Influence of Nonoptimal Ripener Applications and Postharvest Residue Retention on Sugarcane Second Ratoon Yields

Ryan P. Viator,*† Richard M. Johnson, Edward P. Richard, Jr., Herman L. Waguespack, and Windell Jackson

ABSTRACT

Retention of sugarcane (interspecific hybrids of Saccharum spp.) postharvest residue and certain glyphosate ripener application regimes may independently reduce yields of the subsequent ratoon crop in wet climates. The objective of this experiment was to determine the effects of ripener application and ripener treatment to harvest intervals (THI) on yields of the treated first ratoon, and the combined effects of these treatments and postharvest residue retention on the subsequent second ratoon. Whole plots consisted of either a nontreated control or 0.21 kg a.e. ha$^{-1}$ glyphosate applied to the first ratoon of cultivar LCP 85–384. Split-plots consisted of THI of 40, 50, and 60 d for all plots. Split-split plot treatments consisted of partial removal of postharvest residue or complete retention for second ratoon. Averaged across all THIs for the first ratoon, glyphosate increased sucrose yield by 300 kg ha$^{-1}$ compared with the control. The 60 d THI reduced second ratoon cane and sucrose yields by 5.4 Mg ha$^{-1}$ and 900 kg ha$^{-1}$, respectively, compared with the means of the 40 and 50 THI and sucrose yields by 300 kg ha$^{-1}$ compared with the control. Full residue retention reduced second ratoon cane and sucrose yield by 2.3 Mg ha$^{-1}$ and 300 kg ha$^{-1}$, respectively, compared with partial removal. Residue retention and glyphosate application were not negatively synergistic. Producers should remove postharvest residue from the row top and harvest ripener-treated cane at a THI of 40 to 50 d to maximize sucrose yields in the first ratoon while also preventing yield losses in the subsequent second ratoon.

It is common practice to burn sugarcane before harvesting to reduce fuel cost, reduce extraneous matter, and increase harvester efficiency. Many industries throughout the world are no longer burning sugarcane before harvest (often referred to as green-cane harvesting), mainly due to public pressure to eliminate the smoke and soot that result from burning standing sugarcane and potential agronomic advantages in dry climates. These agronomic advantages include increased soil organic matter (Graham et al., 2002), water use efficiency (Meyer et al., 2005), and sucrose recovery (Richard et al., 2001).

Green-cane harvesting, though, in wet climates actually has agronomic disadvantages. The 6 to 24 Mg ha$^{-1}$ of postharvest residue, regardless of whether the crop is manually or mechanically harvested, imposes stress on developing buds and shoots by reducing soil temperatures, increasing soil moisture, and releasing autotoxic leachates (Richard, 1999; Viator et al., 2005, 2006). Any stress that affects these buds has the potential to reduce yields throughout the remaining crop cycle (Dissanayake et al., 1998). Residue retention can also reduce nutrient availability, reduce tillering, increase water logging of soil, and increase the difficulty of cultivating (Monzon, 1956; White, 1983; Wood, 1991). Therefore many industries in wet climates conduct green-cane harvesting such as Louisiana, burn postharvest residue.

Another practice in many sugarcane producing countries is the application of plant growth regulators to artificially induce ripening. Ripening is defined as the period when the theoretical recoverable sucrose (TRS) in cane stalks increases due to a reduction in vegetative growth (Lingle and Tew, 2008). High incident light, low night temperatures, and low soil moisture later in the harvest season promote natural ripening by retarding vegetative growth and increasing sucrose accumulation (Legendre, 1975; Robertson et al., 1999). These conditions do not always exist at the beginning of harvest, so plant growth regulators are used to artificially hasten maturation to increase sucrose yields (Nickell, 1984). Internationally, the most commonly used ripener is glyphosate [isopropylamine salt of N-(phosphonomethyl) glycine] (Eastwood and Davis, 1997; James, 2004).

The application of glyphosate as a ripener may have negative effects on the subsequent ratoon crop. Glyphosate is phytotoxic to crown buds which could adversely affect ratoon regrowth, stalk population, and yields (Nomura et al., 1986; Legendre et al., 2002). Sublethal doses of glyphosate have altered membrane permeability in root tissue causing subsequent cellular leakage into the root zone (Hess, 1993). In greenhouse studies, glyphosate increased the severity of Pythium root rot in sugarcane (Dissanayake et al., 1998).

