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Evaluating the Effects of Chemical Ripening with Fluazifop-p-butyl on Sugarcane (*Saccharum officinarum*) Yield and Sugar Content

M. Muhwiridzwa[1], B. T. Manenji[2*], T. Madanzi[2] and W. Mahohoma[2]

[1]Matopos Research Station, P.O.Box 776, Bulawayo, Zimbabwe.
[2]Department of Agronomy, Midlands State University, P. Bag 9055, Gweru, Zimbabwe.

Authors' contributions

This work was carried out in collaboration between all authors. Authors MM and WM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors BTM and TM managed the literature searches and analyses of the study. Author WM managed the experimental process. All authors read and approved the final manuscript.

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ABSTRACT

Ripening in sugarcane refers to an increase in sugar content on a fresh weight basis prior to commercial harvesting. Ripening is often prompted by use of chemicals and environmental cues such as moisture stress. The aim of this research was to determine the effects of Fluazifop- p-butyl, a chemical ripener on sugarcane yield and sugar content. The experiment was laid out as a Random Complete Block Design (RCBD) with five replications. Treatments were: Fluazifop- p- butyl (0.45 lha^{-1}), drying off, Fluazifop- p- butyl (0.45 lha^{-1}) + drying off and the control (no Dry off, no Fluazifop- p- butyl). The experiment was carried out at Triangle Estate which is located in the South East Lowveld of Zimbabwe from March 2012 to May 2012. Data on sugarcane yield, sugar quality (Pol % and ERC %) and sugar yield was collected 56 days after establishment of the experiment. Analysis of variance was done on yield and quality data using Genstat 14th edition. Results showed that there were significant differences (P = 0.05) among treatments on sugarcane yield, sugar yield, Pol% and ERC%. The sugarcane yield was highest for the control where no ripener was used.

**Corresponding author: E-mail: manenjibt@gmail.com;*

Fluazifop- p- butyl treatment attained 13.9% lower sugarcane yield relative to the control. Application of Fluazifop- p- butyl resulted in the highest sugar yield which was 35.6% higher than that of the control where no ripener was used. A combination of Fluazifop- p- butyl and Dry of resulted in the highest Pol % and highest ERC %. It can be concluded that Fluazifop- p- butyl is effective in increasing sugar yield although it results in a reduction in sugarcane yield. Combining Fluazifop- p- butyl with Dry off results in increased Pol% and ERC%. There is need for further studies to determine the optimum period from spraying Fluazifop- p- butyl to harvesting of sugarcane as this was only done at the end of the drying-off period.

Keywords: Sugarcane; chemical ripening; dry off; sugar yield; sugar quality.

1. INTRODUCTION

Sugarcane is an important crop in Zimbabwe grown for sugar, ethanol and other products such as molasses, bagasse and for electricity generation [1-3]. In Zimbabwe sugarcane production is confined to the South Eastern Lowveld where it is mainly grown under irrigation by Tongaat Hulett, large multinational corporate and resettled farmers. The South Eastern Lowveld is characterised by high temperatures which are favourable for the growth of the crop [2].

