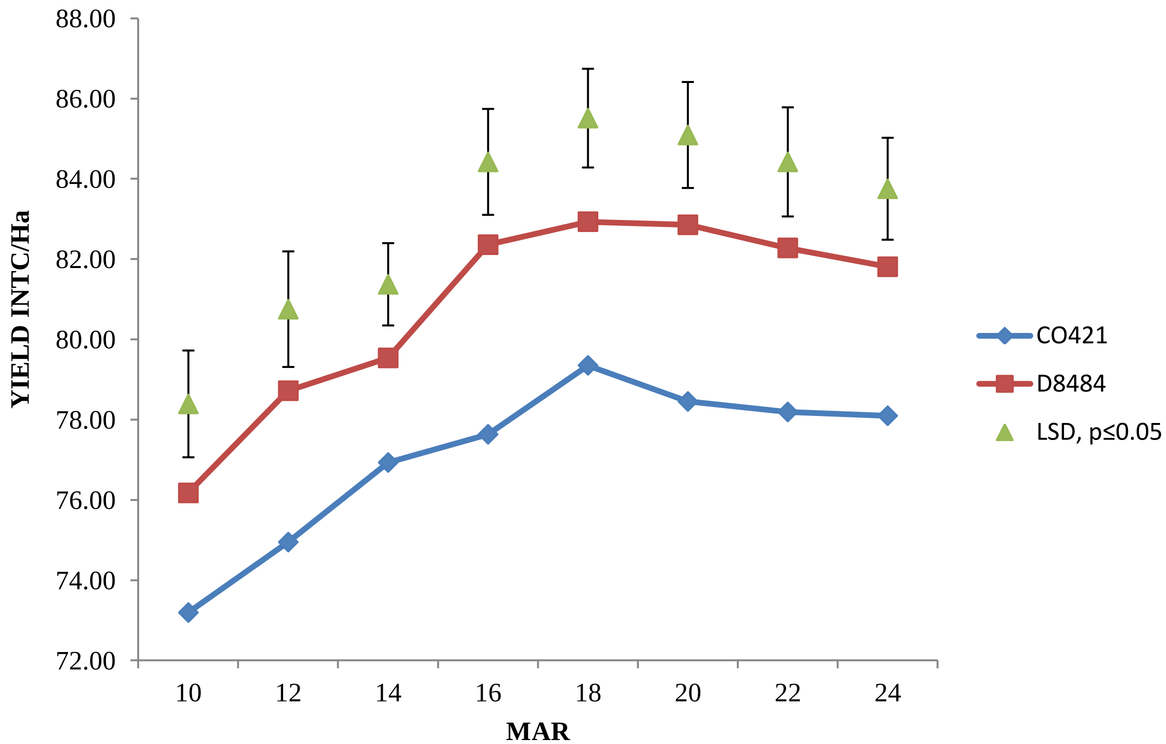


Figure 1 Comparison of the sugarcane yields (in TC/Ha) due to varieties

Throughout the monitoring period, variety D8484 out-yielded ($p \leq 0.05$) variety CO421. In previous studies variety CO421 yielded differently from other varieties in Australia (Hurney & Berding 2000). However, in Ethiopia there were no yield differences in several cane varieties (Ambachew, Abiy, & Zeleke 2012) possibly due to the difference in environmental conditions or lack of genetic diversity in varieties tested. The higher yield of D8484 over CO421 support the earlier results from plant crop improvement studies (Jamoza 2005; Wawire et al. 2006), that the newly developed and released varieties in western Kenya were superior in yields compared to the old varieties. These results demonstrate that such yield superiority was maintained in the ratoon crop. The results further show that proper varietal selection is important for realization of good yields in sugarcane production even in ratoon crops. In both varieties yields responses with MAR were quadratic reaching maximum at 21 and 20 MAR for CO421 and D8484, respectively. Despite CO421 being a late maturing variety, and D8484 an early maturing variety (Jamoza 2005; Wawire et al. 2006), surprisingly their tail off time after ratooning was the same. These results demonstrate that in both varieties, based on yields harvesting ratoon crops should be done at between 16 and 21MAR in both varieties and that there is no yield benefit accruing from the ratoon crops staying in the field beyond these periods. Indeed, past this period, yields start declining.

There were sporadic responses ($p \leq 0.05$) to nitrogen rates with CO421 responding in 12$^{th}$, 16$^{th}$, 18$^{th}$ and 24$^{th}$ MAR and D8484 responding from the 16$^{th}$ to 20$^{th}$ MAR (Figure 2). In the months when there were significant ($p \leq 0.05$) responses, the 60 kg N/ha rate was superior. Although sugarcane yield responses to nitrogen have been recorded in several studies (Ambachew et al. 2012; Ashraf et al. 2008; Bahrani, Shomeili, Zande-Parsa, & Kamgar-Haghighi 2009; Mengistu 2013; Muchovej & Newman 2004), even in Kenya (Ong'injo & Olweny 2011). In the maximum responses were realised at higher nitrogen rates than the 60 kg N/ha observed in a ratoon crop herein. This could be due to varietal differences in responses to nitrogen (Ambachew et al. 2012; Schroeder, Wood, & Meyer 1993, ) and/or geographical area of production (Ambachew et al. 2012). The recommended rate of nitrogen for ratoon crop sugarcane is 100-120 kgN/ha (Anonymous 1985). The results presented herein demonstrate that application of higher nitrogen rates than 60 kgN/ha to ratoon crop maybe unnecessary. Péné & Coulibaly-Ouattara (2019) reported that in ratoon sugarcane, at N-rates higher than 100 to 110 kg/ha, sugar yield increase was negligible and concluded that the observation was not the case for the return cost of any additional N-rate applied. A study on the effect of nitrogen rates and application time on sugarcane yield and quality concluded that the critical N rates ranged from 40 to 60 kgN/ha (Lofton & Tubaña 2015).

