INFLUENCE OF NITROGEN FERTILIZATION ON SUGARCANE RESPONSE TO THE RIPENERSGlyphosate AND TRINEXAPAC-ETHYL

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ABSTRACT

Utilization of synthetic chemical ripener to improve early season stalk sucrose concentration is a standard cultural practice for many sugarcane producers in Louisiana. Since 1980, glyphosate has been the sole sugarcane ripening agent utilized in Louisiana. Trinexapac-ethyl was recently approved as a sugarcane ripening agent by United States Environmental Protection Agency. Research conducted over two years evaluated the relationship between nitrogen rate and the sugarcane ripeners glyphosate and trinexapac-ethyl. Nitrogen at 67, 112, and 157 kg ha\(^{-1}\) was applied to the sugarcane cultivar HoCP 96-540 (plant-cane) on March 27, 2010 and April 20, 2011. Glyphosate (210 g ae ha\(^{-1}\)) and trinexapac-ethyl (350 g ai ha\(^{-1}\)) were applied above the sugarcane canopy on August 20, 2010 and August 24, 2011. Stalk weight, percent fiber, sugarcane yield, theoretically recoverable sugar (TRS), and sugar yield levels were each equivalent regardless of N rate. For the ripener treatments six weeks after application, TRS, averaged across N rates, was 11% greater for glyphosate than the nontreated and 9% greater for glyphosate compared with trinexapac-ethyl. The TRS for trinexapac-ethyl was equivalent to the nontreated. Sugarcane yield and sugar yield when glyphosate and trinexapac-ethyl were applied were each equivalent to the nontreated.

INTRODUCTION

Sugarcane (\textit{Saccharum} spp.) is a C\textsubscript{4} perennial grass capable of storing large quantities of sucrose in parenchyma cells (Rae et al. 2005). In Louisiana in 2011, sugarcane was grown on 165,000 hectares and was economically the most valuable row crop commodity in the state (Salassi et al. 2011). Unlike most other sugarcane producing areas in the world, which are tropical or sub-tropical, the climate in Louisiana is temperate. The northern boundary of the sugarcane growing region is in Cheneyville, LA (latitude: 31.01N, longitude: -92.28W) and the southern boundary is in Theriot, LA (latitude: 29.35N, longitude: -90.83W). Louisiana often experiences periods of freezing temperatures in the months of December, January, February, and March (Grymes 2007), potentially limiting the growth period of sugarcane to a maximum of 9 months.

To avoid the threat of freezing temperatures, Louisiana sugar factories begin processing sugarcane in late-September or early-October. Sugarcane maturity, in terms of sucrose accumulation (theoretically recoverable sugar/ton of cane or TRS/TC) is lowest at the onset of
harvest and increases throughout the harvest period for most cultivars. The chemical ripener glyphosate [N-(phosphonomethyl) glycine] is commonly applied at 160 to 470 g ae ha\(^{-1}\) four to six weeks prior to the initiation of the harvest season with applications continuing through the first sixty days of the harvest season to increase sucrose concentration within immature portions of the stalk. Since 1980, glyphosate has been the only ripener used in the Louisiana sugarcane industry and 62% of the total harvested hectares were treated in 2005 (Legendre et al. 2005). Glyphosate is a systemic herbicide which enters the plant through the leaf tissues and is then translocated to the shoot and root meristematic regions (Hilton et al. 1980) resulting in decreased levels of new cell wall production and reducing sugars within immature internodes. Invertase activity is decreased in mature internodes within 24 to 48 hours of glyphosate application, resulting in retarded vegetative growth.

