Advances in Crop Science and Technology

Hagos et al., Adv Crop Sci Tech 2014, 2:3
http://dx.doi.org/10.4172/2329-8863.1000133

Research Article Open Access

Effect of Drying Off Period and Harvest Age on Quality and Yield of Ratoon Cane (*Saccharium officinarium L.*)

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Abstract

Field experiment was conducted at Metahara Sugar Estate during the 2011/2012 cropping period to determine the effect of drying off period and harvest age on quality and yield of ratoon sugarcane (Saccharium officinarium L.). Major variety B52-298 was used under the four levels of drying off periods (25, 45, 65 and 85 days) and harvest ages (12, 13, 14 and 15 months) in a completely randomized block design with 4*4*3 factorial treatment arrangements. All data's were collected at the end of each levels of drying off periods and harvest ages. Analysis of variance (ANOVA) showed that drying off period significantly influenced maturity testing parameters (sheath moisture content and handrefractometer brix), quality parameters (brix, pol, purity and CCS) and yield parameters (sugar yield) (P < 0.001). Brix, pol, juice purity, estimated recoverable sucrose and sugar yield were significantly increased when the level of drying off period was increased with a peak at 65 days. Brix, pol, juice purity, estimated recoverable sucrose and sugar yield were significantly increased with increasing level of drying off period up to 65 days. In contrast, soil moisture content, sheath moisture content, plant height and stalk diameter were reduced with increasing drying off period. Sugar yield increased by 20.97 % with extending drying off period from 25 days to 65 days with no further increase at 85 days drying off period. Effect of harvest age also significantly influenced maturity testing parameters (hand refractometer brix), quality parameters (brix, pol, purity and ERS) and yield parameters (plant height, cane yield and sugar yield) (P < 0.001). Increase in harvest age, significantly increased brix, pol, juice purity, estimated recoverable sucrose, plant height, cane yield and sugar yield. Optimum yield was recorded on 65 days drying of period and 15 months harvest age with economically acceptable marginal rates of return 2544% and 135%, respectively. Therefore, adjusting the drying off period to 65 days and the harvest age to 15 months for variety B52-298 under the tested soil condition for ratoon cane is recommended to increase sugar yield at Metahara Sugar Estate.

Keywords: Drying off period, harvest age, maturity, ratoon crop (sugarcane cutting)

Introduction

In ratoon sugarcane, irrigation is often withheld before harvest to reduce soil compaction from harvesting machinery and to enhance quality parameters (brix%, pol%, purity and estimated recoverable) to be deposited preferentially in sugarcane stalks [1,2]. The days required for pre-harvest drying-off to improve sucrose accumulation in sugarcane could range from 30 to 150 days depending on low to high water holding capacity of the soil [3]. The complete suspension of irrigation for the final two months before harvest gave the best results of soluble solids and sucrose content in South African sugarcane industries [2]. Australian researchers found highest sucrose content and sugar yield at 56 days drying off period retarding stalk height and shortening vegetative growth of sugarcane as compared to the shorter drying off period (35 days) [3]. In 61% of the drying-off treatments in South Africa, there was a significant increase in the soluble solids together with dehydration throughout the stalk. However, sucrose yields only increase if water stress reduces stalk biomass by less than 4% or unchanged [4]. However, severe stress could develop in crops grown in low moisture available soils when completely suspending irrigation for a long period of time before harvest [5].

Changes in sheath moisture content can well reflect the effects of water stress on plants [6]. Sheath moisture content is measured to determine the level of water stress as influenced by drying off period. As a result, after 35 days of drying off period the morphology was changed because sugar cane sheaths showed signs of wilting and dramatically decreased its moisture content [5]. Sheath moisture content was high in unstressed treatments but after 19 days after irrigation was withheld it was reduced from 80 to 75% [7]. The standard sheath moisture of sugarcane to have peak sucrose concentration was 68-74% [8,9].

On the other hand, harvest age was one of the factors that determine maturity of sugarcane. Sheath moisture content was reduced as harvest age increased because at later ages of growth there was a possibility that the crop may have lost some potential of root activities [10]. At a later age old root system of cane stalk gradually ceases to function and decay with time resulting to decreased sheath moisture content of the plant [9]. High sheath weight per stalk in young canes may be used as an indicator of the water status of the crop [7]. The percentage of sheath moisture content of sugarcane in old cane could be decreased because at senescence green leaves are dried and decrease in number [1].