Significant yield responses to split application of nitrogen fertilizer were not observed in CO421, however, D8484 and mean of varieties recorded significant ($p \leq 0.05$) yield values at 16th, 18th and 20th MAR (Figure 3). The data did not follow any particular pattern for CO421 and the mean. However, for D8484, the single dose and split into two applications produced better yields that were not significantly different from 16th to 20th MAR. Similar sporadic responses as in CO421 and the mean to splitting nitrogen fertilizer on cane yields had been observed in Florida (Muchovej & Newman 2004). However, as was also observed in many months in this study, yield responses to splitting nitrogen fertilizer application can be rare (Stranack & Miles 2011). Thus, for ratoon crops in Kenya, there is no yield benefit in splitting application of nitrogen fertilizer for old varieties, but for new varieties like D8484, splitting the nitrogen application beyond two times has no yield benefit.

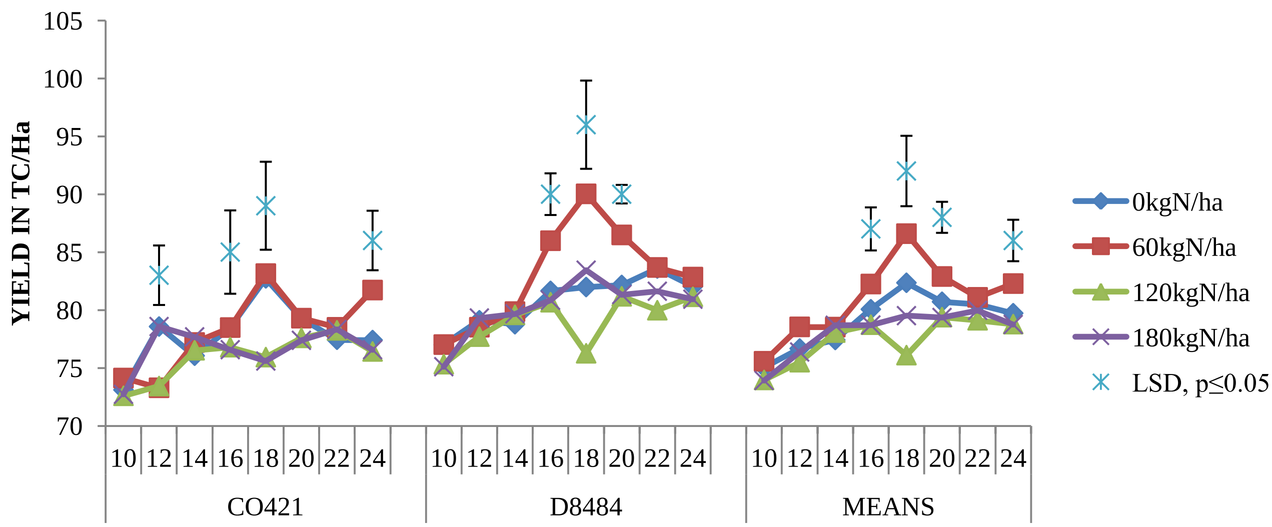


Figure 2 Effect of nitrogen fertilizer rates on cane yields (in TC/Ha) of CO421 and D8484

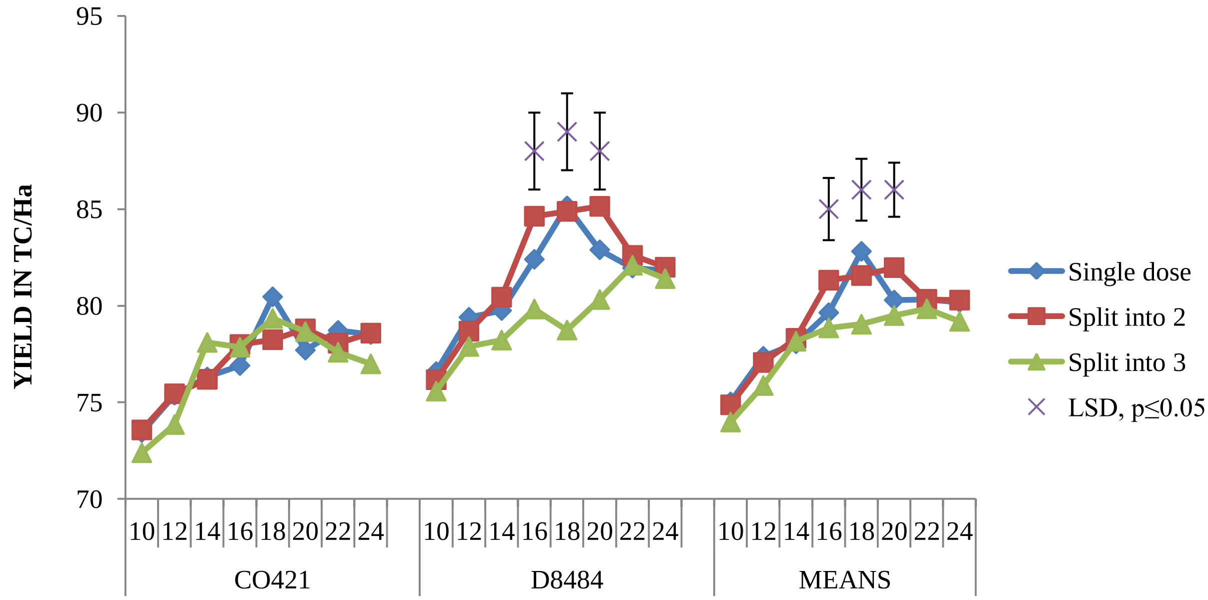


Figure 3 Effect of split applications of nitrogen fertilizer rates on cane yields (in TC/Ha) of CO421 and D8484

### 3.2. Variations in quality parameters of the cane varieties

The variations in pol with MAR are presented in Figure 4. Except in the 18th MAR when the pol levels crossed, there were significant ($p \leq 0.05$) variations in pol throughout the study period. In the early stages up to 16th MAR, D8484 had higher ($p \leq 0.05$) pol values than CO421. The converse was observed from 20th to 24th MAR. In earlier studies elsewhere (Hurney & Berding 2000), sucrose accumulation rates varied with varieties. These results demonstrate that when pol is used as a quality determinant, it is beneficial to harvest D8484 ratoon crop between 14th and 16th MAR, while CO421 can be harvested from 14th to 20th MAR without severe loss in pol. Indeed these results confirm that D8484 is an early maturing variety (Jamoza 2005; Wawire et al. 2006).