Trinexapac-ethyl [4-(cyclopropylhydroxymethylene)-3, 5 dioxocyclohexanecarboxylic acid] has been shown to be an effective sugarcane ripening agent. Trinexapac-ethyl is an acycloclohexanedione that interferes with plant hormone biosynthesis by mimicking 2-oxoglutaric acid late in the gibberellic acid 1 (GA1) biosynthesis pathway where co-substrates 2-oxoglutaric acid and dioxygenases catalyze biological reactions (Rademacher 2000). Disruption of GA1 results in stunted growth due to lack of cell elongation. In Brazil, sugar content was increased by 10% for the 25 most important sugarcane cultivars when trinexapac-ethyl was applied at 200 g ai ha\(^{-1}\) (Resende et al. 2000). The optimal treatment to harvest interval was 45 to 60 days. In Australia, when six cultivars were treated with trinexapac-ethyl at 200 g ai ha\(^{-1}\) and harvested between 6 and 10 weeks after application, sucrose levels were greater than the nontreated (Kingston and Rixon 2007). Sugarcane yield in the subsequent ratoon crop for the cultivars Q205, Q188, Qs92-330, and Qs93-286, however, was negatively affected. Trinexapac-ethyl has also been used in Australia as a growth retardant to shorten internode length, decreasing the potential for lodging of sugarcane used for planting (Croft and Magnanini 2006). In 2012, the United States Environmental Protection Agency (EPA) approved trinexapac-ethyl (Moddus 2EC\(^{®}\)) for use as a sugarcane ripener and growth retardant. Trinexapac-ethyl can be applied at 200 to 350 g ai ha\(^{-1}\) in both plant-cane and ratoon crops.

In sugarcane, stalk sucrose concentration has been shown to be related to nitrogen availability and uptake. Nitrogen, an essential plant nutrient, is a constituent of chlorophyll, amino acids, proteins, and other biochemical plant compounds (Foth and Ellis 1997). In Louisiana, nitrogen recommendations for sugarcane are based on soil texture and crop age. Recommended N rates range from 67 to 112 kg ha\(^{-1}\) for the plant-cane crop on light- and heavy-textured soils to 90 to 134 kg ha\(^{-1}\) for ratoon crops on light- and heavy-textured soils, with the higher rates recommended for heavier soil types (Gravois 2013). Previous research demonstrated a direct relationship between nitrogen rate and sugarcane yield, and nitrogen rate and stalk sucrose concentration (Borden 1942; Chapman et al. 1994; Das 1936; Muchow et al. 1996; Wiedenfeld 1995). Applying excessive nitrogen to sugarcane, especially in the ratoon crop, has often been shown to increase sugarcane yield (TC), but it has also been shown to decreases sucrose content (TRS). Lower nitrogen application rates often reduce TC while increasing TRS. Clowes and Inman-Bamber (1980) in South Africa concluded that nitrogen level did not affect sugarcane response when treated with glyphosate ripener.
Variability in response to glyphosate ripener in Louisiana can be attributed to cultivar, application date (early or later in growing season), environmental conditions following application, and harvest interval following ripener application (Clowes and Inman-Bamber 1980; Legendre et al. 2005). Nitrogen fertilizer rates can also vary from farm to farm, and may also contribute to variability in response to ripener application. Even though glyphosate ripener is used on a majority of the harvested sugarcane grown in Louisiana and increases in sucrose can be observed, decreases in sugarcane tonnage due to ripener application may not always result in greater yield of sugar per hectare. Research was conducted to evaluate the relationship between N-fertilization rate and ripener use, and to evaluate trinexapac-ethyl as an alternative ripener to glyphosate.