In Southern Africa, Zimbabwe is the second sugar producer after South Africa, with a production of about 600 000 tonnes of sugar per year [4]. Sugarcane crop is a key industrial and cash crop in Zimbabwe. Agriculture in Zimbabwe contributes approximately 12.2% to Zimbabwe's Gross Domestic Product (GDP) and is the main source of livelihood for about 70% of the population [5]. The sugar industry contributes 1.4% to the Zimbabwean GDP with more than 25 000 people directly employed (Esterhuizen [3]) while 125 000 people are indirectly employed in sugar industry in Zimbabwe. More than 60% of sugar produced is exported to neighbouring countries and European Union [6,1]. Despite a number of benefits associated with sugarcane production, its productivity has significantly gone down over the years due to high production costs [1]. This could be mitigated by ensuring production of high quality sugarcane which has high sucrose levels. Sugarcane growers are paid according to the amount of Estimated Recoverable Crystals (sucrose) yield per hectare which is calculated by multiplying the sugarcane stalk yield per hectare by the sucrose of fresh weight cane. Zimbabwe's sugarcane harvest season commences in early April when the sucrose content in sugarcane is relatively low. There are only two sugar mills in Zimbabwe albeit the high sugarcane production hence the need to spread out the harvesting season to avoid congestion at the mills. Harvest ends in December to give time for the annual mills maintenance programme that runs up to March of the following year. As the end season cannot be stretched beyond December, this necessitates the harvest season to begin earlier (April). This comes with a cost in profitability in that sucrose levels are lower at the beginning of the harvest season (April). The cost of handling low quality stalk material that is often incurred when the sucrose content is low also reduce the profitability of the crop. There is thus need to quicken sugarcane ripening process so that the sucrose (Pol %) levels of at least 12.3% is reached [7]. According to Clements [8] sugarcane ripening is described as a physiological senescence that occurs between phases of growth and plant death. In the process there is sucrose accumulation in the sugarcane stalks and this occurs from the basal internodes to the apex [9]. The increase in sucrose accumulation in the internodes of developed stalks is strongly influenced by environmental conditions that are unfavourable for plant growth and development [10]. This is stimulated by several environmental cues including cooling temperatures and low soil moisture [11]. Sugarcane is often harvested before acquiring the desired maturity level in the early season (April-May). Most sugarcane farmers are still using the conventional natural ripening method of drying off to accelerate sugarcane maturation so that it acquires the desired sucrose levels before harvesting. However, drying off periods for early harvested sugarcane has been marked with interceptions of late seasonal rainfall. Current global climatic changes have been forestalled to increase temperatures and change rainfall patterns [6]. Climate change has instigated weather shifts in the Lowveld and resulted in varying rainfall patterns. Late seasonal rainfall offers favourable conditions for cane growth during dry off periods thereby obscuring the effectiveness of drying off especially for the early harvested crop. Consequently growers are delivering poor quality that generates low returns to both the growers and the millers.

Chemical ripeners are one strategy that the Zimbabwean sugar industry may employ to improve sucrose gains for the early harvested sugarcane crop. The use of chemical ripeners has been reported to cause increase sucrose quality above those achieved by natural ripening [12-17]. Chemical ripeners have been found to increase sugar yields when applied under conditions favouring cane growth [10]. Although ripeners are currently used extensively in the world's top sugar producers, this is not the case for Zimbabwe. Ripener research in Zimbabwe faltered after the year 2006 when a number of trials gave variable and inconsistent results [18]. Over the years, research efforts from various scientists [11,19-21] have improved the use of chemical ripeners to obtain beneficial responses from ripeners. Use of chemical ripeners presents an excellent opportunity for the Zimbabwe sugar industry to increase its productivity. The main objective of this study is to determine the effects of chemical ripener, Fluazifop- p- butyl, on sugarcane yield (Tonnes of cane per hectare) and sucrose content (Pol %) and Estimated Recoverable Crystals (ERC %).

2. MATERIALS AND METHODS

The experiment was carried out at Triangle Estate which is located in the South East Lowveld of Zimbabwe (21°20' S and 30°27' E and 400 m asl).The area falls under Natural farming region 5 and receives an average rainfall of 450 mm per annum [22]. Rainfall is poorly distributed and confined to the late summer months. Mean daily temperatures range from 16℃ in winter to 26℃ in summer. The experiment was carried out in field 502 which is characterised by sandy loamy soils with estimated total available moisture (TAM) of 85 mm within a soil depth of 100 cm.

The experiment was laid in a Random Complete Block Design with four treatments (methods of sugarcane ripening) replicated five times, giving a total of 20 treatments. The blocking factor was slope (Table 1). Each plot measured 6 m^2. The experiment was carried out on a second ratoon crop of variety ZN10 at cane age 10 months. The crop was ratooned on the 7th of May 2011 and harvested on the 7th of May 2012. Management of the crop was done according to the Triangle guidelines of sugarcane production (Triangle Estate Agricultural Procedures, Unpublished report, 1998).

Table 1. Description of treatments used in the experiment

Treatment	Treatment description
1	Fluazifop- p- butyl
2	Dry-off
3	Dry-off + Fluazifop- p- butyl
4	Control (no Dry-off, no ripener)

The soil water balance approach adopted from Cackett [23] was used for irrigation scheduling. Irrigation was done at 50% moisture depletion level. The water was conveyed by a canal from source to field edge. Water was drawn from the main canal into the feeder canal from which water is drawn on to the field by means of 40 mm or 63 mm PVC siphons.