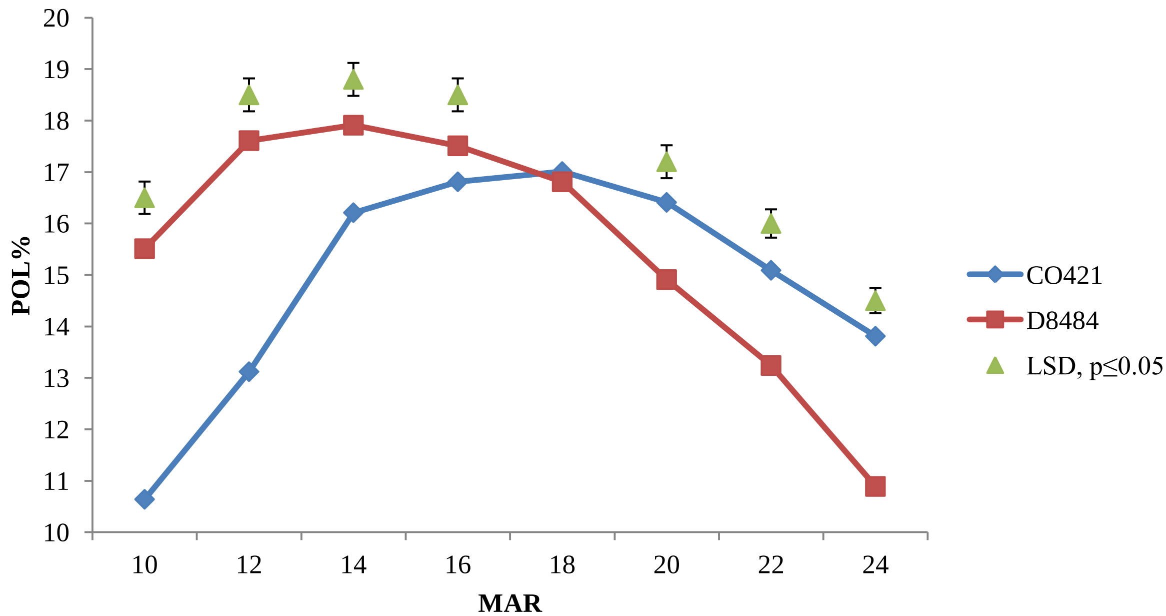


Figure 4 Comparison of pol% of cane varieties CO421 and D8484

Pol content of variety CO421 did not respond to nitrogen fertilizer rates (Figure 5), similar to an earlier observation on CO421 in South Africa (Stranack & Miles 2011). However, D8484 had significant ($p \leq 0.05$) pol variations from the 12$^{th}$ to 16$^{th}$ MAR. All nitrogen rates produced higher ($p \leq 0.05$) than the control. The period of significant responses (Figure 5) coincided with when the variety had maximum pol (Figure 4). These results show that in variety D8484, application of nitrogen fertilizer is necessary for high quality realization.

Unlike in some previous studies (Koochekzadeh et al. 2009; Madhuri, Kumar, Rao, Sarala, & Giridhar 2011; Muchovej & Newman 2004; Yahaya, Falaki, Amans, & Busari 2009), in which there was decline in pol with increase in nitrogen rates, higher pol in D8484, were at 60 kg N/ha although the levels were not significantly different from pol levels at 120 and 180 kg N/ha. There was a general decline in pol levels with increase in nitrogenous fertilizer rates between 60 and 180 kg N/ha in D8484, although this did not attain significant values. In both varieties, there were no variations in pol levels due to splitting nitrogen fertilizer application (Figure 6), as had been recorded in other studies elsewhere (Koochekzadeh et al. 2009; Madhuri et al. 2011; Muchovej & Newman 2004; Stranack & Miles 2011; Yahaya et al. 2009). The data was however, in contrast with other studies (Azzay & Elham 2008; Bahrani et al. 2009; Mengistu 2013; Ong'injo & Olweny 2011; Yousef, Taha, & Ahmad 2000), in which splitting nitrogen application improved pol levels. Most of the published data are however on plant crop. Little data exists on ratoon crop. However, these results demonstrate that splitting nitrogen application to ratoon crop of CO421 and D8484 in Kenya did not benefit sugar recovery.

