THE INFLUENCE OF POST-HARVEST RESIDUE MANAGEMENT ON WATER QUALITY AND SUGARCANE YIELD IN LOUISIANA

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ABSTRACT

Louisiana sugarcane (*Saccharum officinarum* L.) growers are increasingly harvesting fields ‘green’, without pre-harvest burning to eliminate leafy material. The post-harvest residue, however, is generally burned on the ground to avoid the debilitating effects of the residue on the subsequent ratoon crop in the production cycle. A best management practice (BMP) that allows for the retention of the residue to minimize surface runoff and increase the soil fertility status would be viewed as both environmentally sound and producer friendly. The objectives of this study were to evaluate the effects of four post-harvest residue management treatments on surface water quality and sugarcane development and yield at two locations in the Vermilion-Teche watershed. Treatments included two approaches designed to mitigate the adverse effects of retained residue on sugarcane, the application of stabilized urea plus composted tea (generated from sugarcane bagasse, poultry litter and corn gluten) and the shredding of the residue for accelerated decomposition; and two treatments currently employed by the industry, ground burning of the residue and full post-harvest retention of the residue. “Edge-of-field” runoff collections were made using automated samplers. Rainfall collection-event load averages for all of the principal water quality parameters (total suspended and total dissolved solids, biological oxygen demand, nitrate and total phosphorus) for the four residue management treatments were not significantly different. Seasonal differences in soil erosion rates among the residue management treatments, however, indicated that exposed soil in the burned areas would be subject to higher sediment removal with high rainfall during the period from post-harvest burning to full-crop canopy. Neither of the residue management treatments designed to hasten residue decomposition was effective, with the urea-compost tea treatment producing elevated N levels in runoff and the shredded-residue treatment generating the greatest volume of surface runoff. The urea/compost tea and shredded-residue treatments were also ineffectual in either enhancing cane and sugar yield or promoting residue decomposition. Burning of the residue did not result in higher yields than retaining the residue.

Keywords: sugarcane; water quality; post-harvest residue management

INTRODUCTION

The 1972 Clean Water Act requires states to develop a list of impaired water bodies and establish Total Maximum Daily Loads (TMDLs) of pollutants for these waters. BMPs are employed on a voluntary basis to control the pollutants in runoff from agricultural lands. The Everglades Agricultural Area in south Florida has effectively utilized BMPs to reduce P loads emanating from sugarcane cropping systems (Lang et al. 2008; Rice et al. 2002). Currently in Louisiana, the sugarcane harvest residue deposited on the soil surface is burned because research has documented significant reductions in yield in subsequent ratoon crops (Richard 2001; Rozeff 1995; Viator et al. 2008) if the residue is left on the soil surface. The environmentally responsible approach to reduce non-point source pollution calls for the elimination of burning in favor of the development of management practices that retain the residue for sediment control and soil organic matter maintenance. The search for alternatives that mitigate the adverse effects of residue retention in the temperate growing region of Louisiana has included shredding of the residue to reduce particle size (Kennedy and Arceneaux 2006), timing and method of residue removal (Viator et al., 2008) and the application of fertilizer N (Viator et al. 2008) and compost tea (Deras 2008). Unfortunately, to date none of these treatments has been sufficiently evaluated or deemed successful enough for adoption by the industry.

A previous investigation of post-harvest residue management strategies revealed no meaningful differences in water quality parameters as a result of residue burning, retention or repositioning into the wheel furrow (Bengtson and Selim 2006). Differences in soil, N, P and K losses among the three residue management treatments also were not significant. Sugar yield, however, was 9.8% greater for the residue-burned treatment, a similar finding to industry observations and other research results.

The objectives of this study were to evaluate the effects of four post-harvest residue management treatments on surface water quality and sugarcane development and yield. Harvest-residue management treatments included two treatments designed to mitigate the adverse effects of retained residue on sugarcane, the application of stabilized urea plus composted tea and the shredding of the residue for accelerated decomposition; and two treatments currently employed by the industry, ground burning of the residue and full post-harvest retention of the residue.

MATERIALS AND METHODS

Two sites, Jeanerette (29^0 57’ 39.05” N, 91^0 43’ 02.52” W) and Youngsville (30^0 07’ 55.32” N, 91^0 57’ 28.58” W), within the Louisiana Vermilion-Teche watershed were selected to evaluate the residue management treatments. The effects of treatments on sugarcane yield are reported for both locations for consecutive harvests. Water quality results, however, are reported only for the Jeanerette site because of un-resolvable back flow issues at the Youngsville site.