Several maturity testing schemes have been proposed during the growing and harvest season. The common practice is to test the standing cane in the field for brix with a hand refractometer, which is a measure of the amount of sucrose in the cane [11]. Sugarcane matures when top/bottom brix ratio approached unity. It can also be done by using bottom minus top brix and bottom minus middle brix together and recommended to harvest when the two indices approach zeros [12]. The highest hand refractometer brix reading of top to bottom portion of ripened stalk is required to have 19 and 20% (a ratio of 0.95) brix %, respectively [13]. With stalk maturation, more and more internodes reach the same condition and a progressive increase in total soluble solids to include sucrose [14].

The quality parameters (brix%, pol%, purity and estimated

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Received May 29, 2014; **Accepted** July 15, 2014; **Published** July 17, 2014

Citation: Hagos H, Worku W, Takele A (2014) Effect of Drying Off Period and Harvest Age on Quality and Yield of Ratoon Cane (Saccharium officinarium L.). Adv Crop Sci Tech 2: 133. doi:10.4172/2329-8863.1000133

recoverable sucrose) in juice were improved with increasing harvest age which indicates the function time on the storage of sugar due to the effect of diluting the structural cell wall components [15,16]. Estimated recoverable sucrose and sugar yield were increased in a first ratoon crop, for harvest age ranging between 8 to 14 months [17]. The growth and yield parameters such as stalk height, cane yield and sugar yield were increased with increasing age of sugarcane suggesting that more growth and sucrose accumulation was achieved in the longer harvest ages [18]. From the research conducted on different harvest ages of ratoon cane in South Africa (10 months, 12 months, 14 months and 16 months) longer height, high cane and sugar yield was obtained from the two longer harvest ages (14 and 16 months) [19,20].

The current sugar production of the Ethiopian Sugar Industry covers only 60% of the annual demand for domestic Consumption while the deficient is imported from abroad. In order to make the country self-sufficient in sugar and export the surplus sugar and produce ethanol and other by-products, the Federal government of Ethiopia is working to establish sugarcane plantation on 325,000 ha in addition to the vast expansion project of the previously established farms with erection of high crashing capacity 10 new sugar mills [21].

However, improper pre-harvest practices; drying off period (wet or excessive drying) of fields before harvest and harvesting many fields without considering crop age are common constraints in sugarcane production in Ethiopian Sugar Estates [22]. The importance of determining yield potentials for sugarcane has been noted by many scientists with goals to aim for barriers to be broken. Law of the minimum suggests that there is always some factor limiting yield. Therefore, yield potential need to be defined in terms of the limiting factor [23].

Efforts have been made in the past to address the effects of drying off period [23,24] and harvest age [19,25] on first cuttings of sugarcane in various countries. However, there are no studies dealing with yield and quality response of ratoon crops as influenced by different drying off period and harvest age on Ethiopian Sugar Estates. So, this experiment is initiated with the following specific objectives:

(1) To determine quality and yield responses that will be attained under various drying off period of ratoon cane

(2) To examine the influence of harvest age on ratoon cane quality and yield parameters

Material and Method

The study was conducted on clay soils of Metahara Sugar Factory. The clay soils cover more than 90% of the estate and they are grouped into four distinct textural groups as heavy clay, clay, clay loam and loam soil groups [26]. The experiment has two factors namely, drying off period (25, 45, 65 and 85 days before harvest) and harvesting age (12, 13, 14, and 15 months) with a factorial combination giving 16 treatments. Optimum drying off period and harvest age of ratoon crops was not yet studied at Ethiopia Sugar Industries. To address this problem, a standard sugar cane variety B52-298, was selected because of its high yielding potential and high area coverage which is 23% of the total area covered by various commercial varieties in the Sugar Estate.

The experiment was carried out on a first ratoon cane using randomized complete block design (RCBD) with three replications in the cool season. Each plot had five rows with 10 m length and 1.45 m width for each row (10 m x 1.45 m x 5 rows) having an area of 72.5 m^2 for a single plot. The distance between plots was 2.9 m while it was 4.35 m between replications. The harvested plot consisted of three rows with 10 m length and 1.45 m width each (10 m x 1.45 m x 3 rows) with an area of 43.5 m^2.

