SUGARCANE RESIDUE MANAGEMENT EFFECTS IN REDUCING SOIL EROSION FROM QUARTER DRAINS IN SOUTHERN LOUISIANA

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ABSTRACT. *Rainfall events which occur each spring in southern Louisiana have intensities and runoff that can cause significant soil erosion of alluvium small surface ditches (quarter-drains) to remove excess surface water from sugarcane furrows to main field surface ditches. As a result sediment from furrows and eroded soil from quarter-drains accumulate in quarter-drains and main ditches reducing their capacity to carry runoff water from flat sugarcane fields. An experiment was conducted following the 2001 harvest season in Southern Louisiana on alluvial soil to determine the effect of two sugarcane residue management practices on soil erosion and deposition in quarter-drains. Selected post-harvest residue management treatments were: (1) residue left on the field and swept from row-crowns to furrows and (2) residue removed by burning. Based on six rainfall events (cumulative rainfall = 368 mm), residue left on-site significantly reduced erosion from quarter-drains by 60% in comparison to quarter-drains where residue was burned, the average reduction in soil loss from these rainfall events where residue was swept and left in the furrows was 0.89 kg/m of quarter-drain length; the average soil bulk density of 1.5 Mg/m^3. Maximum erosion occurred at the junction or intersection with the quarter-drains and the main field ditch. For plots where residue was removed by burning, a gradual deterioration of the side-walls of the quarter-drain occurred, including at the intersection with the field ditch, where maximum erosion depths in excess of 18 mm were recorded. Based on these results, sugarcane residue left on-site was effective in reducing soil erosion from quarter-drains during a four-month period from spring to early summer in the 2002 growing season.*

Keywords. *Post-harvest residue, Small surface ditches, Quarter-drain, Residue burning, Soil erosion.*

Sedimentation has been identified as a major water quality concern for alluvial soils in Southern Louisiana. Alluvial soils in Louisiana contain significant amounts of clay (27%) in the surface horizon and are susceptible to erosion by surface runoff from cropland (USDA-SCS, 1977). Ground surface cover, in the form of post-harvest residue, reduces energy associated with raindrop impact and flowing water (runoff), thus reducing surface sealing and maintaining infiltration, reducing runoff velocity and volume, and subsequent soil loss. Surface residue also contributes to improved soil quality through improved soil properties (Reeves et al., 1995). Gilley at al. (1986) stated that even small amounts of crop residue substantially reduced soil erosion. The primary benefits of crop residues are reduction of soil erosion, improvement of soil properties, and reduction of soil surface sealing (Schwab et al., 1993). Dickey et al. (1986) reported that crop residue is increasingly being used as a major tool to reduce the loss of one of our most valuable natural resources — topsoil. Conservation practices encourage the use of residue as a protective blanket from rainfall and to enrich soil structure by increased organic matter content.

Blough et al. (1990) concluded that 30% of corn stover residue incorporated into a vertical slit in the soil reduced runoff 25% and 50% less erosion than the bare soil. According to Brown and Norton (1994), who examined the residue effect on erosion from consolidated ridges in a poorly drained silt loam soil, the average detachment rate and average flow velocity decreased 92% and 71%, respectively, with 45% of corn residue cover. Mann et al. (2002) evaluated the potential environmental effects in removing corn stover and indicated that issues of greatest concern are soil erosion and soil organic carbon (SOC) dynamics associated with reducing rates of carbon sequestration.

Historically, sugarcane residue has been burned following harvest, thus eliminating all benefits of the residue, such as organic carbon (OC) buildup and reduction of runoff and soil erosion. This has serious implications in terms of the production on alluvial soils with naturally low organic matter (<1.0%). Viator et al. (2006) reported that after harvesting green sugarcane (manually or mechanically) worldwide from 6000 to 24000 kg/ha of post-harvest sugarcane residue remains on the field. Typically, in Southern Louisiana each year 8600 kg/ha of residue (unpublished data collected) on average is lost due to burning entire sugarcane fields (Kornecki, personal correspondence, 2004). This amount of residue burning translates to 3600 kg/ha of organic carbon released to the atmosphere and to 1200 kg/ha of organic carbon sequestered each year. According to Brady and Weil (1999) about 42% of carbon is in the plant dry tissue material.