The level of residual stress on the subsequent ratoon crop varies with the THI of a ripener application. In radiolabeled glyphosate studies, glyphosate distribution in the leaves, apical meristem, stem, roots, and secondary tillers was altered with time (Nomura et al., 1986). In an effort to reduce translocation of glyphosate to the ratoon buds, the maximum recommended THI in Louisiana is 49 d (Legendre et al., 2002).
Poor harvesting conditions (rain and saturated soils), often force Louisiana growers to extend the THI beyond the recommended interval because waterlogged fields are not accessible to harvesting equipment.

It has been reported that other factors, such as moisture stress and poor fertility, can compound the residual effects of ripeners on the subsequent ratoon crops (Clowes, 1980; Donaldson and Inman-Bamber, 1982; Legendre et al., 2002). We are concerned that the retention of postharvest residues combined with greater than optimal THI may also exacerbate the residual negative effects of a glyphosate-ripening application on subsequent ratoon crops. The objective of this experiment was to determine the effects of ripener application and ripener treatment to harvest intervals on yields of the treated first ratoon, and the combined effects of these treatments and postharvest residue retention on the subsequent second ratoon.

**MATERIALS AND METHODS**

Trials were conducted in 2003–2004 and 2004–2005 on Bull Run Plantation in Schriever, LA using a Schriever clay (very-fine, smectitic, hyperthermic Chromic Epiaquerts) soil with the first ratoon regrowth of cultivar LCP 85–384 (Milligan et al., 1994) grown on raised beds 1.8 m wide. LCP 85–384 was planted to 91% of the sugarcane acreage in Louisiana in 2004 (Legendre and Gravois, 2004). The experiment was planted in a RCBD with six replications and a split-split plot arrangement. Whole plots consisted of either a nontreated control or the glyphosate treatment formulated as Polado L (Monsanto Co., St. Louis, MO) with a 0.25% v/v nonionic surfactant. The glyphosate was applied on 1 Oct. 2003 and 3 Oct. 2004 using a helicopter mounted sprayer at 45 m s⁻¹ and 240 kPa to deliver 94 L ha⁻¹ at 0.21 kg a.e. ha⁻¹. The whole plots were 50 m long and 32.4 m wide with a buffer consisting of 5 m of cane between each plot. Split-plots consisted of THIs of 40, 50, and 60 d for both glyphosate-treated and nontreated cane; these plots were 50 m long and 10.8 m wide. Split-split plot treatments consisted of a partial removal of the residue by mechanical repositioning of postharvest residue into the wheel furrow a week after the first ratoon harvest with a ground-speed driven, serrated rubber toothed sweep (Orthman Residue Remover, Orthman Manufacturing Inc., Lexington, NE) or complete residue retention. These plots were 25 m long and 10.8 m wide, and all data were taken from the two center rows of these six 1.8-m row plots.

First and second ratoon experiments were harvested using a chopper harvester. Cane yield (Mg ha⁻¹) was determined using a modified billet wagon equipped with electronic load cells (Johnson and Richard, 2005). The TRS (kg Mg⁻¹) was assessed using the core press method (Johnson and Richard, 2005) from a billet sample randomly collected from each plot. Sucrose yield was determined by multiplying cane yield by TRS. In the second-ratoon crops, numbers of harvestable stalks (>1.4 m in height) were recorded from a 2 m row-length in mid-August, and stalk heights were measured from 10 randomly selected stalks. Initial data were analyzed in SAS using PROC MIXED (SAS Institute, 2001) with trial, replication, ripener treatments, harvest intervals, and residue treatments as fixed effects to determine potential interactions between trial and treatments. There were no interactions between trial and treatments so data were pooled across trials with ripener treatments, harvest intervals, and residue treatments as fixed effects and trial and replication as random effects. This analysis revealed ripener treatment × harvest interval interactions for some parameters. These interactions were evaluated using the SLICE option of LSMEANS procedure. Differences between treatment least square means were compared using the pdiff option (Saxton, 1998) at P < 0.05.