Cultural practices such as weeding, fertilizer application, molding, pesticide application and irrigation frequency of the experimental field were based on the current practice practices of Metahara Sugar Estate except manipulating harvest age and drying off period before harvest. Irrigation was applied with hydroflume application system delivering water to the furrows at an average inflow rate of 5 l/s with 89 minutes cut off time for the 100 m length furrow [26].

Economic analysis was done using partial budget analysis procedures [27]. The average sugar yield was adjusted down ward by 20% to reflect the yield difference between the experimental yield and commercial yield which was deteriorated by pre-harvest burning, delaying at field to reach the milling center, yield loss with impurities and yield loss by low factory efficiency.

Result and Discussion

Effect of drying off period on soil moisture content

Drying off period affected soil moisture content negatively (Figure 1). Although soil sample was taken from two depths 0-30 cm and 0-60 cm, their average was taken for discussion because both depths showed similar decline in soil moisture content with increasing days of drying off period. Shorter drying off periods (25 days and 45 days) had a relatively higher mean soil moisture content of 38.77% and 31.47% respectively, at the end of drying (Figure 1). An initial soil moisture content of 45.58% was recorded two days after irrigation at field capacity as a reference to compare with the moisture loss by drying off periods. Thus, a sharp decline of soil moisture content was observed when drying off period was increased to 65 and 85 days which had 24.94% and 19.58%, respectively. The soil moisture content of 24.94% obtained from 65 days drying off period could be considered as adequate for maximum sucrose (pol) accumulation as indicated in Table 2. Similarly, previous studies reported that the average soil moisture content of 24.0 to 27.5% was adequate for high sucrose accumulation [24]. The average reduction of soil moisture content over 65 days and 85 days drying off periods was 26.18% and 55.45%, respectively as compared to the control drying off period (45 days). Another studies also confirmed that there is high soil moisture content in the short drying off periods [5]. However, soil moisture was reduced with increasing days of drying off period. Thus, longer drying off period was needed as the water holding capacity of soils increase to improve sucrose accumulation in sugarcane stalks (Figure 1).

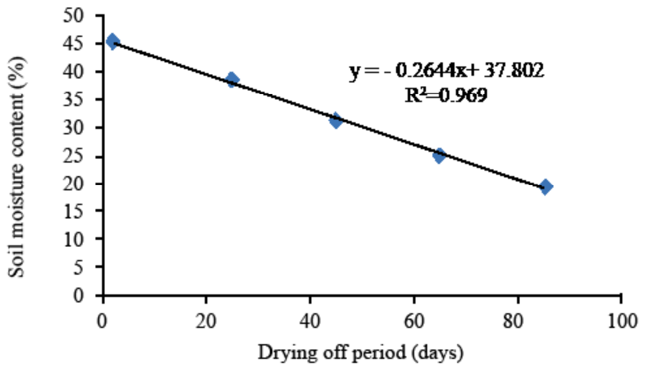

Figure 1: Relationship between drying off period and soil moisture content at the end of drying periods

Effect of drying off period and harvest age on sheath moisture content

Sheath moisture content of ratoon cane was significantly influenced by drying off period ($p < 0.001$) and harvest age ($p < 0.01$) while the interaction effect was not significant. Highest mean sheath moisture content was recorded on the two short drying off periods (25 and 45 days) while lower sheath moisture content was recorded from the two longer drying off periods (65 and 85 days) (Table 1). Previous studies confirmed that, as drying off period increased, sheath moisture content was reduced [3]. Drying off period creates depression of leaf water potential by the dehydrative effect of water stress due to excessive evapo-transpiration [28].

The highest percent sheath moisture content was obtained at the early age (12 months) of the crop and the lowest sheath moisture content was recorded under the longest harvest age (15 months) of the crop (Table 1). However, there was no significant difference between the two upper age levels. An increase of one to three months harvest age from the lowest (12 months) decreased sheath moisture content by 2.3%, 2.9% and 5.6%, respectively. In general, significant decrease in percent sheath moisture of ratoon sugarcane was noted with increased age in this study. In line to this, decreasing sheath moisture content with increasing cane age was obtained from previous studies [10]. This could be due to loss of some potential activities of root resulting in lower sheath moisture content of the crop. Old root system of cane stalk gradually ceases to function and decay with time enhancing water stress in the photosynthesis area of the plant [9].