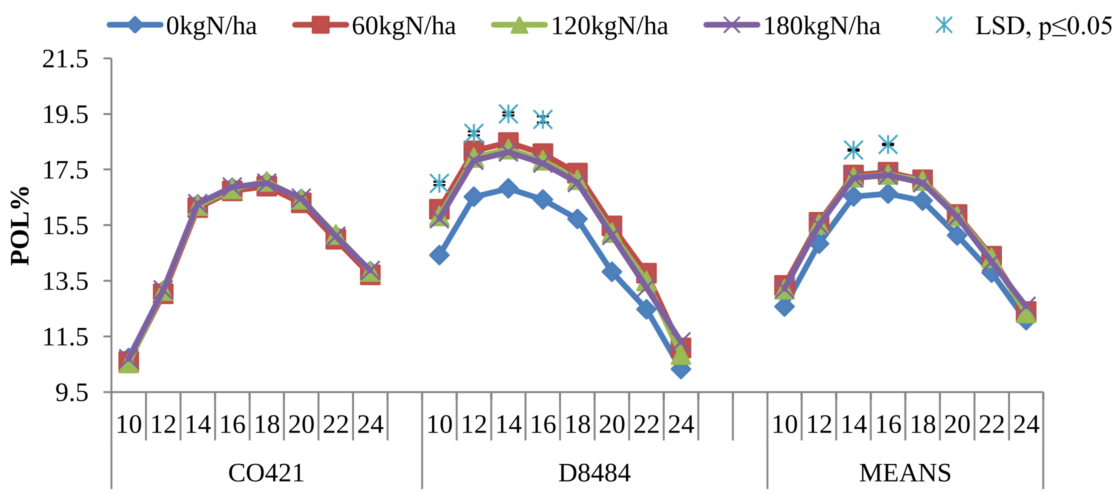


Figure 5 Effect of nitrogen fertilizer rates on cane pol% of CO421 and D8484

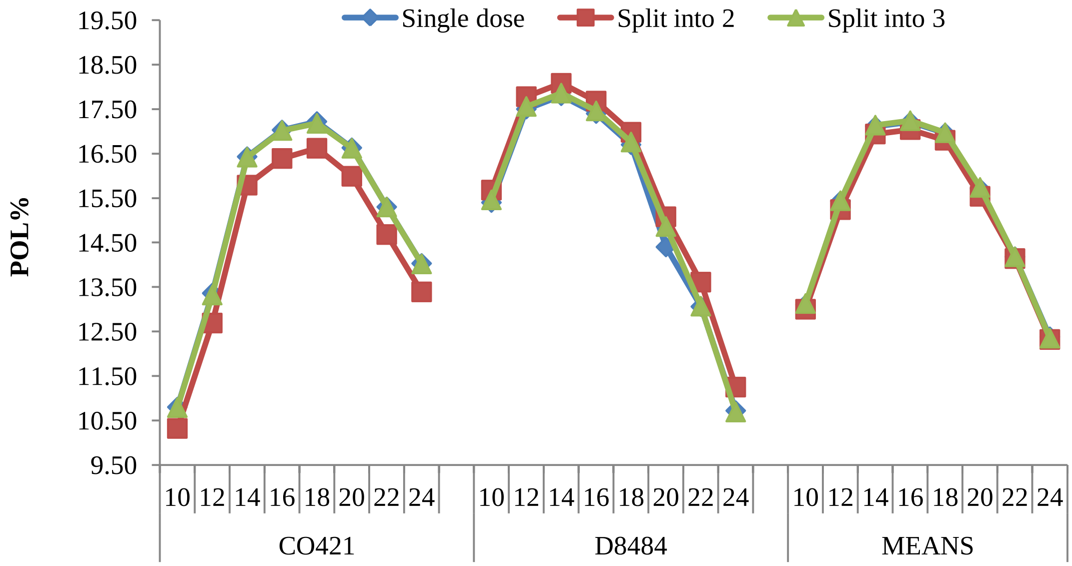


Figure 6 Effect of split applications of nitrogen fertilizer rates on cane pol% of CO421 and D8484



Most of soluble solids in cane juice (brix) are sugars including glucose and fructose. Throughout the study period, the brix levels of CO421 and D8484 were different ($p \leq 0.05$) and followed the same pattern as the pol levels (Figure 7). Brix levels were higher ($p \leq 0.05$) in D8484 than in CO421 from 10th to 16th MAR after that the values interchanged. This observation was not strange since brix and pol are interrelated and highly correlated (Breaux 1972) and had been observed in plant crop in previous studies (Hurney & Berding 2000; Jamoza 2005; Wawire et al. 2006). Thus, D8484 ratoon crop should be harvested between 10th and 18th MAR, while CO421 can be harvested from 15th to 22nd MAR without losses in quality as measured by brix.

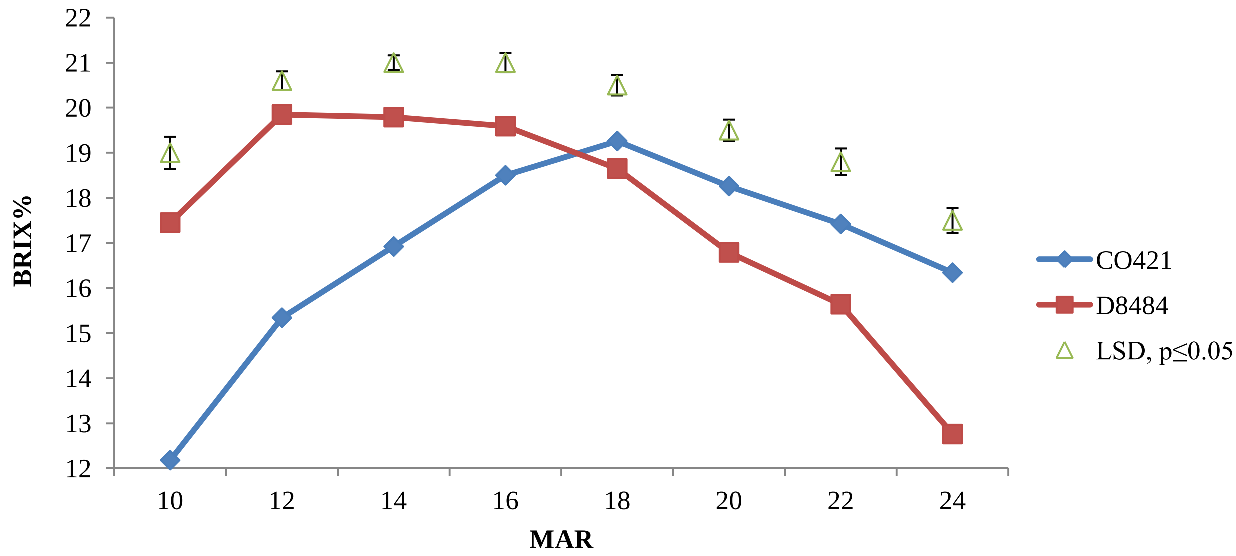


Figure 7 Comparison of brix% of cane varieties CO421 and D8484

Although the patterns of curves of response of brix to nitrogen rates were the same in both varieties (Figure 8), in CO421 significant ($p \leq 0.05$) responses were only observed in the 10$^{th}$, 15$^{th}$, 18$^{th}$ and 24$^{th}$ MAR. In D8484 the response ($p \leq 0.05$) were observed only in 15$^{th}$ and 24$^{th}$ MAR. Such responses were clearly sporadic. Although sporadic responses had been reported on brix responses to nitrogen rates (Berding, Hurney, Salter, & Bonnett 2005; Koochekzadeh et al. 2009; Mengistu 2013; Saleem, Ghaffar, Anjum, Cheema, & Bilal 2012; Yahaya et al. 2009), other studies recorded brix decline with increase in nitrogen fertilizer rates in plant crops (Azzay & Elham 2008; Bahrani et al. 2009; Ong'injo & Olweny 2011; Yousef et al. 2000). In this study, however, 0 kg N/ha had lower brix levels than where nitrogen had been applied. This is similar to results on pol. The contrast in the results can be attributed to the soil type and properties and climatic conditions (Wiedenfeld 2000).