**RESULTS**

**First Ratoon Crop**

Glyphosate treatments and THIs significantly affected the first-ratoon TRS, cane yield, and sucrose yield (Table 1). There was also a significant glyphosate by THI interaction for TRS indicating that sugarcane responded differently to glyphosate treatments at different THIs. Researchers in Florida reported a similar interaction (Dusky et al., 1986). Least square means were estimated for TRS to take into account the glyphosate by THI interaction (Table 2). At a 40 d THI, TRS was not significantly increased by the glyphosate ripener application relative to the nontreated control. At the 50 and 60 d THI, the glyphosate ripener treatment increased TRS by 18 and 14 kg Mg⁻¹ (16 and 12%), respectively, compared to the nontreated control. When one compares all the nontreated cane harvested at the different THIs, the 60 d THI

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>TRS</th>
<th>Cane yield</th>
<th>Sucrose yield</th>
<th>Stalk height</th>
<th>Stalk population</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First ratoon (2003 and 2004)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glyphosate (G)</td>
<td>53.3***</td>
<td>3.82*</td>
<td>4.6*</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Treatment to harvest interval (THI)</td>
<td>15.0***</td>
<td>12.8***</td>
<td>28.3***</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>G × THI</td>
<td>3.16*</td>
<td>0.99</td>
<td>0.53</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Second ratoon (2004 and 2005)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>0.02</td>
<td>0.74</td>
<td>23.60*</td>
<td>8.31***</td>
<td>3.81</td>
</tr>
<tr>
<td>THI</td>
<td>2.17</td>
<td>4.30*</td>
<td>5.52*</td>
<td>11.54***</td>
<td>18.75***</td>
</tr>
<tr>
<td>Residue (R)</td>
<td>1.03</td>
<td>5.05*</td>
<td>42.01*</td>
<td>23.18***</td>
<td>42.00**</td>
</tr>
<tr>
<td>G × THI</td>
<td>0.24</td>
<td>1.27</td>
<td>3.86*</td>
<td>0.12</td>
<td>0.70</td>
</tr>
<tr>
<td>G × R</td>
<td>0.51</td>
<td>0.04</td>
<td>0.75</td>
<td>3.68</td>
<td>0.36</td>
</tr>
<tr>
<td>THI × R</td>
<td>0.85</td>
<td>0.05</td>
<td>0.70</td>
<td>1.16</td>
<td>3.86</td>
</tr>
<tr>
<td>G × THI × R</td>
<td>1.00</td>
<td>0.14</td>
<td>0.73</td>
<td>0.89</td>
<td>0.73</td>
</tr>
</tbody>
</table>

* Significance at 0.05 probability level.
** Significance at 0.01 probability level.
*** Significance at 0.001 probability level.
increased TRS by 9 kg Mg⁻¹ (8%) relative to the average TRS at the 40 and 50 d THI indicating natural ripening.

Unlike TRS, cane and sucrose yields did not exhibit a glyphosate by THI interaction. Averaged across all THIs, glyphosate decreased cane yield by 3.0 Mg ha⁻¹ (5%) but increased sucrose yield by 300 kg ha⁻¹ (4%) compared with the control. This indicates an economic advantage to a glyphosate-ripening treatment when harvested at a 40 to 60 THI in first ratoon since sucrose is the marketable product not actual cane biomass. Dusky et al. (1986) reported that THIs beyond 8 wk were not economically practical for sugarcane in Florida.

**Second Ratoon Crop**

When the first ratoon crop was treated with glyphosate (Table 3), the THI had no residual effect on TRS in the second ratoon crop. Previous research indicated that residual crop effects of glyphosate applications on TRS occurred in the subsequent ratoon crop (Dusky et al., 1986). The THI of glyphosate-treated cane in the first ratoon crop affected both cane and sucrose yields in the second ratoon crop. Due to the glyphosate by THI interaction for sucrose yield (Table 1), least square means were reported by harvest interval and glyphosate treatment for both sucrose yield and sucrose yield parameters (Table 3). This interaction indicates that the residual effects of glyphosate applications on sucrose yields were not consistent across different THIs. A THI of 60 d reduced second-ratoon cane and sucrose yields (54.2 Mg ha⁻¹ and 6900 kg ha⁻¹) compared with the 40 (59.1 Mg ha⁻¹ and 7800 kg ha⁻¹) and 50 d THIs (60.2 Mg ha⁻¹ and 7800 kg ha⁻¹) for glyphosate-treated cane. Stalk height was reduced by the longest THI by an average of 6 cm compared with the other intervals, but stalk population was not affected for glyphosate-treated cane. Substantial reductions in regrowth, stalk population, and yield have been reported at a THI exceeding 49 d (Legendre and Gravois, 2004).