Effect of drying off period and harvest age on hand refractometer brix% test of sugarcane cane parts at maturity

Drying off period ($p < 0.001$) and harvest age ($p < 0.01$) significantly influenced hand refractometer brix test of sugarcane parts but not by their interaction. The highest hand refractometer brix was obtained on 65 days drying off period in all the bottom, middle and top parts of the stalk (Table 1). In this drying off period, all the stalk parts accumulated peak soluble solids indicating the sign of maturity to harvest. The lowest hand refractometer brix in all stalk parts was obtained on the shortest drying off period (25 days). Comparatively, longer drying off periods (65 and 85 days) showed greater refractometer brix content than the shorter drying off periods (25 and 45 days). For the middle part of the plant, there was no significant difference between the two upper drying off levels. In general, sequential accumulation of soluble solids was observed from the base to the top of the stalk on different parts of the stalk. High brix content was obtained from the moderately dried than fully irrigated treatments in all parts of the stalk with sequential accumulation of soluble solid from bottom to the top part of the stalk [29]. The low brix content of the top part is consistent with the fact that this part is more active in non-soluble solid storing metabolism (e.g. processes involving respiration and growth). Drying off period enhances brix content of the cane segments with high brix content at the bottom segment fallowed by the middle and top segments [1].

Drying off period (D)	SHMC (%)	BHRB (%)	MHRB (%)	THRB (%)
25	75.54^{a}	13.09^{d}	12.75^{c}	10.86^{c}
45	74.07^{a}	14.39^{c}	13.69^{b}	11.58^{c}
65	66.70^{b}	19.38^{a}	18.92^{a}	18.71^{a}
85	63.67^{c}	18.50^{b}	18.20^{a}	16.99^{b}
Harvest Age (MAP)				
12	72.12^{a}	13.74^{c}	13.45^{c}	11.32^{c}
13	70.54^{ab}	14.36^{c}	14.07^{c}	11.93^{c}
14	68.52^{bc}	17.60^{b}	17.20^{b}	16.14^{b}
15	66.80^{c}	19.66^{a}	19.35^{a}	18.75^{a}
LSD (5%)	2.85	0.85	0.86	0.77
CV (%)	4.92	6.25	6.45	6.32

Means followed by the same letter within a column are not significantly different. D, days; MAP, months after planting; SHMC, sheath moisture content; BHRB, bottom hand refractometer brix; MHRB, middle hand refractometer brix; THRB, top hand refractometer brix; ns, non-significant

Table 1: Mean comparison of maturity testing parameters as influenced by drying off period and harvest age at Metahara Sugar Estate

Harvest age affected hand refractometer brix and increased levels of harvest age enhanced hand refractometer brix of the stalk parts. The highest hand refractometer brix percent was obtained on the longest harvest age (15 months) in all stalk parts (Table 1). Similarly, the lowest mean value was recorded on the shortest harvest age (12 months). However, there was no significant difference between the first two (12 and 13 months) harvest ages in all parts of the stalk. Similar to drying off period, harvest age also showed sequential storage of soluble solids. The bottom part stored highest amount of brix followed by the middle and top part of the stalk. In agreement with this result, studies reported that brix percent of all the bottom, middle and top parts of the stalk increase with cane age [11]. In milling operations, the preferred varieties are those with high and nearly equal percentage of hand refractometer brix on its all stalk parts at maturity (bottom, middle and top parts [14].

Effect of drying off period and harvest age on quality parameters of ratoon cane

Percentage of soluble solids, pol, purity and estimated recoverable sucrose were significantly ($p < 0.001$) affected by drying off period and harvest age. The highest percent soluble solid, pol, purity and estimated recoverable sucrose were obtained at 65 days drying off period and the lowest yield of all the quality parameters were recorded at 25 days drying off period (Table 2). The increase of the percentage of quality parameters until 65 days drying off period was due to the decrease of the proportion of reducing sugars resulting in an increase of sucrose content. Because biomass was stored preferentially as sucrose rather than being drawn into the production of reducing sugars or non-sucrose materials (fiber).Withholding irrigation water beyond 65 days resulted in a decline of the value of all the quality parameters. This might be due to the fact that the stored assimilates were remobilized to supply the damaged part of the plant during severe stress. Sugarcane researchers indicated that moderate water stress in cane tissue was recognized as a means of cane ripening because it decreased vegetative growth and hasten the quality parameters (brix and pol) during ripening period [3,30]. The greatest contribution to change in sucrose dry weight concentration with drying off is from an increase in the dry weight concentration of soluble solids and sucrose content [2].