Sampling and Analytical Procedures for Water Quality

The Jeanerette site utilized an “edge-of-field” approach for collecting runoff samples. Each of two blocks contained the four treatments arranged across the field. Treatment plots consisted of three "raised bed" rows, each 30.5 m in length. Each plot was designed to discharge into its own water collection device, with the two furrows within the tree-row plot draining into an H-flume. Lateral movement of surface flow was controlled not only through the use of the "raised beds", which directed flow of the runoff water in the furrows to the H-flume, but also by bordering plots with three crop rows to prevent contamination among adjacent treatments. Earthen dams were placed at row ends to prevent cross flow at the collector site. Also, blocks were separated by 30.5 m buffer zones. Drains, which directed surface flow to lateral ditches, were placed down field from the collectors to intercept flow and prevent contamination between blocks. Teledyne Isco Avalanche samplers (Isco, Lincoln, NE) instrumented with Teledyne Isco 720 submerged probe flow modules were used to collect and composite water samples. Analyses were made for total suspended solids (TSS), total dissolved solids (TDS), turbidity, total Kjeldahl nitrogen (TKN), NO_3^--N and NO_2^--N, Cl^-, and SO_4^{2-}, total phosphorus (TP) and biological oxygen demand (BOD). Analytical methods used for each water quality parameter are shown in Table 1. Total loads are the product of multiplying measured flow times concentration.

Table 1. Analytical methods for determination of water quality parameters

Parameter	Analytical method[1]	Equipment and manufacturer
TSS	EPA 160.2	Filtration
TDS	EPA 160.1	Filtration
turbidity	EPA 180.1	Model 2100N turbidimeter, Hach Co., Loveland, CO
TKN	EPA 351.4	Accumet Research Benchtop Meter-Model AR50, Fisher Scientific, Pittsburgh, PA and Fisher Block Digestor-Model BD40, Fisher Scientific, Pittsburgh, PA
Cl^-, NO_3^-, NO_2^-, SO_4^{2-}	EPA 300.0	Dionex ICS-2000 ion chromatograph, Sunnyvale, CA
TP	EPA 365.2	Bausch & Lomb spectrometer, Rochester, NY
BOD	EPA 405.1	VWR Symphony dissolved oxygen meter, Thermo Electron Corporation, Beverly, MA

[1] US EPA 1999.

Agronomic Procedures

The sugarcane cultivar 'LCP 85-384' (Milligan et al. 1994) was planted on a silty clay loam (Vertic Haplaquoll) at Jeanerette and on a silt loam (Typic Hapludalf) at Youngsville in the fall of 2004. Standard management for fertilization, cultivation and crop protection was employed. Residue management treatments were: 1) post-harvest residue burning, 2) full post-harvest residue retention, 3) post-harvest application to the residue of 201 kg ha^{-1} N as stabilized urea and compost tea, and 4) post-harvest reduction in the size of the residue particles by an 8:1 ratio. Treatments 1, 3, and 4 were implemented in approximately 2 weeks after the residue was generated by the combine. Treatment 3 consisted of broadcast-applying the stabilized urea as dry pellets and the compost tea. A standard method for the creation of compost tea was developed. A windrow compost, 0.92 m high, 1.22 m wide, static bed, composed of 1 part sugarcane tops and trash; 3 parts sugarcane bagasse, 1 part poultry litter (for N), and 3 parts corn gluten was created and aerated for 3 weeks. From this compost, a compost tea was developed in an aerated 200 L barrel (5 min on, 15 min off aeration) for 24 h, with the addition of molasses to supplement the growth of aerobic microorganisms. This was strained through a mesh bag to obtain the compost tea, which was immediately transported to the site and applied with a hand sprayer at a rate of 160 L ha^{-1}. Shredding of the residue in Treatment 4 was accomplished using a tractor-mounted chipper/shredder.