When comparing glyphosate treatments with the non-treated control for the 40 and 50 d THIs, TRS, cane yields, and sucrose yields were not affected, but stalk height was reduced with the glyphosate treatments. However, a THI of 60 d reduced sucrose yield by 300 kg ha⁻¹ and stalk height by 8 cm compared with the control. Previous research indicated that initial stalk height differences due to glyphosate treatment tended to decrease with time and the initially lower populations in the treated plots tended to increase and surpass those of the untreated control plots before finally stabilizing at a level similar to those of sugarcane that was not treated with glyphosate (Clowes, 1980).

Glyphosate and residue treatments showed no interaction, therefore residue management data were pooled across glyphosate treatments. The lack of a glyphosate by residue management interaction indicates that this stress and glyphosate THI acted independently. Residue treatments did not affect TRS, but all other measured parameters measured were affected. Full residue retention reduced cane and sucrose yields by 2.3 Mg ha⁻¹ and 300 kg ha⁻¹, respectively, compared with partial removal (Table 3). These yield differences were reflected by a 6-cm reduction in stalk height and a reduction of 1900 stalks ha⁻¹ in stalk population with full retention relative to partial removal.

**DISCUSSION**

The Polado L label for sucrose enhancement in Louisiana stipulates a THI of 21 to 49 d (Monsanto Company, 2004). Our study showed a sucrose yield advantage at a 40 to 60 d THI for first ratoon yields. Prior research in South Africa and Louisiana indicated that a 42 d interval was the optimal THI because, after this time, decreases in stalk mass brought about by the inhibition of apical growth negated increases in sucrose content (Clowes, 1980; Legendre et al., 1980). Similar reductions in cane tonnage that negated increases in TRS were not observed in our study.

There are several possibilities for these inconsistencies in optimal THIs. Cultivars differ greatly in their response to a glyphosate application (Millholon and Legendre, 1996). Another explanation is that the growing season in Louisiana is 6 to 10 mo whereas most other sugarcane regions have 12 to 24 mo growing seasons. Therefore, Louisiana sugarcane is not as physiologically mature when it is treated with ripeners as it would be in most other sugarcane regions. The physiological content (Clowes, 1980; Legendre et al., 1980). Similar reductions in cane tonnage that negated increases in TRS were not observed in our study.

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**Table 2. Treatment least square means for theoretical recoverable sucrose (TRS), cane and sucrose yield for two first-ratoon crops (2003 and 2004) of LCP 85-384 exposed to glyphosate treatments at three different treatment harvest intervals (THI) (40, 50, and 60 d) compared with nontreated controls.**

<table>
<thead>
<tr>
<th>Ripener</th>
<th>40 THI</th>
<th>50 THI</th>
<th>60 THI</th>
<th>All THI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRS</td>
<td>kg Mg⁻¹</td>
<td>Mg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
</tr>
<tr>
<td>Control</td>
<td>111A</td>
<td>113B</td>
<td>121A</td>
<td>58.7A</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>119Ab†</td>
<td>131Aa</td>
<td>135Aa</td>
<td>7100A</td>
</tr>
</tbody>
</table>

† Means within a column followed by the same uppercase letter or in a row followed by the same lowercase letter are not statistically different using the F probability values and the PROC MIXED macro as described by Saxton (1998) at the 0.05 probability level.

**Table 3. Treatment means for theoretical recoverable sucrose (TRS), cane and sucrose yield, and stalk heights and population for two second-ratoon crops (2004 and 2005) of LCP 85-384 exposed to glyphosate treatments at three different treatment harvest intervals (THI) compared with nontreated controls with full or partial removal of postharvest crop residues.**

<table>
<thead>
<tr>
<th>THI</th>
<th>Control</th>
<th>Glyphosate</th>
<th>Control</th>
<th>Glyphosate</th>
<th>Control</th>
<th>Glyphosate</th>
<th>Control</th>
<th>Glyphosate</th>
<th>Control</th>
<th>Glyphosate</th>
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<tr>
<td></td>
<td>Magazine</td>
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<tr>
<td>TRS</td>
<td>kg Mg⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td>kg ha⁻¹</td>
</tr>
<tr>
<td>40 d</td>
<td>130A†</td>
<td>132Aa</td>
<td>53.8A</td>
<td>59.1Aa</td>
<td>57.8A</td>
<td>60.2Aa</td>
<td>7000Aa</td>
<td>7800Aa</td>
<td>198Aa</td>
<td>193Aa</td>
</tr>
<tr>
<td>50 d</td>
<td>128Aa</td>
<td>130Aa</td>
<td>56.3Aa</td>
<td>60.2Aa</td>
<td>59.5Aa</td>
<td>64.8Aa</td>
<td>7200Aa</td>
<td>7800Aa</td>
<td>197Aa</td>
<td>194Aa</td>
</tr>
<tr>
<td>60 d</td>
<td>130Aa</td>
<td>127Aa</td>
<td>55.4Aa</td>
<td>54.2Aa</td>
<td>57.3Aa</td>
<td>61.3Aa</td>
<td>7200Aa</td>
<td>6900Bb</td>
<td>196Aa</td>
<td>188Bb</td>
</tr>
</tbody>
</table>