Increased levels of harvest age also enhanced all quality parameters. The highest percent soluble solid, pol, purity and estimated recoverable sucrose were obtained at the longest harvest age (15 months) (Table 2). This might be due to the dilution effect of sugarcane enzymes changing the reducing sugars and non-sucrose materials (fiber) to sucrose or it could be due to positive impact of harvest age on the yield components (plant height and cane yield) which allow accumulation of additional soluble solid or sucrose by delaying harvest age. Percent of soluble solids, percent pol, purity and percent of estimated recoverable sucrose significantly increased as age of sugarcane increased [19]. However, in over aged ratoon cane, the sucrose content is reduced due to heavy lodging and remobilization to supply the unproductive bull shoots (newly growing shoots) [11].

Effect of drying off period and harvest age on cane and sugar yield of ratoon cane

Cane yield was significantly influenced by drying off period (Table 3). The reason could be reduction of plant height and stem diameter under extended drying off periods might have been offset by greater accumulation of soluble solids. The research result in South Africa reported that, from a total of 53 treatments applied to drying off period 24 treatments (i.e. about one-half) showed an increase in sucrose concentration with no significant fall in cane yield [2]. Sugar yield was significantly ($p < 0.001$) influenced by drying off period. The highest value of sugar yield was obtained at 65 days drying off period. The increase of sugar yield observed under moderate drying off period could be due to the positive impact of drying off period on all quality parameters (Table 2). Further increase of the drying off period to 85 days reduced sugar yield. This could be attributed to the negative effect of the severe stress on growth and quality parameters. From the research result of previous studies, high sugar yield was recorded on the moderate drying off period (56 days) than the shorter drying off treatment (35 days) [3]. However, severe (91 days) drying off period reduced sugar yields when the benefit from the higher sucrose content is negatively affected by more severe stress [4].

Cane yield and sugar yield were highly significantly ($p < 0.001$) influenced by harvest age. The highest cane yield and sugar yield were recorded on 15 months harvest age, followed by 14 months harvest age. This might be due to the increasing effect of longer harvest ages on yield components (plant height, cane yield) and quality parameters (brix, pol, purity and estimated recoverable sugar). The lowest cane yield and sugar yield was obtained from earliest harvest age (12 month) (Table 3). Significant increase in cane yield was recorded with an increase in harvest age from 8 to 16 months [19]. The major drop in sugar yield with an age restriction of below 14 months might be due to many hectares of crop being forced to be harvested when expected yields are extremely low as well as older crops being disallowed [15].

Economic Analysis

The partial budget analysis for drying off period showed that 25 and 45 days drying off period were dominated (Table 4). Marginal rate of return for 65 days drying off period was 2544%. Decreasing drying off period below 65 days will lead to increase in additional costs without compensating benefit. The marginal rate of return obtained at 65 days drying off period was above the 100% of the CIMMYT's minimum rate of return required for adoption of agronomic practices. The 2544% MRR recorded at 65 days drying off period indicated that for every one dollar invested in ratoon crop it could give a net return of 25.4 USD Dollars. Comparative results were reported in Australia indicating that 56 days pre-harvest drying off period was profitable for ratoon canes [3].

The profitability of sugar yield within various harvest ages considers a time value. So, the partial budget analysis for harvest age was computed in terms of t/ha/month (Table 4). The important parameters of maximizing sugar yield and net revenue in relation to harvest date and crop age is expressed by t/ha/month as an index of time value of sugarcane crop [8]. Accordingly, the partial budget analysis for harvest age gives MRR of 107% at 14 and 135% at 15 months which were both above the CIMMIT's minimum requirements of 100% MRR (Table 4). Even thought, both 14 and 15 months harvest ages give MRR above the CIMMIT's minimum requirements, fifteen months harvest age is more profitable and advisable to first ratoon cane because it gives opportunity to additional profit from investing additional cost.