2.1 Spraying of the Chemical Ripener Fluazifop- p- butyl

A spray mixture was prepared for a hectare and this consisted of 0.45 liters Fluazifop- p- butyl which was mixed with 1.5 litres molasses and 28 litres of water. Molasses acted as an anti-drift agent as well as a sticking agent. Spraying was done using a fixed wing air craft on the 17th of March 2012 in the morning when weather conditions were relatively calm. At this stage the ratoon crop was 10 months old.

2.2 Drying-off

Drying-off was done according to the Zimbabwe Sugar Industry guidelines as outlined in the Triangle Estate Agricultural Procedures (Unpublished report, 1998) Using this method irrigation water was withheld from the drying-off treatments until the total available moisture (85 mm) was depleted.

2.3 Data Collection

2.3.1 Sugarcane yield

Data on yield of sugarcane was collected at eight weeks (7 May 2012) after spraying the chemical ripener (Fluazifop- p- butyl) which was also 56 days of drying off and the scheduled date of harvest of the field where the experiment was done. The convenience sampling method was used for the selection of sugarcane stalks from the plots [24]. Each sample size equalled ten sugarcane stalks. All sugarcane stalks were stripped of all leaves and topped at the natural breaking point and then weighed. The weight was expressed to equivalent weight per hectare using the formula below

$$W = \frac{120000}{10\ stalks} * weight\ of\ ten\ stalks\ (tons)$$

where, 120000 is the stalk population per hectare

2.3.2 Sugar content

The samples were sent to the Triangle Estate Mill Laboratory for Pol % cane and estimated recoverable crystals (ERC % cane) content analysis. The sugar yield per hectare (Estimated recoverable crystals in tonnes per hectare) was determined from the ERC % cane and weight (t ha^{-1}) using the formula below

$$ERC(tha^{-1}) = \frac{ERC\ \%\ cane * cane\ yield\ (tha^{-1})}{100}$$

2.4 Statistical Analysis

Analysis of variance (ANOVA) was done on data on sucrose content, ERC % and yield of sugarcane using Genstat 14th edition at 5% level of significance. Separation of means was done using least significance difference (LSD) at 5% level of significance.

3. RESULTS

3.1 Effects of Fluazifop- p- butyl on the Yield of Sugarcane

There were significant differences (*P* = 0.05) among the treatments on sugarcane yield. The treatment which had a combination of Fluazifop-p- butyl and Dry off resulted in the lowest sugarcane yield of 76.8t/ha while the control (no ripener used) recorded the highest sugarcane yield, followed by the treatment where dry off was used on its own (Table 2).

3.2 Effects of Fluazifop- p- butyl on Sugar Yield (t/ha)

Significant differences (*P* = 0.05) were observed in sugar yield (t/ha) among the treatments. The highest sugar yield was attained in the Fluazifop-p- butyl treatment while the lowest sugar yield was recorded for the control treatment, where no ripener was used. There were no statistical differences in sugar yield between dry off treatment and the treatment where there was a combination of Dry off + Fluazifop- p- butyl (Table 3).

Table 2. Effect of fluazifop- p- butyl on sugarcane yield

Treatments	Sugarcane yield (t/ha)
Fluazifop- p- butyl (0.45 l / ha)	97.5^{b}
Dry off (56 Dry off days)	100.4^{bc}
Dry off (56 Dry off days) + Fluazifop- p- butyl (0.45 l / ha)	76.8^{d}
No ripener (control)	113.3^{a}
CV%	3.5
LSD	7.00
P-value	*P* = 0.05

Means with the same letter(s) in a column are not significantly different

Table 3. Effect of fluazifop- p- butyl on sugar yield

Treatments	Sugar yield (t/ha)
Fluazifop- p- butyl (0.45 l / ha)	13.69^{a}
Dry off (56 Dry off days)	10.97^{b}
Dry off (56 Dry off days) + Fluazifop- p- butyl (0.45 l / ha)	12.27^{bc}
No ripener (control)	8.81^{d}
CV%	5.0
LSD	1.349
P-value	*P* = 0.05

Means with the same letter are not significantly different

3.3 Effects of Fluazifop- p- butyl on the Sucrose Content (Pol % Cane) of Sugarcane

There were significant differences (*P* = 0.05) among all the four treatments on sucrose content. Treatment which had a combination of Fluazifop- p- butyl (FS) + Dry off (DO) recorded the highest sugar content (Pol % cane) and this was followed by Fluazifop- p- butyl (sole treatment). The lowest sucrose content was recorded in the control where no ripener was used (Fig. 1).