Comparisons were made for post-harvest residue dry matter (kg ha^{-1}) remaining in the field, TRS (g kg^{-1}), cane yield (Mg ha^{-1}) and sugar yield (Mg ha^{-1}). Harvest dates for the Jeanerette and Youngsville sites were October 24, 2006 and October 29, 2007 and October 20, 2006 and October 1, 2007, respectively. Cane yield for both first and second ratoon crops at both locations was determined by weighing each plot row with a weigh wagon instrumented with electronic load cells. Cane yield for each plot was estimated from the plot weight, less 14% to adjust for leaf-trash weight. Ten-stalk samples were used to extract the juice. Different methods were used to analyze for juice quality in this experiment. In 2006, juice was extracted using a 3-roller sample mill. Brix was measured with a Model RFM110 Bellingham & Stanley Refractometer (Lawrenceville, GA) and pol was measured using a Autopol 880 Rudolph Research Saccharimeter (Flanders, NJ). In 2007, stalks were shredded by a Dedini Shredder and scanned using a Spectracane 200 NIR (Lower Hutt, New Zealand). Sugar yield was estimated as the product of cane yield and TRS.

Statistical Procedures

A randomized complete block design, with four replications, was used to evaluate treatment effects on crop yield and dry matter residue. Runoff samples were collected from only two of the four replications.

Proc Mixed procedure (SAS v9.1) was used to analyze the water quality data, with date of collection used as repeated measures. Treatment and date of collection were considered to be fixed effects and replication as a random effect in the model. The Akaike Information Criterion was used to determine the most appropriate covariance structure for the parameters. The covariance structure selected to describe repeated measures covariance for the dependent variables (water quality parameters) was compound symmetry (CS) for BOD, independent (IND) for TSS, TP, nitrate, turbidity, TDS, chloride and sulfate, and first order autoregressive (AR1) for TKN and nitrite. Least square means were separated using the LSD test.

Yield and dry matter residue data were also analyzed with the Proc Mixed procedure, with the analysis using crop (first and second ratoons) as repeated measures. Replication was considered a random effect and other model terms were considered fixed effects. Independent covariance structure was used to describe repeated measures covariance for each of the dependent variables (sugar and cane yields and TRS). The LSD test was used to separate least square means.

RESULTS AND DISCUSSION

Hydrologic Data

Surface runoff samples were collected at Jeanerette from January 2006 through May 2007. Rainfall recorded for the collections only totaled 106.9 cm, with a grand total of all rainfall for the 15-month collection period equaling 209.8 cm. Only relative differences in treatment efficacy were of interest and, therefore, accounting for total sediment loss was not an objective of the project.

During the sample collection phase surface runoff events with sufficient flow volume for sample analysis occurred 23 times at the Jeanerette site. Sample contamination and/or flow measurement irregularities precluded the use of two collections; when backflow into flumes was observed on April 29 and July 6, 2006. For the purpose of comparing the relative differences in water quality among the four residue management treatments, all 21 events were included in the statistical analysis.

Table 2 shows the probability values for fixed effects from the analysis of variance for the water quality parameters. Only turbidity had a significant treatment by date interaction; and, therefore treatment means are reported as an average of all collection-event dates. Table 3 contains the treatment means for the 15-month collection period. Collection-event load averages for all of the principal water quality parameters (TSS, TDS, BOD, NO_3^-N and Total P) for the four residue management treatments were not significantly different. These results are similar to the findings of Bengtson and Selim (2006). Differences between the two treatments common to both studies, residue-burned and residue-retained, were not significant for water quality parameters. While treatment losses, averaged over all collection events, for these parameters were similar and indicated that the quality of runoff water appeared unaffected by residue management, a closer examination of the Jeanerette data revealed seasonal differences.

Table 2. P-values for fixed effects for water quality parameters

Parameter	Source		
(kg ha^{-1})	Treatment (T)	Date (D)	T*D
TDS	0.4412	0.0001	0.6554
TSS	0.5925	0.0001	0.0827
Turbidity	0.2311	0.0001	0.0001
BOD	0.2613	0.0001	1.0000
TKN	0.7384	0.0001	0.9693
TP	0.7418	0.0001	0.6119
NO_3^- -N	0.2693	0.0001	0.1645
NO_2^- -N	0.3269	0.0572	0.0571
Cl^-	0.0476	0.0001	0.1587
SO_4^{2-}	0.0561	0.0001	0.2761

Table 3. Mean loads[1], averaged over 21 collection events, for the residue management treatments for water quality parameters measured at Jeanerette