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From the total amount, two-thirds of carbon is used by microbes as the source of energy and released to the atmosphere as carbon dioxide. However, one-third of the total (initial) amount of carbon is converted by microbes to organic carbon by adding it to humus (1204 kg/ha). Based on the amount of sugarcane residue discharged during harvest (8600 kg/ha dry mass) the total amount of carbon that could be sequestered to the soil from residue is 3612 kg/ha. This is important from the standpoint of building organic matter level for low organic matter content in the alluvial soils of Southern Louisiana. When sugarcane residue is burned, 3612 kg/ha of carbon is lost as carbon dioxide which otherwise would increase soil organic carbon content. Environmental concerns about burning and public concerns for clean air, especially in newly developed suburban areas adjacent to sugarcane plantations, has moved the sugar industry toward green cane harvesting that leaves all residue in the fields. Burning of residue has been prohibited in many areas, and such prohibitions will likely be expanded in the future. Because of these concerns, there is a need to evaluate and quantify management alternatives, including benefits associated with reducing soil erosion and improving soil quality.

Each year in early spring, quarter-drains (small surface ditches with a semicircular cross-section dug perpendicular to furrows) are installed or refurbished in sugarcane fields to route runoff from furrows to larger field surface drainage ditches (fig. 1). Installation of a new quarter-drain requires removal of about 0.065 m^3 of soil per meter of length, which is discharged and spread (airborne) by the installation equipment over the adjacent field surface. Based on an average bulk density (1.45 Mg/m^3) for clay loam soil (USDA-SCS, 1977), the mass of soil removed is about 94 kg/m. Calculation of the removed soil amount was based on dimensions and geometry of the rotary tool for removing soil (fig. 1) that constructs a quarter-drain with the volume of removed soil equal to the portion of the cylinder (having the diameter of the rotary tool) oriented horizontally on the curved plane beneath the horizontal plane at the soil surface.

Figure 1. Installation of semi-circular quarter-drain, perpendicular to sugarcane furrows, using a PTO-driven circular cutting trencher blade to remove soil.

Intense rainfall events during spring months in Southern Louisiana commonly have rainfall energies that can severely erode topsoil in sugarcane fields, including the quarter-drains. Without adequate protection, sediment moves with runoff to field ditches and culverts. Sediment build-up diminishes capacity and function of the surface drainage system within the field.

This protection of top soil from frequent exposure to rainfall energy is especially important in the Lower Mississippi River Valley where flat agricultural land (slopes from 0 to 0.5%) provides only limited outflow of runoff from sugarcane fields. Therefore, maintaining good functionality of surface drainage system including quarter-drains is essential to provide adequate drainage for improved sugarcane growth and production. To address erosion in quarter-drains, two sugarcane post-harvest residue management practices were investigated to determine benefits from sugarcane residue under typical weather and field conditions in Southern Louisiana.

Our objective was to determine sediment yield under typical soil and weather conditions in Southern Louisiana from quarter-drains with (1) residue left on-site but swept from row-crowns into furrows and (2) removed from the field by burning residue after harvest. This study was conducted at the USDA ARS sugarcane research site on the LSU Ag Center St. Gabriel Sugar Research Station, near Baton Rouge, Louisiana.

Methods and Materials

The study was conducted on a Commerce silt loam (Fine-silty, mixed, nonacid, thermic; Aeric Fluvaquents Alfisols). Soil properties are shown in table 1.

Following the 2001 fall harvest of sugarcane, residue (8600 kg/ha) discharged by the chopper harvester was left on the entire study area. This amount of residue on the soil surface was determined by obtaining samples of sugarcane residue collected from four randomly selected areas of 1 m^2 per plot and averaged. The residue mainly contained pieces of leaf parts chopped to 10 to 15 cm lengths and finer pieces of sugarcane skin stalk. For the treatment where residue was left in the field, the residue was swept from row-crowns to furrows spaced 1.8 m with a one-row mechanical rotating brush (similar to a street sweeper). Sweeping residue from the row-crowns provided adequate soil water and temperature conditions for the next growing season (early spring) for an optimum emergence of sugarcane. Sweeping width from row-crowns was 0.4 m. Swept residue in the furrow was 1.3 m wide so that 71% of the field area had residue cover.