3.4 Effect of Fluazifop- p- butyl on ERC % Cane

There were significant differences (*P* = 0.05) among all the four treatments on Estimated recoverable crystals (ERC %) cane.

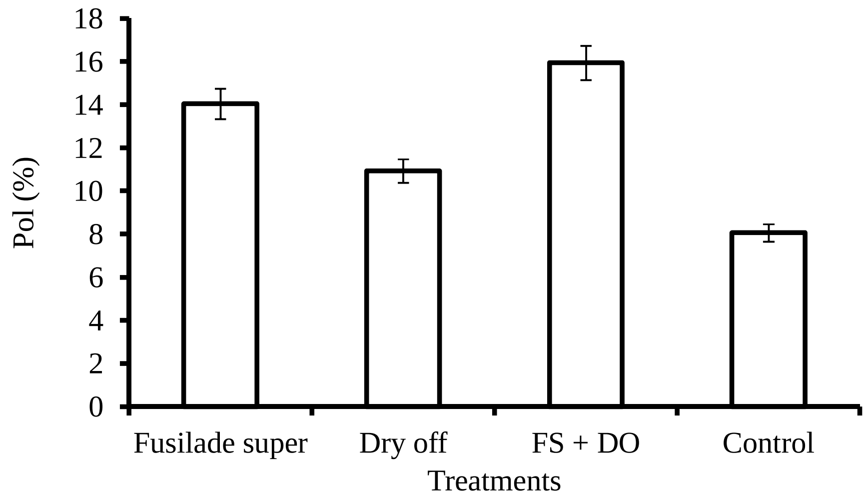

Fig. 1. Effects of fusilade super (fluazifop- p- butyl) (FS) and drying off (DO) on the sucrose content (Pol % cane) of sugarcane

A combination of Dry off and Fluazifop- p- butyl resulted in the highest ERC % cane followed by Fluazifop- p- butyl. The control treatment resulted in the lowest ERC % cane (Table 4).

Table 4. Effect of fluazifop- p- butyl on ERC % cane

Treatments	**ERC % cane**
Fluazifop- p- butyl (0.45 l / ha)	14.04^{b}
Dry off (56 Dry off days)	10.93^{c}
Dry off (56 Dry off days) + Fluazifop- p- butyl (0.45 l / ha)	15.94^{a}
No ripener (control)	8.06^{d}
CV%	4.8
LSD	0.808
P-value	P = 0.05

Means containing the same letter are not significantly different

4. DISCUSSION

4.1 Effect of Fluazifop-p-butyl on the Yield of Sugarcane

Both the chemical ripener (Fluazifop- p- butyl) and Dry off led to a decrease in sugarcane yield (Table 2). Sugarcane yield losses were greater in Fluazifop- p- butyl ripened treatments. This is because Fluazifop- p- butyl stopped growth of the sugarcane plant resulting in a decrease in biomass accumulation. However, for the treatments that were put on dry-off, weight losses were not as great as observed on chemical ripened treatments. Under dry-off, growth is not stopped per se, but there is a gradual decrease in growth until it stops completely provided there is no intermittent rainfall during the drying off period [25]. To some extent, growth continues hence biomass accumulation during the early drying off period until moisture depletion start affecting photosynthesis. This signifies why losses in weight in treatments under dry-off were lower than observed in Fluazifop- p- butyl treated treatments. The chemical ripener stopped growth completely while moisture depletion instigated by drying-off disrupted photosynthesis. All this together with respiration and dehydration inferred severe weight losses in the combination treatment. These results are in line with those of Donaldson [26] who found that fibre and non-sucrose content were reduced by about 10% while sucrose content was increased by 15% upon addition of chemical ripeners. A study by van Heerden et al. [27] also showed a reduction in sugarcane yield as a result of application of trinexapac-ethyl (Moddus®). From the research it was concluded that the ripener has a hormonal mechanism, it inhibits production of plant hormone giberellic acid thereby leading to a restriction of internode elongation and leaf growth hence a reduction in the ultimate sugarcane yield.