Conclusions

Improper drying off period and improper harvest age are recurrent problems of pre-harvest cultural practices, which severely affect quality and yield of ratoon cane. The economic analysis indicated that 65 days drying off period and 15 months harvest age gave the highest net benefit of 10,910.8 $ /ha and 350.2 $ /ha /month with acceptable MRR of 2544 and 135%, respectively. From this economic analysis, it is possible to conclude that, 65 days drying off period and 15 months harvest age can be recommended for ratoon cane production at Metahara to obtain maximum sucrose and sugar yield with optimum maturity. Moreover, further research could be undertaken for other popular varieties used by the estate under different soil types with extending harvest age beyond 15 months.

Acknowledgements

We would like to thank Ethiopian Sugar Corporation for financing the research and Hawassa University College of Agriculture for their unreserved material and other facilities support.

Drying off period (D)	Brix %	Pol %	Purity (%)	ERS (%)
25	20.52^{c}	16.99^{d}	87.64^{c}	11.12^{d}
45	20.58^{c}	18.21^{c}	88.48^{bc}	12.57^{c}
65	22.04^{a}	20.16^{a}	91.44^{a}	14.27^{a}
85	21.30^{b}	19.05^{b}	89.39^{b}	13.25^{b}
LSD (5%)	0.59	0.54	1.41	0.45
Harvest age (MAP)				
12	20.18^{c}	17.86^{d}	88.45^{b}	12.03^{c}
13	20.77^{c}	18.16^{c}	88.61^{b}	12.42^{c}
14	21.42^{b}	18.88^{b}	89.28^{ab}	12.99^{b}
15	22.08^{a}	19.77^{a}	90.61^{a}	13.77^{a}
LSD (5%)	0.59	0.54	1.41	0.45
CV (%)	3.36	3.48	1.89	4.19

Means followed by the same letter within a column are not significantly different. D, days ; Brix %, Percentage of refractometer brix; Pol%, percentage of sacharometer pol; ERS, estimated recoverable sucrose; MAP, months after planting; ns, non-significant

Table 2: Quality parameters of first ratoon cane as influenced by drying off period and harvest age at Metahara Sugar Estate

Drying off period (D)	PH (m)	SD (cm)	CY (t/ha)	SY (t/ha)
25	2.99^{a}	2.99^{a}	139.33	15.56^{c}
45	2.97^{a}	2.98^{a}	138.70	17.48^{b}
65	2.66^{b}	2.77^{b}	137.78	19.69^{a}
85	2.65^{b}	2.75^{b}	136.83	18.20^{b}
LSD (5%)	0.08	0.19	Ns	1.14
Harvest Age (MAP)				
12	2.58^{d}	2.80	129.12^{c}	15.53^{c}
13	2.73^{c}	2.84	132.54^{c}	16.50^{c}
14	2.90^{b}	2.92	141.11^{b}	18.31^{b}
15	3.09^{a}	2.93	149.89^{a}	20.59^{a}
LSD (5%)	0.08	NS	7.72	1.14
CV (%)	3.52	7.54	6.70	7.72

Means followed by the same letter within a column are not significantly different. D, days ; PH, plant height; SD, stalk diameter; CY, cane yield; SY, sugar yield; MAP, months after planting; ns, non-significant

Table 3: Yield parameters of ratoon cane as influenced by drying off period and harvest age at Metahara Sugar Estate

Treatment	Adjusted sugar yield (t/ha)	Gross field benefit ($ USD /ha)	Total variable cost ($ USD)	Net benefit ($ USD /ha)	Change in net benefit ($ USD /ha)	MRR (%)
DRP (days)						
85	14.56	10,115.4	0	10,115.4		
65	15.75	10,942.1	31.3	10,910.8	795.4	2541.2
45	13.39	9,302.5	62.5	9,240.0^{d}		
25	12.45	8,649.5	93.8	8,555.7^{d}		
HA(month)	t/ha/month	$ USD /ha/month	$ USD /ha/month	$ USD /ha/month	$ USD /ha/month	MRR (%)
12	0.41	287.7	0	287.7		
13	0.44	305.7	31.3	274.4		
14	0.49	339.2	31.3	307.9	33.5	107.1
15	0.55	381.5	31.3	350.2	42.3	135.2

DRP, drying off period; HA, harvest age; D, dominated; MRR, Marginal rate of return

Table 4: Partial budget analysis of the ratoon cane as influenced by drying off period and harvest age

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