MATERIALS AND METHODS

Research was conducted in 2010 and 2011 at the Sugar Research Station in St. Gabriel, LA, on a Commerce silt loam (Fine-silty, mixed, nonacid, thermic Aeric Fluvaquent) soil. Nitrogen at rates of 67, 112, and 157 kg ha\(^{-1}\) were applied to the sugarcane cultivar HoCP 96-540 (plant-cane) on March 27, 2010 and April 20, 2011. Liquid, 32% urea-ammonium nitrate fertilizer was applied using knives, one on each side of the sugarcane drill spaced 71 cm apart and placed 10 cm deep. Treatments were arranged in a split block experimental design with three replications. Nitrogen rates were whole plots and ripener treatments, glyphosate (Touchdown Total\(^{®}\)) at 210 g ae ha\(^{-1}\), trinexapac-ethyl (Palisade EC\(^{®}\)) at 350 g ai ha\(^{-1}\), and a nontreated control, were subplots. Glyphosate and trinexapac-ethyl were applied above the canopy on August 20, 2010 and August 24, 2011 using a CO\(_2\)-pressurized backpack sprayer calibrated to deliver 140 L ha\(^{-1}\) at 190 kPa. Subplots consisted of a single row of sugarcane 1.8 m wide by 6.1 m long. Each plot was separated by a 1.5 m nontreated buffer. Six weeks after ripener application (September 30, 2010 and October 5, 2011) a 10-stalk sample from each plot was hand-harvested from each plot, and the leaves were removed prior to processing. Samples were weighed and processed at the Sugar Research Station Sucrose Laboratory in St. Gabriel, LA. Brix, pol (Z°), and percent fiber were measured by NIR SpectraCane (Gravois et al. 2008). A high degree of relationship between NIR estimations and standard laboratory techniques for Brix (R\(^2\) = 0.96), fiber content (R\(^2\) = 0.85), moisture (R\(^2\) = 0.94) and pol (R\(^2\) = 0.94) has been reported (Gravois et al. 2008). Theoretical recoverable sugar (sucrose content) was calculated using normal juice sucrose, Brix and fiber (TRS = 0.5(0.28 * Normal Juice Sucrose – 0.08 * Brix)(100 – (55.67 * Fiber)/(100 – Fiber)) (Gravois and Milligan 1992). Plots were harvested with a sugarcane combine and loaded into a wagon equipped with load cells to measure actual cane yield. Sugar yield was calculated by multiplying TRS by sugarcane yield.

Data were analyzed using SAS v9.3 software (SAS Institute 2012) and were subjected to the Proc Mixed procedure using the following linear model:

\[ Y_{ijkl} = \mu + W_i + R_{(i)} + P_k + RP_{ij(k)} + N_l + G_{kl} + E_{ijkl}. \]

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1 Touchdown Total\(^{®}\), potassium salt of glyphosate. Syngenta Crop Protection, LLC. P. O. Box 18300, Greensboro, North Carolina 27419-8300.

2 Palisade\(^{®}\) 2EC, trinexapac-ethyl. Syngenta Crop Protection, LLC. P. O. Box 18300, Greensboro, North Carolina 27419-8300.
where \( Y_{ijkl} \) is the observed response of year \( i \) in replication \( j(i) \) of ripener treatment \( k \) and nitrogen \( l \); \( \mu \) is the overall mean; \( W_i \) is the year effect; \( R_{j(i)} \) is the replication effect nested within year; \( P_k \) is the ripener treatment effect; \( RP_{j(i)k} \) is the replication(year) by ripener interaction; \( N_l \) is the nitrogen effect; \( PNR_{ijkl} \) is the ripener by nitrogen interaction; \( E_{ijkl} \) is the experimental error.

Least square means were calculated, and mean separation was performed using the PDIF option (\( P \leq 0.05 \)). Letter groupings were converted using the PDIFF option (Saxton 1998).

**RESULTS AND DISCUSSION**

Analysis of variance showed no significant (\( P \leq 0.05 \)) effect due to nitrogen fertilizer rate for any of the parameters measured (Table 1). Stalk weight, percent fiber, sugarcane yield, TRS, and sugar yield levels were each equivalent whether nitrogen was applied at 67 or 157 kg ha\(^{-1} \) (Table 2). Tubaña et al. (2007) also reported that N rate (0, 45, 90, and 120 kg ha\(^{-1} \)) had no effect on sugar yield or normal sucrose when averaged across plant-cane LCP 85-384, HoCP 96-540 and L 99-226.