The experiment was initiated to determine the effect of residue cover on stability of freshly constructed quarter-

Table 1. Physical properties for Commerce silt loam in St. Gabriel area, Iberville Parish, LA[a].

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Permeability (cm/h)	Soil Type Classification
0 28	36.0	37.0	27.0	1.0	Clay loam
28 74	50.0	36.5	13.5	1.5	Silt loam
74 153	50.0	39.5	10.5	2.7	Loam

[a] Data were obtained from USDA SCS (1977).

drains on large field plots planted to sugarcane. Each experimental unit had an area of 0.2 ha to simulate realistic field conditions in typical settings for sugarcane production in Southern Louisiana. A randomized complete block (RCB) design with two sugarcane residue treatments (residue left and residue burned) with three replications for each treatment was employed to measure the soil loss following each rainfall event (six plots total). The experimental setup for each plot is shown in figure 2.

Statistical analyses were performed by SAS software (SAS, 2001) utilizing the ANOVA General Linear Model (GLM) procedure. Treatment means were compared with Least Significance Difference (LSD) Fisher test (Steel and Torrie, 1980) with 10% significant level ($\alpha = 0.1$). On three plots residue was swept to furrows (Treatment 1), where 71% of the plot area had residue cover after sweeping row-crowns to furrows. Comparison was made with similar quarter-drains on three plots where residue was removed by burning (Treatment 2). The experiment was designed to measure soil loss from quarter drains, and at junctions between quarter drains and field ditches. The field ditch was located in the middle of each plot and two perpendicular quarter-drains (13.5 m long) were constructed at the end of the plot with the opposite slope of 0.2% toward the field ditch (fig. 2). In early March 2002, 30-cm long plastic rulers were inserted in a grid pattern (30 cm apart) into the bottoms of freshly constructed quarter-drains. Rulers were carefully inserted to a depth of 15 cm using a custom made tool set (knife and pusher) so that 15 cm of the ruler was initially above the soil surface and provided a benchmark for soil erosion measurements in the quarter-drain (fig. 3).

Soil erosion depth was measured at each ruler after rainfall events to quantify changes by erosion in quarter-drains along its length. To quantify average soil loss, a template of the original cross-sectional area of the quarter drain was used in conjunction with ruler grid (fig. 4a).