Parameter (kg/ha)	Residue management Burned	 Retained	 Urea/ Compost tea	 Shredded
TDS	62.1 a	71.9 a	60.7 a	80.5 a
TSS	310.0 a	250.8 a	307.2 a	354.7 a
Turbidity	1427 a	1376 a	1724 a	1303 a
BOD	1.14 a	1.11 a	0.99 a	1.29 a
TKN	0.20 a	0.21 a	0.29 a	0.27 a
TP	0.06 a	0.06 a	0.06 a	0.06 a
NO_3^- -N	1.21 a	1.09 a	1.89 a	1.37 a
NO_2^- -N	0.03 a	0.07 a	0.28 a	0.05 a
Cl^-	1.60 b	1.13 c	1.24 c	1.99 a
SO_4^{2-}	1.61 a	1.27 b	2.02 c	1.56 ab

[1]Means in a row followed by the same letter are not significantly different (LSD test at alpha = 0.05).

From harvest until crop canopy closure in May-June of each spring, the burned plots generated higher (P = 0.33) TSS than both residue-retained and urea/compost tea plots, but only a numerically higher amount than the shredded plots (Table 4). Because of the relatively high P level there may be more confidence in stating that there exists a trend or tendency for plots with exposed soil to be more susceptible to erosion than plots in which soil is protected by residue.

Table 4. Differences in mean[1] TSS and NO_3^- -N (kg/ha) among the four residue management treatments as an average of collections made prior to canopy closure each spring at Jeanerette

Residue management	TSS	NO_3^- -N
Burned	305 a	0.6413 b
Retained	166 b	0.4452 b
Urea/compost tea	175 b	1.4534 a
Shredded	242 ab	0.9687 ab
LSD test at alpha =	0.33	0.08

[1]Means in columns followed by the same letter are not significantly different at the designated alpha level.

Nevertheless, a cautionary comment is warranted concerning the seasonally high soil loss that accompanied residue burning. In both winter-spring periods in which runoff was sampled in this project rainfall amounts were below normal, suggesting that the exposed soil in the burned areas would be subject to higher erosion rates with high rainfall during the period from post-harvest burning to full crop canopy.

Another meaningful difference between the treatments was the elevated level of N captured in runoff from the plots receiving fall-applied urea fertilizer and compost tea (Table 4). The amount of NO_3^--N captured in surface runoff from harvest to canopy closure each year was greater (P = 0.08) in the plots receiving urea/compost tea than for both the residue-burned and residue-retained plots. Nitrogen content of the runoff was not significantly different between the urea/compost tea treatment and the residue-shredded treatment. It is obvious that the attempt to mitigate the problems associated with residue retention through the use of a N-rich environment resulted in excessive amounts of N being removed from the plots.

The other treatment designed to mitigate the residue-retention problems, shredding of the residue, unpredictably generated prior to canopy closure relatively high amounts of sediment and N (Table 4), which was undoubtedly due to greater (P = 0.09) flow volume for the residue-shredded plots. Average collection-event flow for the residue-burned, residue-retained, urea/compost tea and residue-shredded treatments was 2,415, 2,340, 1,848 and 3,406 L, respectively. The shredded plots, therefore, should be viewed with caution when considering soil protection. For these reasons, both the urea/compost tea and residue-shredded treatments have to be dismissed as viable alternatives to existing management approaches.

Agronomic Data

The analysis of variance revealed that post-harvest dry matter residue differed significantly among residue management treatments. Dry matter means are shown by location, crop and residue sampling date to emphasize changes over time (Tables 5 and 6). As an average of both crops and all treatments, at the March sampling 48% and 65% of the residue had disappeared on the Jeanerette and Youngsville fields, respectively. Plots with shredded residue had greater amounts of residue than the other treatments with each measurement subsequent to deposition, except for the March 2007 sampling at Youngsville. It was postulated that shredding would enhance residue decomposition by reducing particle size and increasing surface area for microbial degradation (Ambus and Jensen 1997; Angers and Recous 1997; Kennedy and Arceneaux 2006), but the rate of disappearance for shredded plots was not greater than that for the other treatments. While the reason for this is unknown, it is possible that reducing the particle size may have resulted in inflated retained-residue measurements. Residue disappearance rate for the plots receiving urea and compost tea was also disappointing. Both treatments designed to enhance residue decomposition rate, therefore, were not effective.

Table 5. Jeanerette sugarcane harvest-residue dry matter means (mg/ha)[1]

Residue management	Residue sampling			
	First stubble crop		Second stubble crop	
	12/06/2005	03/10/2006	10/26/2006	03/08/2007
Burned	13.17 b	2.49 c	12.95 a	2.02 b
Retained	10.80 b	6.36 b	10.93 a	5.47 b
Urea/Compost tea	11.72 b	7.26 b	11.18 a	4.84 b
Shredded	15.66 a	12.21 a	12.39 a	10.39 a

[1] Means in a column followed by the same letter are not significantly different (LSD test at alpha = 0.05).