† Means within a column followed by the same uppercase letter or in a row followed by the same lower case letter are not statistically different using the F probability values and the PROC MIXED macro as described by Saxton (1998) at the 0.05 probability level.
stage of the cane at the time of application affects ripener activity (Nickell, 1984), thus the particular time during the growth season that ripener is applied influences efficacy (Cutino et al., 1992). Moreover, based on weekly growth measurements taken at the USDA-ARS Arkydome Farm (unpublished data, 2007), stalk height can increase by as much as 35% during the harvesting period in Louisiana (October–December). Thus, it is a challenge to balance sugarcane ripening and cane growth in temperate climates such as in Louisiana.

For the ripener application and ripener THI effects on sucrose yields of the subsequent second ratoon crop, the glyphosate by harvest interval interaction indicates that glyphosate effects were not consistent across THI. Only the THI of 60 d had residual effects on sucrose yields in the subsequent second ratoon. As noted previously at this harvest interval in the first ratoon crop, ripener application did increase sucrose yields. Radioisotope experiments have indicated that glyphosate is distributed into other portions of the plant such as the stalk and roots (Hilton et al., 1976). Germination of nodal buds or ratoon shoots mobilizes the glyphosate residues into these areas of metabolic activity. The analysis of several ratoon shoots after removal of all the aboveground-treated plant and existing tillers showed that radioactivity stored in the stool had moved into new growth (Nomura et al., 1986). Moreover, the amount of glyphosate translocated to other plant parts was dependent on the duration of exposure (Hayamichi, 1991), which in the case of our experiment would be THI.

The lack of an interaction of postharvest residue retention and ripener application on yields of the subsequent second-ratoon crop indicates that these stresses are independent of each other which is a positive finding since both of these stresses often occur simultaneously in Louisiana. It was thought that these two stresses would be negatively synergistic because both occur at the crop establishment stage and have independently shown negative effects on yield. Prior research has indicated that in Louisiana, residue retention reduces soil temperatures and increases soil moisture, both of which delay emergence and growth (Viator et al., 2005). Greenhouse studies using cultivars grown in Louisiana suggest that glyphosate can reduce sugarcane growth by increasing the severity of root rot, which delays emergence and growth (Dissanayake et al., 1998). Prior research also indicated yield losses due to residual glyphosate effects only occur when the residual glyphosate stress was accompanied by another stress such as inadequate moisture (Donaldson and Inman-Bamber, 1982). However, stress physiology experiments with other crops have determined with a dominant-stress factor model, following the Liebig-Sprengel law of the minimum, that when a plant encounters multiple sources of stress, the most severe stress determines yield (Ben-Gal and Shani, 2003; Shani and Dudley, 2001).

A possible explanation for the discrepancies with prior research is that the cultivar used in this study is more tolerant to ripener stress than cultivars used in other studies in Louisiana. Prior research indicated that genotypes responded differently to glyphosate applications both in the crop where it was applied and the subsequent crop (Clowes and Inman-Bamber, 1980; Dusky et al., 1986; Millholon and Legendre, 1996; Roston, 1989). The sugarcane cultivar used in our study, LCP 85–384, is a small stalk diameter, high population cane, whereas most other cultivars grown have a larger diameter and lower population (Milligan et al., 1994). High population sugarcane cultivars similar to LCP 85–384 have demonstrated greater tolerance to environmental stress than lower population cultivars (Viator et al., 2005). Other work has demonstrated cultivar differences in tolerance to residue retention (Viator et al., 2005). Future research should focus on identifying cultivars with regrowth tolerance to glyphosate applications and residue retention. Until tolerant cultivars are identified, Louisiana producers should remove postharvest residue from the row top to mitigate yield losses in subsequent ratoons. We also advise that delaying harvest of first ratoon sugarcane until 60 d after a ripener is applied may result in decrease yields in the second ratoon crop.

ACKNOWLEDGMENTS

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REFERENCES