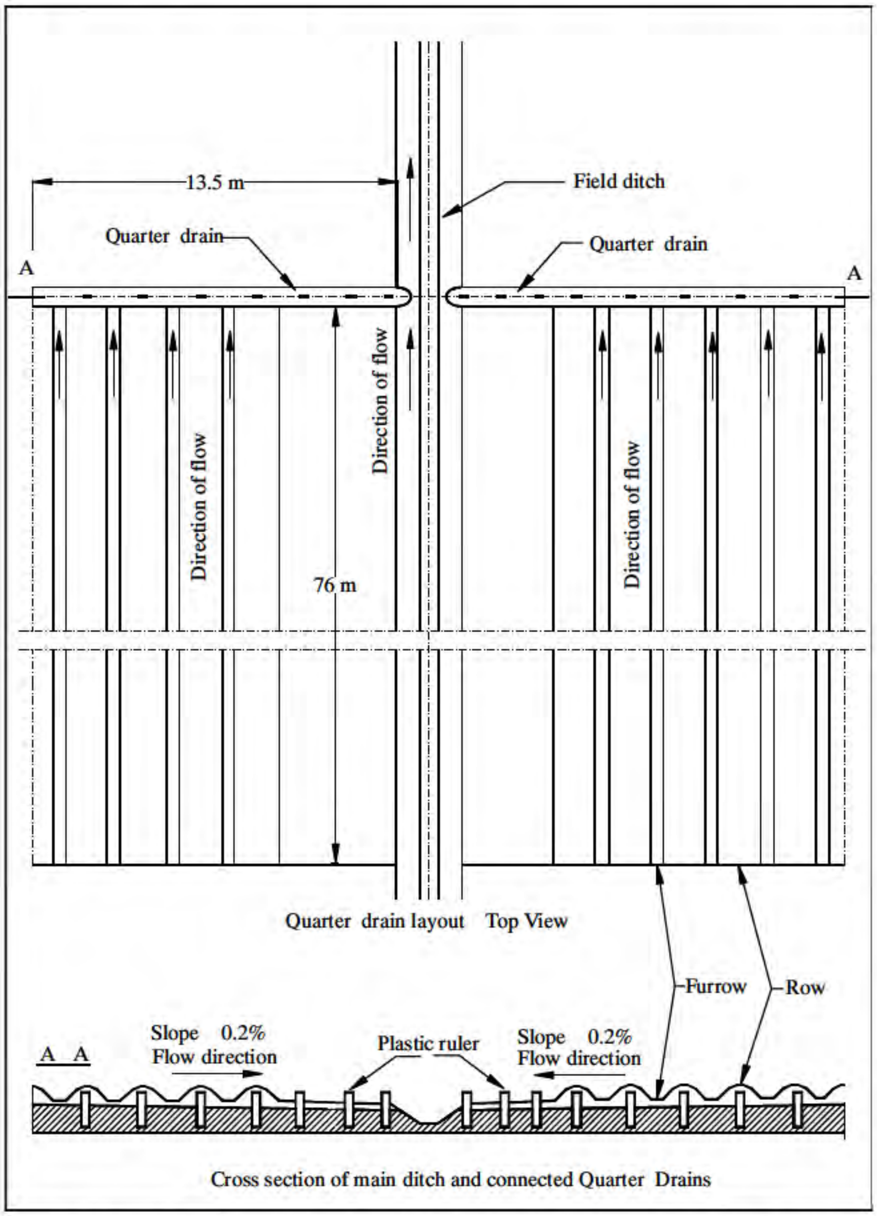

Figure 2. Experimental unit (plot) design (0.2 ha) for soil erosion study with two methods of managing residue (left on site and burned after harvest).

Figure 3. Inserting plastic rulers for soil erosion study in freshly constructed quarter-drain using a custom made knife to cut 15-cm deep soil opening, and a pushing tool to place each ruler at the exact same depth.

The ideas of using inexpensive rulers and sheet metal templates of the quarter-drain cross-section were created because of limited financial resources to acquire additional specialized instrumentation to conduct the research, while not compromising methods to produce scientifically sound and realistic measurements of surface ditch erosion within the large field area. Another reason for using rulers was that the automatic runoff measurement/sampling systems on the experimental site were designed to quantify sediment loss transported in field runoff at the surface drainage outlet for the whole plot area. However, to quantify soil loss at particular locations in quarter-drains, inexpensive plastic rulers were appropriate for the task. The original sheet metal template was a part of the circle with the radius of 247 mm and with the depth of 184 mm (fig. 4b). The center of the circular shape was 63 mm above the soil surface to simulate the settings of a horizontal rotary cutting tool used to excavate the quarter-drain. As depicted in figure 1, the cutting tool was a PTO-driven head with steel blades equally mounted on the horizontally rotating head having a working DIA of 494 mm. The center of rotation for the tip of the still blade (which was engaged with the soil) was set 63 mm above the soil surface to create the depth of 184 mm. After each rainfall event, the relative depth of soil at each ruler was recorded and the template was used to calculate the cross-sectional area of a gap between the original perimeter of the quarter-drain and actual perimeter of the cross-section. Depth of erosion and the template's geometry of the non-eroded quarter-drain were used to calculate mass of erosion. The void area was calculated using depth of erosion, length of template radius, and length of radius of the eroded cross section. The area of the eroded cross-section is the area of a trapezoid, where the lower base is the length of semi-circular eroded cross-section of the quarter drain; the upper base is the length of the semicircular part for the template, and the trapezoid's height is the depth of erosion (fig. 4b).

A spreadsheet was used to input these values to calculate soil loss. Next, average void area was calculated for the full length of quarter-drain (sum of all voids from the full length of quarter-drain divided by number of rulers in quarter drain). Sediment volume was calculated by multiplying average void area per full length of quarter drain. The known soil bulk density was multiplied by the void (erosion) volume to obtain the mass of soil loss.