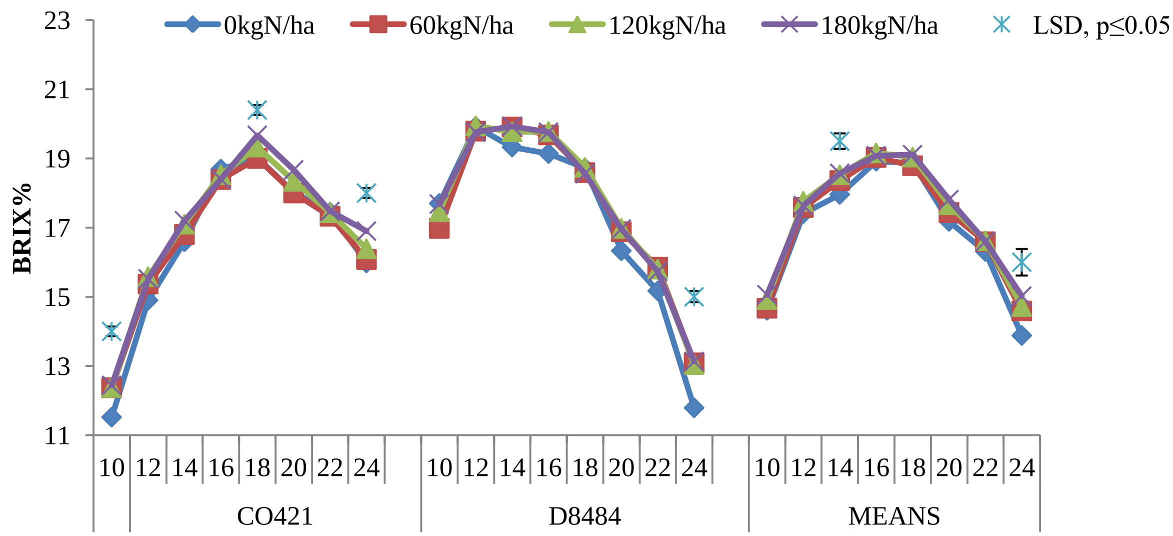


Figure 8 Effect of nitrogen fertilizer rates on cane brix% of CO421 and D8484

There were no responses in brix levels to splitting nitrogen application (Figure 9). Although splitting nitrogen fertilizer application increased sugarcane brix levels in some studies (Azzay & Elham, 2008; Bahrani et al. 2009; Yousef et al. 2000), in other studies (Berding et al. 2005; Koochekzadeh et al. 2009; Mengistu, 2013; Saleem et al., 2012; Yahaya et al. 2009) there were no responses. The results show that the responses can vary with varieties and/or location of production. Split application of nitrogen fertilizer may not therefore increase brix as a measure of quality in varieties CO421 and D8484.

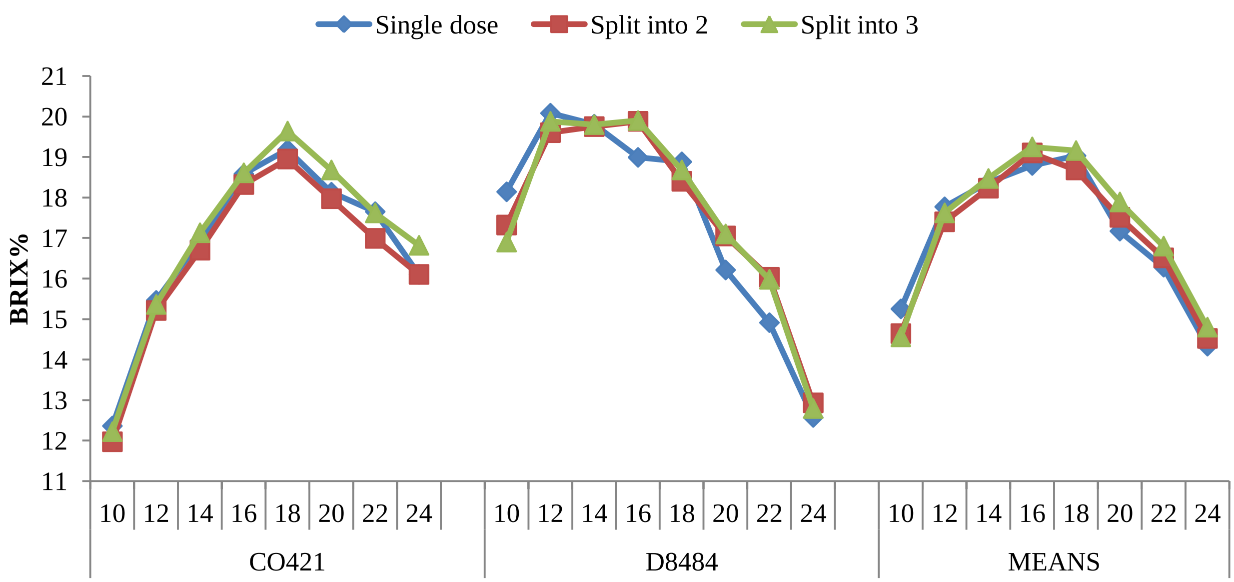


Figure 9 Effect of split applications of nitrogen fertilizer rates on cane brix% of CO421 and D8484