4.2 Effect of Fluazifop- p- butyl on the Sugar yield

Application of Fluazifop- p- butyl resulted in the highest sugar yield which was 35.6% higher than that of the control where no ripener was used (Table 3). This can be explained by the fact that Fluazifop-butyl (Fusilade super) inhibits acetyl Co-A carboxylase an essential plant enzyme which catalyses the de novo synthesis of fatty acids [28,21]. Fatty acids are required for the synthesis of membranes, waxes, suberin and the cutin [29]. All these cellular components are required for the formation of new plant cells in tissues where growth is taking place. Once sprayed, Fluazifop- p- butyl follows the symplast pathway and much of it is metabolised in primary utilization sinks. Young developing leaves (spindle leaves) and the stalk apex are primary utilisation sinks and have the first priority on assimilates [19]. Usually these utilisation sinks along with the storage sinks, root sinks and respiration compete for photo-assimilates. Application of Fluazifop- p- butyl results in a disruption in plant growth. The source of photosynthates, which are the developed leaves are not affected by the chemical. Elimination of the two utilization sinks by the chemical ripener leaves the storage sinks (stalk parenchyma cells) with a more competitive advantage on photosynthates [12]. This results in more photosynthates being stored, in the form of sucrose in the cane, rather than utilized for growth. This supports the increase in sucrose content realized in Fluazifop- p- butyl applied treatments. Morgan [11] reported that a decrease in acid invertase, an enzyme that catalyses conversion of sucrose into its monomers (fructose and glucose) following treating cane with Fluazifop- p- butyl substantiates the increase in sucrose content. This could be also another pointer for the increase in apparent sucrose content in chemical ripened treatments. There was a substantial increase in sucrose content in sole Fluazifop- p- butyl treatment than the one for dry-off only. The chemical ripener caused the total seizure of growth in the plant such that most photo-assimilates were available for storage. Similar results of ripeners resulting in increased sugar content were also observed by Orgeron [10], Rostron [13]; Donaldson and Van Staden [25]; Donaldson [26] and van Heerden et al. [27].

With the exception of the control, all treatments showed substantial increase in apparent sucrose content (Table 3). The increase in sugar content for the dry-off treatment can be explained by the fact that drying off resulted in moisture depletion in the sugarcane crop and this prompted the crop to enter into drought escape mode. This state is characterized by several physiological mechanisms that are initiated by the crop in order to protect itself against the water stress damage and conserve cellular structures such as membranes [11]. A low water potential is created due to moisture depletion within the soil environment where the crop is growing. As such, an osmotic gradient is generated which causes the movement of water from the plant (where there is a higher water potential) into the soil. The crop counteracts by increased carbon deposition in the stalk in order to create a higher solute potential within the plant which would impede the subsequent water loss due to osmosis. Carbon is deposited in the sugarcane stalk as sucrose [19]. This could be the validation for the increase in apparent sucrose content (although not significantly higher than chemical ripened treatments) in drying-off treatments. When sugarcane is put on dry-off, there is no total seizure of growth. Growth is only retarded meaning that there is some considerable growth in the crop albeit the Dry off. This infers that some assimilates produced from photosynthesis will still be used for plant growth. This explains why the sucrose content in treatments under dry-off was relatively lower as compared to chemical ripened treatments.

A significant increase in sucrose content in the combination treatment (dry-off + Fluazifop- p-butyl) above all other treatments (Table 4) may be as a result of combined effects of both Fluazifop- p- butyl and drying off. As already mentioned, Fluazifop- p- butyl affects the meristematic cells at the stalk apex. In the control treatments, the crop used photo-assimilates in growth at the expense of storage which explains the low sucrose content observed. The gain in ERC % cane (Table 4) observed in the dry-off + Fluazifop- p- butyl combination treatment relative to all the other treatments is mainly because of the high Pol %. The main driver of ERC % cane is Pol percentage. These are directly proportional to each other. This supports the trends that were observed on ERC % cane on the different treatments.

5. CONCLUSION

From this experiment it can be concluded that Fluazifop- p- butyl can effectively increase the sugar yield per hectare of sugarcane although it results in a reduction in sugarcane yield. Application of Fluazifop- p- butyl in combination with the Dry off method results in a relatively higher sugar content, higher Pol% and ERC%. It is recommended that farmers use Fluazifop- p-butyl as a ripener. In this research, data was only collected on the scheduled date of harvest of the crop according to the Triangle Estate Cropping Programme. Therefore, the researcher recommends further studies on the optimum period that should be allowed to lapse after spraying the chemical ripener before the crop can be harvested. Further studies on effect of varying the application rates per hectare of Fluazifop- p- butyl on sugarcane yield and sugar quality parameters are also recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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