Ripener application significantly (\( P \leq 0.05 \)) affected stalk weight and TRS 6 weeks after treatment (WAT) (Table 1). There was no significant interaction for nitrogen rate \( \times \) ripener application for any of the parameters measured. Averaged across nitrogen rates, sugarcane stalk weight 6 WAT was reduced 8 and 7\% when glyphosate and trinexapac-ethyl, respectively, were applied compared with nontreated sugarcane (Table 3). Millhollon and Legendre (1996) reported decreased stalk weight in as few as 27 days after glyphosate treatment. Legendre et al. (2001) reported that glyphosate at 210 g ai ha\(^{-1} \) had no effect on sugarcane stalk weight of LCP 85-384 at 5 or 6 WAT, but stalk weight was reduced 7 WAT.

Theoretically recoverable sugar averaged across nitrogen rates was 120 g kg\(^{-1} \) when glyphosate was applied, an 11\% increase compared to the nontreated and a 9\% increase compared to trinexapac-ethyl (Table 3). For trinexapac-ethyl, TRS was equal to the nontreated. Several researchers have demonstrated the ability of glyphosate to increase TRS (Hilton et al. 1980; Martin et al. 1981; Millhollon and Legendre 1996; Legendre et al. 2001; Tianco and Gonzales 1980). In contrast to the present study, Resende et al. (2000) reported an average increase in sugar content of 10\% for the 25 most important cultivars when trinexapac-ethyl was applied in Brazil. Similarly, trinexapac-ethyl increased sucrose levels for many of the cultivars tested in Australia (Kingston and Rixon 2007). In both of these studies, trinexapac-ethyl was applied at 200 g ai ha\(^{-1} \) (150 g ai ha\(^{-1} \) less than for the present study) and sugarcane was harvested around 6 to 9 WAT (harvest of 6 WAT in present study). The inability of trinexapac-ethyl to increase sucrose in the present study may be related to the short growing season in Louisiana combined with environmental conditions affecting sugarcane growth. It is possible that a longer interval between trinexapac-ethyl application and sugarcane harvest may be needed to increase sucrose concentration.

Sugarcane yield was numerically less when both ripeners were applied compared with the nontreated, but these differences were not significant (Tables 1 and 3). Sugarcane yield averaged 62.3 Mg ha\(^{-1} \). Although TRS was greatest where glyphosate was applied, sugar yield was equivalent to the nontreated and averaged across ripener treatments was 7046 kg ha\(^{-1} \). Increasing sucrose concentration is desirable to improve mill efficiency.
Management practices that encourage early season sucrose concentration are vital to the profitability of the Louisiana sugarcane industry. In considering the cost of sugarcane ripeners, producers and sugarcane factory managers should both benefit economically from ripener use. In this study, the focus was on the possible interaction between nitrogen fertilizer rates and sugarcane ripeners, and also on the comparison of the ripeners glyphosate and trinexapac-ethyl. Results showed that sugarcane response to ripener was not affected by nitrogen rate for HoCP 96-540 plant-cane. The finding that increasing nitrogen rate did not lead to increases in TRS or sugarcane yield further substantiated results of other research in Louisiana (Tubaña et al 2007). The consistency in TRS response in sugarcane treated with glyphosate ripener in previous research (Hilton et al. 1980; Martin et al. 1981; Millhollon and Legendre 1996; Legendre et al. 2001; Tianco and Gonzales 1980) was also observed in the present study. Trinexapac-ethyl at 350 g ai ha\textsuperscript{-1} decreased sugarcane stalk weight, as did glyphosate, but trinexapac-ethyl did not improve TRS when measured 6 WAT.