TS is a more accurate measure of productivity than cane yield, pol or brix. Both varieties had quadratic TS response to MAR reaching maximum between 15 and 18 MAR (Figure 10). Up to 20 MAR, D8484 had higher ($p \leq 0.05$) TS than CO421. Overall, variety D8484 registered significantly higher ($p \leq 0.05$) TS per hectare than CO421 until 20$^{th}$ MAR. These results demonstrated that varieties differ in TS production as had also been observed elsewhere (Ambachew et al. 2012; Schroeder et al. 1993; Srinivas, Rao, Suresh, Vijayakumar, & Kishan 2003). For higher economic returns variety D8484 should therefore be harvested between 12$^{th}$ and 16$^{th}$ MAR while CO421 should be harvested between 16$^{th}$ and 20$^{th}$ MAR. Indeed, these results also demonstrated the superiority of the newly developed varieties over old varieties.

In both varieties, at different rates of nitrogen, there were quadratic responses in TS production with MAR (Figure 11). In both varieties, there were ($p \leq 0.05$) differences in monthly responses to rates of nitrogen on TS levels, except in the 16$^{th}$ and 20$^{th}$ MAR for CO421 and 22$^{nd}$ MAR for D8484, which could be due to chance. The 60 kg N/ha produced higher ($p \leq 0.05$) TS levels throughout.

Again, the 0 kg N/ha rate had the lowest (p≤0.05) TS. Although in some previous studies (Ambachew et al. 2012; Bahrani et al. 2009; Koochekzadeh et al. 2009; Madhuri et al. 2011) the TS per hectare increased with rates of nitrogen, decrease in TS due to increasing levels of nitrogen fertilizer, as had also been recorded (Muchow, Robertson, Wood, & Keating, 1995; Rattey & Hogarth, 2001) elsewhere. Herein, such linear responses were not observed. The low TS at 0 kg N/ha in D8484 demonstrated the need to supply nitrogen in western Kenya. However, losses can incurred by applying beyond 60 kg N/ha. The currently used rate on ratoon crops of 100 to 120 kg N/ha (Anonymous 1985) may be inappropriate in western Kenya.