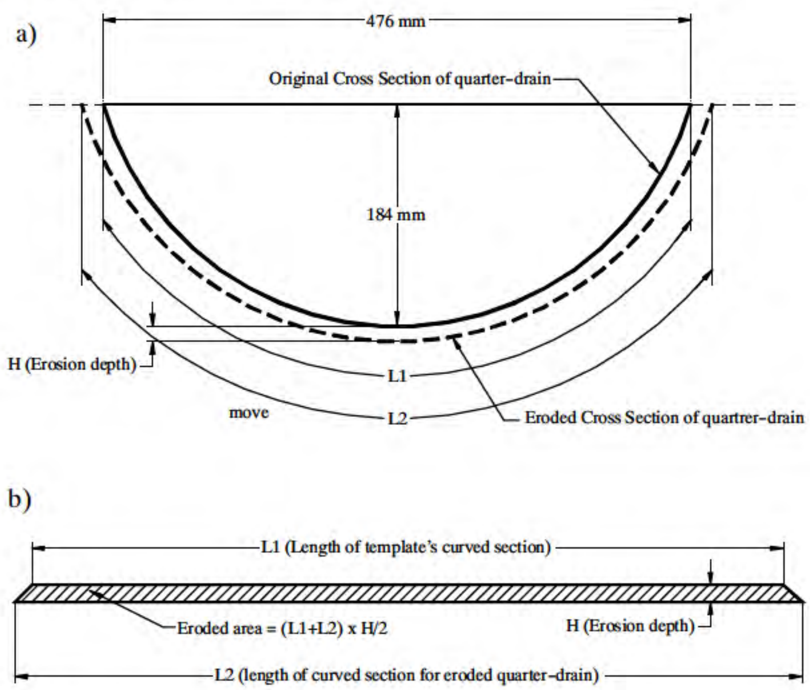

Figure 4. The top drawing (a) shows the measurement with the template in the quarter-drain. Calculation of the eroded area (b) was performed by determining the area represented by the trapezoid. The bottom picture depicts the template with the eroded quarter-drain.

Results and Discussion

Statistical analyses showed that there were significant residue treatment effects on erosion depth (table 2). Overall average erosion depth in quarter-drains was 3.2 mm ± 0.96 mm (Std. Dev.) (for residue left) versus 8.7 mm ± 3.6 mm (Std. Dev.) (for residue burned). In comparison of means for these treatments, the probability was $P < 0.0001$ with LSD value = 0.71 at α probability level = 0.1. Statistical analysis further determined that when comparing means of erosion depth for each rainfall event, the residue treatment did influence soil erosion depth. Except for rainfall event number 2, the differences in the means of depth erosion in quarter drains among rainfall events 1, 3, and 4; and events 5 and 6 were significant (table 2).

Significantly higher erosion depth for plots with residue burned most likely resulted (1) from removing the protective shield of sugarcane residue and exposing bare soil to rainfall energy and flowing water (runoff), (2) in addition, the heat generated from burning, when in contact with the soil, might form organic substances which coat soil particles and could create hydrophobic or water repellent conditions on soil surface decreasing infiltration, thus increasing runoff and sediment amounts. Robichaud (2000), who studied forest fire effects on soil infiltration, stated that burning caused formation of hydrophobic substances on soil surfaces which decreased soil's hydraulic conductivity by 10% to 40%.

Soil erosion reduction from quarter-drains for plots with residue left on the field was observed during all six rainfall events. The measured data showed that residue cover consistently reduced soil loss from quarter drains, whereas removing residue by burning resulted in a steady increase of erosion depth up to the third rainfall event, and after that even more accelerated depth of erosion from quarter-drains was measured (table 2).