REFERENCES


Table 1. Analysis of variance of fixed effects for the 2010 and 2011 plant-cane experiments with HoCP 96-540 to evaluate nitrogen rates and ripener treatments.¹

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Stalk weight</th>
<th>Percent fiber</th>
<th>Sugarcane yield</th>
<th>TRS²</th>
<th>Sugar yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>--------------</td>
<td>---------------</td>
<td>-----------------</td>
<td>------</td>
<td>------------</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.6615</td>
<td>0.2160</td>
<td>0.5390</td>
<td>0.8614</td>
<td>0.5290</td>
</tr>
<tr>
<td>Ripener</td>
<td>0.0436</td>
<td>0.2188</td>
<td>0.5652</td>
<td>0.0002</td>
<td>0.3139</td>
</tr>
<tr>
<td>Nitrogen*Ripener</td>
<td>0.4771</td>
<td>0.3369</td>
<td>0.8823</td>
<td>0.4068</td>
<td>0.8269</td>
</tr>
</tbody>
</table>

¹ Ripener treatments were glyphosate at 210 g ae ha⁻¹ and trinexapac-ethyl at 350 g ai ha⁻¹; nitrogen rates at 67, 112, and 157 kg ha⁻¹.
² TRS, theoretically recoverable sugar.

Table 2. Nitrogen treatment means averaged across ripener treatments for plant-cane experiments with HoCP 96-540 conducted in St. Gabriel, Louisiana in 2010 and 2011.¹,²

<table>
<thead>
<tr>
<th>Nitrogen rate (kg ha⁻¹)</th>
<th>Stalk weight (kg)</th>
<th>Fiber (%)</th>
<th>Sugarcane yield (Mg ha⁻¹)</th>
<th>TRS² (g kg⁻¹)</th>
<th>Sugar yield (kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>67</td>
<td>1.03 a</td>
<td>10.8 a</td>
<td>65.0 a</td>
<td>113 a</td>
<td>7470 a</td>
</tr>
<tr>
<td>112</td>
<td>1.00 a</td>
<td>10.5 a</td>
<td>58.9 a</td>
<td>113 a</td>
<td>6687 a</td>
</tr>
<tr>
<td>157</td>
<td>1.02 a</td>
<td>10.9 a</td>
<td>63.2 a</td>
<td>112 a</td>
<td>6981 a</td>
</tr>
</tbody>
</table>

¹ Ripener treatments were applied August 20, 2010 and August 24, 2011. Sugarcane harvested September 30, 2010 and October 5, 2011. Treatments included glyphosate (210 g ae ha⁻¹), trinexapac-ethyl (350 g ai ha⁻¹), and nontreated.
² Means within a column followed by the same lowercase letter are not significantly different using Fisher’s protected LSD (P > 0.05).
³ TRS, theoretically recoverable sugar.
Table 3. Ripener treatment means averaged across nitrogen rates for plant-cane experiments with HoCP 96-540 conducted in St. Gabriel, Louisiana in 2010 and 2011.\(^1,2\)

<table>
<thead>
<tr>
<th>Ripener</th>
<th>Stalk weight (kg)</th>
<th>Fiber (%)</th>
<th>Sugarcane yield (Mg ha(^{-1}))</th>
<th>TRS(^3) (g kg(^{-1}))</th>
<th>Sugar yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nontreated</td>
<td>1.07 a</td>
<td>11.0 a</td>
<td>65.0 a</td>
<td>108 b</td>
<td>7153 a</td>
</tr>
<tr>
<td>Glyphosate (210 g ae ha(^{-1}))</td>
<td>0.98 b</td>
<td>10.6 a</td>
<td>60.9 a</td>
<td>120 a</td>
<td>7333 a</td>
</tr>
<tr>
<td>Trinexapac-ethyl (350 g ai ha(^{-1}))</td>
<td>1.00 b</td>
<td>10.8 a</td>
<td>61.1 a</td>
<td>110 b</td>
<td>6652 a</td>
</tr>
</tbody>
</table>

\(^1\) Ripener treatments were applied August 20, 2010 and August 24, 2011. Sugarcane was harvested September 30, 2010 and October 5, 2011. Nitrogen rates were 67, 112, and 157 kg ha\(^{-1}\).

\(^2\) Means within a column followed by the same lowercase letter are not significantly different using Fisher’s protected LSD (P > 0.05).

\(^3\) TRS, theoretically recoverable sugar.