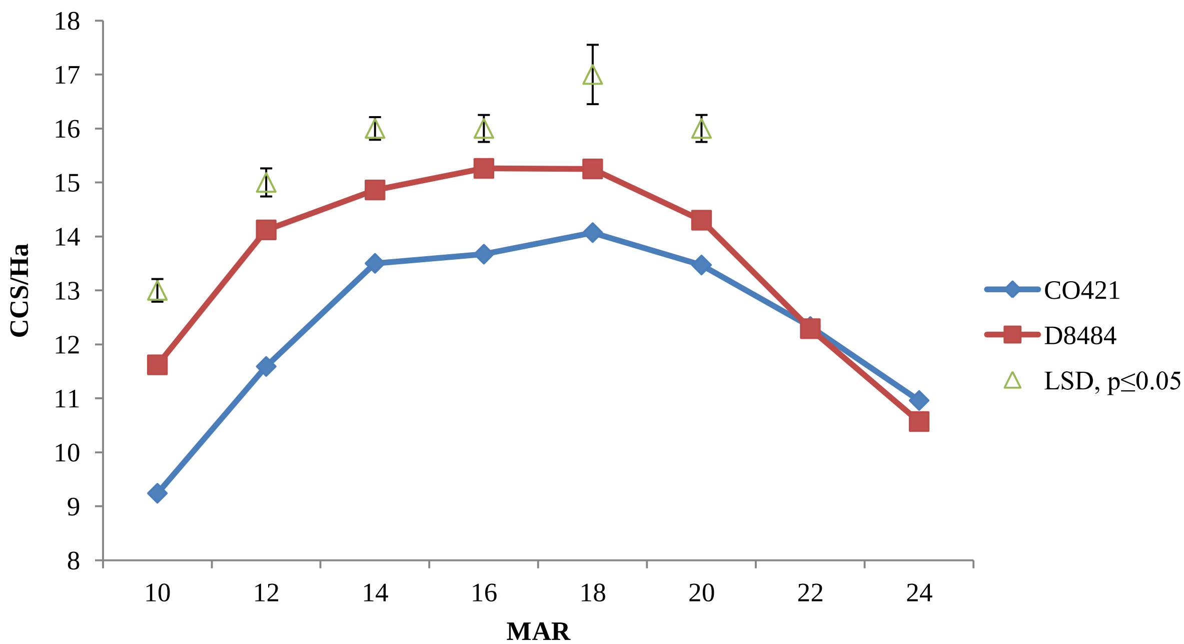


Figure 10 Comparison of CCS/Ha of cane varieties CO421 and D8484

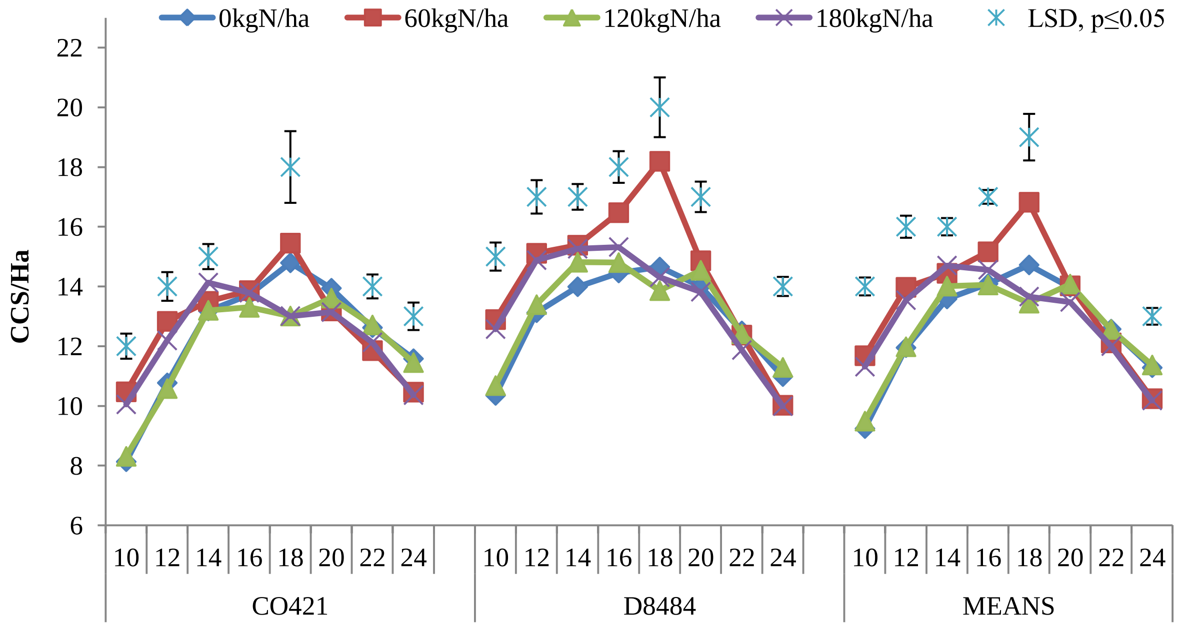


Figure 11 Effect of nitrogen fertilizer rates on CCS/Ha of CO421 and D8484

Splitting nitrogen fertilizer application had no effect on TS production (Figure 12). These results were similar to those observed in some studies (Ramesh & Varghese 2000). However, increase in TS with increase in number of splitting of nitrogen fertilizer application have also been reported (Koochekzadeh et al. 2009; Saleem et al. 2012). The results demonstrated that the geographical area of production and/or varieties could influence such responses. In Kenya, however, these results show that there are no benefits in splitting the nitrogen fertilizer application to ratoon crops of both old and new varieties.

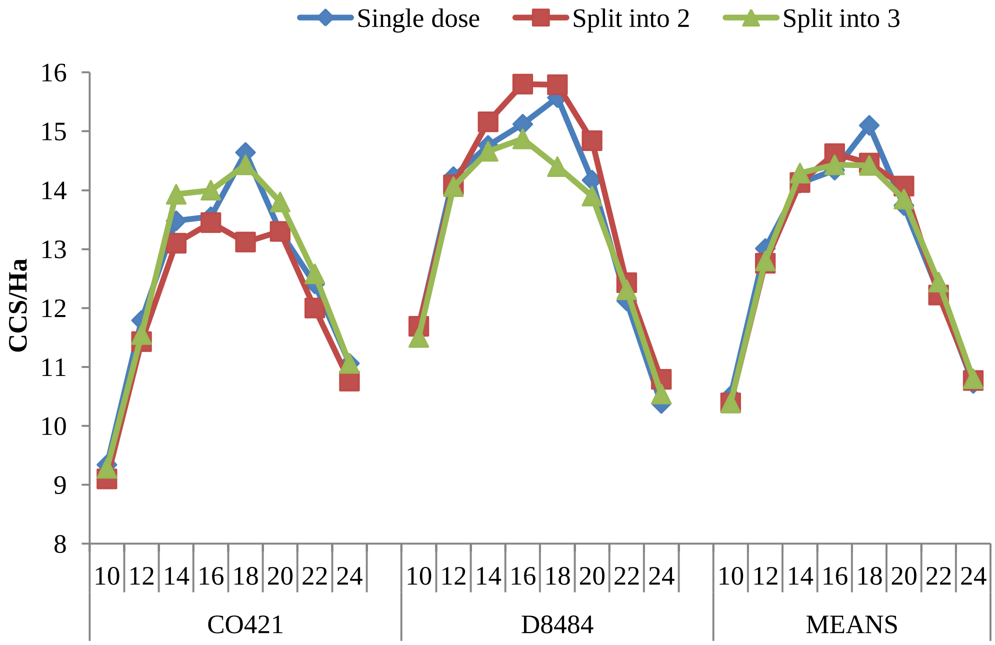


Figure 12 Effect of split applications of nitrogen fertilizer rate on CCS/Ha of CO421 and D8484



### 3.3. Prediction of the optimal maturity time

The response of yield, pol, brix and TS of the two varieties to MAR were subjected to regression analysis to establish pattern of responses with MAR. All the parameters fitted the quadratic model with $r^2$ values 0.75 and 0.83 for yields, 0.97 and 0.98 for pol, 0.98 and 0.96 for brix and 0.95 and 0.95 for TS, for CO421 and D8484, respectively (Table 1). The $r^2$ values for the responses at different rates of nitrogen ranged from 0.28 to 0.89 for yields, 0.97 to 0.99 for pol, 0.95 to 0.98 for brix and 0.89 to 0.98 for TS. The point at which the rate of change of the parameter with time was zero was determined as the maximum output of the individual parameter. Maximum yields, pol, brix and TS were arrived at after 20.12, 18.03, 18.24 and 17.68 MAR, respectively, for CO421 and 18.77, 14.75, 14.77 and 16.44 MAR, respectively, for D8484 (Table 1). For all the parameters, D8484 reached maximum earlier than CO421. The optimal harvesting window for ratoon crop of CO421 is, therefore, recommended at between 17 to 20 MAR, while that of D8484 is approximately 13 to 17

MAR. The results showed that optimal harvesting time is variety depended irrespective of method used in its determination. Failure to harvest cane at the correct time causes losses. The current system of harvesting all ratoon crops at between 16 and 20 months is lowering productivity of some cane varieties. Depending on sugarcane availability, some cane is harvested way before or after the recommended MAR (Mulwa 2006; Wanyande 2001). Such inefficiencies are lowering cane productivities and benefits accruing to from sugarcane farming. Thus, lack of optimal intensification of using recommended management and technologies such as agronomic and cultural practices are among the key factors influencing cane productivity in western Kenya.