Percent reduction was based on soil erosion for plots with residue burned after harvest (fig. 5). The lowest reduction of 36% was observed during the third rainfall event (highest rainfall amount of 91 mm); the highest soil erosion reduction of 80% occurred during the sixth rainfall event (rainfall depth of 62 mm). Residue cover (71% of the total area) significantly reduced soil erosion in quarter-drains after six rainfall events with an overall average reduction of 60% (0.89 kg/m) in comparison with the quarter-drains on plots where residue was removed by burning. Similar findings were reported by other researchers. Cruse et al. (2001) concluded that 80% surface residue cover reduced soil erosion by 70% and 50% for 13% and 5% slopes, respectively, compared to bare soil. Potter et al. (1995) reported that surface residue reduced erosion losses by more than 90% when compared with unprotected surfaces. According to McGregor et al. (1990) utilizing simulated rainfall showed that a 79% cover of wheat residue reduced soil loss by 88%.

The highest erosion depth occurred at intersection areas between quarter-drains and field ditch (fig. 6), as the eroded sediment from quarter-drain was deposited in main field surface ditches. This can be explained by the increased turbulence and velocity of flow and elevation difference between the end of quarter-drain and field ditch (150 mm average). On average, for plots where residue was removed, soil erosion from a quarter-drain was evident throughout the whole length of quarter-drain. However, maximum erosion depth occurred between 1.5 and 3.0 m from the intersection area with field ditch, and with the highest recorded erosion depth of 18 mm at 1.5 m from the intersection. The maximum depth of erosion in quarter-drains with residue left treatment was only 3.5 mm at 2.5 m from the intersection (fig. 7). Data have shown that residue left on site effectively protected quarter-drains from soil erosion and the residue was effective during the entire experiment for six rainfall events from the end of March to the beginning of July 2002.

To protect quarter-drains from erosion, one must minimize raindrops splashing on the soil surface. According to Haan et al. (1994) when raindrops fall on crop residue, the energy is absorbed and thus soil splash is reduced. Savabi and Scott (1994) concluded that winter wheat residue significantly increased interception of rainfall energy when compared to the same amounts of less dense corn and soybean residues. Based on our results, sugarcane residue effectively diminishes impact of raindrops by intercepting rainfall energy reaching the soil surface and reduces runoff velocity in furrows. Otherwise, removal of residue by burning caused significant erosion to topsoil and quarter-drains.

Because data were collected only for one growing season, there was a need to determine whether erosion/deposition results in 2002 represented short-, long-term, or extreme soil erosion results. Thus, the available 12-years rainfall data in St. Gabriel location from 1999 to 2010 were compared. Rainfall results are presented in table 3. Average yearly

Table 2. Statistical results of erosion depth for residue left on the soil surface and residue burned treatments.

Rainfall Event Effects on Soil Erosion Depth from Quarter drains						
Rainfall event no. and date	1 3/28/02	2 4/02/02	3 4/11/02	4 6/20/02	5 6/21/02	6 7/01/02
Rainfall amount (mm)	40	30	91	87	60	62
Cumulative rainfall amount (mm)	40	70	161	248	308	370
Average cumulative erosion depth (mm)	3.4c[a]	4.3c	5.8b	6.1b	7.6a	8.3a
Treatments Effects on Erosion Depth (mm) from Quarter drains						
Cumulative residue left	2.0b	3.1a	4.5b	3.5b	3.3b	2.7b
Cumulative residue burned	4.9a	5.6a	7.1a	8.7a	11.9a	13.9a
LSD[b]	2.3	2.9	0.6	3.2	3.6	3.6

[a] LSD value 1.23 for six rainfall events at α 0.1 level of significance. Values followed by the same letter are not significantly different and comparisons are valid only within rows.

[b] LSD values are for α 0.1 level of significance. Values followed by the same letter are not significantly different and comparisons are valid only within two columns for residue left and residue burned treatments.