Table 6. Youngsville sugarcane harvest-residue dry matter means (mg/ha)[1]

Residue management	Residue sampling			
	First stubble crop		Second stubble crop	
	01/04/2006[2]	03/27/2006	11/13/2006	03/08/2007
Burned	7.94	0.93 b	5.67 a	0.31 b
Retained	7.94	2.70 a	6.03 a	2.52 a
Urea/Compost tea	7.94	3.07 a	5.05 a	3.81 a
Shredded	7.94	3.73 a	7.75 a	2.77 a

[1] Means in a column followed by the same letter are not significantly different (LSD test at alpha = 0.05).

[2] To avoid affecting subsequent measurements, only the plots scheduled to be burned were used to sample for this date.

As shown in Table 7, the analysis of variance indicated that the treatment by location interaction was nonsignificant for all yield traits, as were the crop by treatment and crop by location by treatment interactions. While the crop by location interaction was significant for all traits, it involved differences in magnitude among the means and not reversals in mean rankings. Comparisons, therefore, among residue management treatments were made as an average of locations and crops.

Table 7. Analysis of variance of fixed effects for both locations for the first and second ratoon crops harvested in 2006 and 2007

Source	Num. df	Den. df	Sugar yield		Cane yield		TRS	
			F	*P*	*F*	*P*	*F*	*P*
Location (L)	1	6	22.60	0.0031	79.31	0.0001	71.09	<0.0001
Treatment (T)	3	18	3.50	0.0368	3.26	0.0458	0.85	0.4739
L*T	3	18	0.28	0.8414	0.45	0.7188	0.04	0.9875
Crop (C)	1	24	126.21	<0.0001	59.01	<0.0001	108.66	<0.0001
L*C	1	24	6.27	0.0195	37.71	<0.0001	38.10	<0.0001
T*C	3	24	0.03	0.9931	0.57	0.6431	0.98	0.4090
L*T*C	3	24	0.39	0.7639	0.16	0.9246	0.34	0.7946

Table 8 contains the data on cane and sugar yields as an average of both harvests and both locations. The analysis of variance indicated that residue management treatments significantly affected sugar and cane yield but not TRS. Both cane and sugar yield for the

Table 8. Cane yield, recoverable sugar and sugar yield means[1] averaged over locations and crops

Residue management	Cane Yield Mg/ha	TRS g/kg	Sugar Yield Mg/ha
Burned	72.7 a	117 a	8.4 a
Retained	68.5 ab	118 a	8.0 ab
Urea/Compost tea	65.7 b	115 a	7.5 b
Shredded	66.0 b	115 a	7.5 b

[1] Means in a column followed by the same letter are not significantly different (LSD test at alpha = 0.05).

residue-burned treatment was significantly greater than for the urea/compost tea and shredded-residue treatments but not the residue-retained treatment. As has been demonstrated in other studies (Bengtson and Selim 2006; Richard 2001; Viator et al. 2008), sugarcane grown on plots with burned residue generally exhibits higher yield than that where residue is retained. In this case cane and sugar yields were not significantly different between the two industry-employed approaches to residue management, burning and full retention of the residue, at either site. The relatively poor yield performance of sugarcane grown on plots on which urea/compost tea and shredded residue were applied further serves to condemn these residue management approaches.

CONCLUSIONS

The failure to identify residue management practices that could serve as viable alternatives to residue burning leaves the sugar industry with no new options for residue management. Soil loss measured for the runoff events sampled was moderate and within the "acceptable" range of 5 to 8 Mg ha^{-1} per year. Without viable alternatives, growers will continue to burn until a management practice(s) is identified that utilizes the residue to reduce runoff and enhance soil fertility while minimizing the impact of residue on the subsequent crops. Prescribed burning is a BMP that encourages growers to use proven guidelines to manage smoke and large particulates. Like a number of other agricultural industries that use prescribed burning, the Louisiana sugar cane industry will continue to research ways to eliminate burning. Currently, effort is being made to identify sugarcane varieties that tolerate the residue blanket and to search for amendments that alleviate the yield-limiting effects of the retained residue.

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