Similar observations had been made in India (Singh, Singh, Nigam, Munshi, & Singh 2012), Australia (Bramley & Quabba 2001) and Vietnam (Mui, Preston, Binh, Ly, & Ohlsson 1996). Thus, key technological inputs including timing harvesting need to be applied on cane production in western Kenya to improve productivity of the sector.

The Kenya Sugar Industry should develop optimal harvesting period for the individual varieties in different production zones. It is also important for the Kenya Sugar Industry to move away from current harvesting policy, where all canes are harvested after 20 months, irrespective of variety. Such policy reduces productivity and can lead to serious losses by the farmer, especially when quality is used as the cane price determinant as proposed in the Kenya Sugar Act (Anonymous 2001).

The critical parameter in sugarcane production is TS. Variety D8484 performed better than CO421 in both total productivity and short duration to optimal harvesting time (Table 1). For D8484, the short return time can give higher production through more frequent harvesting and at each time producing more TS than CO421. Intensifying use of early maturing varieties similar to D8484 is a management option to improve production. Although there was on slight decline in possible maximum TS in CO421 by not applying nitrogen fertilizer, in D8484, the decline was higher ($p \leq 0.05$). The new variety seemed more sensitive to nitrogen fertilizer application than the old variety. In CO421 use more than 60 kg N/ha did not increase possible production of TS, but in D8484 use of beyond 60 kg N/ha reduced TS production. Application of 60 kg N/ha seems adequate for ratoon crops in Kenya, irrespective of variety. Splitting nitrogen fertilizer application had no influence on productivity and the quality parameters.

## 4. Conclusions

Results demonstrated superiority of D8484 over CO421 and that ratoon crops attain maturity age between 15 and 18 MAR, while CO421 between 17 and 19 MAR. The 60 kg N/ha fertilizer rate produced higher ($p \leq 0.05$) yield, pol, brix and commercial cane sugar in both varieties, from 16th MAR. In addition, splitting of fertilizer application did not affect productivity.

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Table 1 Summary of quadratic regression statistics for the different parameters of CO421 and D8484

| Var | N Rate | Yield | | | Pol | | | Brix | | | TS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $R^2$ | MAR for Max. | Max Yield (T/ha) | $R^2$ | MAR for Max. Pol | Max %Pol | $R^2$ | MAR for Max brix | Max % Brix | $R^2$ | MAR for Max TS | Max (ton/ha) |
| CO421 | 0 | 0.604 | 21.09 | 90.00 | 0.970 | 17.98 | 17.14 | 0.981 | 18.53 | 19.01 | 0.978 | 18.19 | 14.45 |
| | 60 | 0.696 | 22.57 | 81.15 | 0.969 | 17.99 | 17.58 | 0.982 | 18.45 | 18.87 | 0.896 | 16.93 | 14.56 |
| | 120 | 0.844 | 20.59 | 77.61 | 0.973 | 18.12 | 17.37 | 0.980 | 18.38 | 19.00 | 0.941 | 18.32 | 13.71 |
| | 180 | 0.276 | 19.41 | 77.85 | 0.968 | 18.03 | 17.25 | 0.970 | 18.70 | 19.34 | 0.901 | 17.00 | 13.96 |
| | Mean | 0.605 | 20.92 | 81.65 | 0.970 | 18.03 | 17.34 | 0.978 | 18.56 | 19.06 | 0.929 | 17.61 | 14.17 |
| D8484 | 0 | 0.904 | 22.59 | 82.80 | 0.971 | 14.69 | 16.56 | 0.972 | 14.36 | 19.66 | 0.975 | 17.09 | 14.75 |
| | 60 | 0.774 | 18.94 | 86.86 | 0.986 | 14.81 | 18.48 | 0.951 | 15.07 | 19.84 | 0.898 | 16.16 | 16.96 |
| | 120 | 0.486 | 25.55 | 81.12 | 0.986 | 14.82 | 18.25 | 0.967 | 14.87 | 19.95 | 0.886 | 16.91 | 14.84 |
| | 180 | 0.886 | 19.41 | 82.40 | 0.976 | 14.66 | 17.94 | 0.974 | 14.58 | 19.74 | 0.967 | 15.58 | 15.37 |
| | Mean | 0.763 | 21.62 | 83.30 | 0.980 | 14.75 | 17.81 | 0.966 | 14.72 | 19.80 | 0.932 | 16.44 | 15.48 |
| CO421 | N Split | | | | | | | | | | | | |
| | Single dose | 0.806 | 20.69 | 79.12 | 0.970 | 18.00 | 17.36 | 0.983 | 18.49 | 19.25 | 0.958 | 17.75 | 14.42 |
| | Split into two | 0.976 | 20.25 | 78.83 | 0.970 | 18.10 | 16.92 | 0.975 | 18.52 | 18.88 | 0.964 | 17.79 | 13.86 |
| | Split into three | 0.931 | 18.46 | 79.20 | 0.970 | 18.15 | 17.59 | 0.980 | 18.75 | 19.48 | 0.975 | 17.71 | 14.62 |
| | Mean | 0.904 | 19.80 | 79.05 | 0.970 | 18.08 | 17.29 | 0.979 | 18.59 | 19.20 | 0.966 | 17.75 | 14.30 |
| D8484 | Single dose | 0.860 | 19.34 | 83.56 | 0.971 | 14.71 | 17.71 | 0.966 | 13.92 | 19.76 | 0.968 | 16.39 | 15.54 |
| | Split into two | 0.929 | 19.13 | 84.96 | 0.978 | 14.80 | 18.00 | 0.965 | 14.86 | 19.68 | 0.981 | 16.57 | 15.95 |
| | Split into three | 0.883 | 31.61* | 82.63 | 0.983 | 14.77 | 17.82 | 0.956 | 15.10 | 19.86 | 0.966 | 16.39 | 15.04 |
| | Mean | 0.891 | 23.36* | 83.72 | 0.977 | 14.76 | 17.84 | 0.962 | 14.63 | 19.77 | 0.972 | 16.45 | 15.51 |