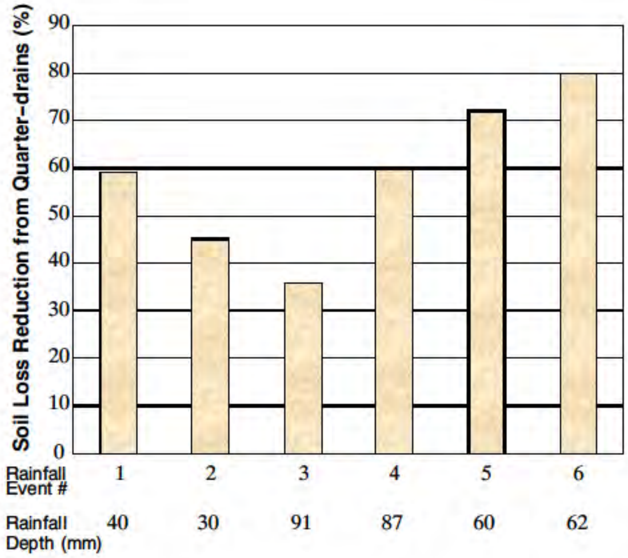

Figure 5. Soil loss reduction (%) for each rainfall event with respect to residue left on site in comparison with residue burned.

Figure 6. Sediment deposition at the cross-section between two quarter-drains and the main field ditch after the third rainfall event (90 mm depth).

precipitation during 12 years was 1285 mm of rainfall depth and for comparable period of conducting experiment (from 28 March to 1 July) rainfall amount was 376 mm. In 2002 the total yearly rainfall amount was 1671 mm and was the second highest rainfall after 1734 mm in 2001 during these 12 years. Although comparing the amount of rainfall that occurred in

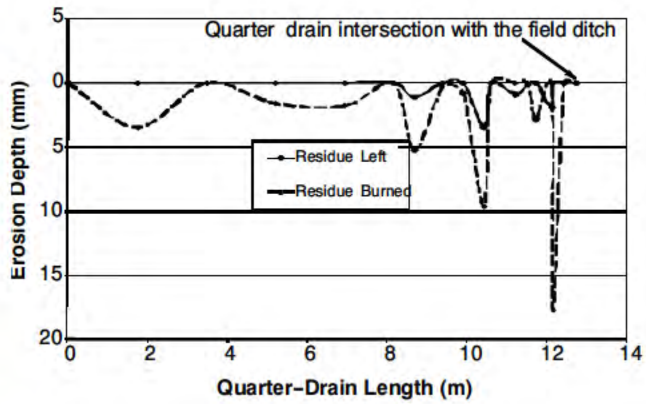

Figure 7. Depth erosion comparison for residue left and residue burned treatments with respect to the quarter-drain particular length (starting at the beginning of the quarter-drain to the intersection with the main field ditch) after six rainfall events.

2002 during spring and early summer period of conducting the experiment and data collection, the rainfall was 370 mm that was almost identical to the average rainfall during the 12-year period. Based on these finding, it appears that 2002 erosion/deposition results represent the average normal return period.

Summary

Based on six rainfall events with a total rainfall of 370 mm, sugarcane residue left in the field significantly reduced average soil erosion depth in quarter-drains by 60% compared to residue removed via burning. For an average soil bulk density of 1.5 Mg/m^3, average reduction in soil loss from these rainfall events by residue cover was 0.89 kg/m of the quarter-drain length. The highest erosion amount for both treatments occurred at intersection areas between quarter-drains and the field ditch; however, erosion depth for quarter-drains with residue burned was six times higher than quarter-drains where residue was left.

Based on these results, sugarcane residue left in the field after harvest was effective in reducing soil erosion during the 4-month period from March to beginning of July 2002. Future research with residue cover should include measurements of soil properties and runoff water quality from sugarcane fields. Also, improved depth and grade-control for the quarter-drainage channels would improve surface drainage and reduce the potential for trapping sedimentation in depressional areas.

Table 3. Rainfall data for twelve years (1999 to 2010) in St. Gabriel, Louisiana location.

Year and Rainfall Period	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg
	Rainfall Depth (mm)												
28 March to 1 July	378	208	658	370	306	610	558	274	403	199	100	446	376
From 28 to 31 March	20	0	58	30	1	28	4	2	0	0	1	0	12
April	19	30	52	104	139	174	61	210	120	21	68	23	85
May	134	8	14	31	6	213	170	56	120	134	24	153	89
June	205	140	533	153	160	195	323	6	152	44	7	237	180
1 July	0	31	0	52	0	0	0	0	11	0	0	33	11
Total	1314	1131	1734	1671	1265	1498	1233	689	988	1017	1470	1405	1285

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