POLYACRYLAMIDE (PAM) APPLICATION EFFECTIVENESS IN REDUCING SOIL EROSION FROM SUGARCANE FIELDS IN SOUTHERN LOUISIANA

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ABSTRACT. *Intense storm events on slowly permeable alluvial soils in southern Louisiana sugarcane fields cause significant soil erosion. Sediment–bonded pesticides and nutrients are washed from the field and sediment fills surface drainage channels (quarter–drains) within the field and increases the cost of maintaining the ditch system. A field experiment was conducted in the spring of 2002 to determine the effectiveness of Polyacrylamide (PAM) in reducing soil erosion from quarter–drains in fields planted to sugarcane. Eroded quarter–drain depth and soil loss per meter were measured after six rainfall events that occurred between 28 March and 1 July and produced a total cumulative rainfall of 368 mm. In March 2002 PAM was sprayed as an aqueous solution directly on newly installed quarter–drains at a rate of 18 kg ha^{-1}. The relative depth of erosion was measured after each storm event using plastic rulers, which were inserted into the bottom of quarter–drains using a custom made tool. When applied directly to the primary quarter–drains, PAM significantly reduced erosion depth by 76% compared with the no–PAM application. PAM was most effective for the first three storm events (cumulative rainfall depth of 161 mm) with an average 88% reduction in soil depth loss. Based on one year of study in St. Gabriel, Louisiana, PAM sprayed as an aqueous solution in a single application was effective in reducing soil erosion for the quarter–drain systems during the 4–month period after PAM application under normal Southern Louisiana weather condition. For soil with an average bulk density of 1500 kg m^{-3}, the average reduction in soil loss for PAM treated quarter–drain was 0.65 kg m^{-1} of the primary quarter–drain for six events. At transition points between primary and secondary quarter–drains where PAM was not applied, a gradual deterioration of the side walls of the quarter–drain was visible. The original shape of semicircular quarter–drains was preserved through six consecutive storms events for plots treated with PAM.*

Keywords. *Soil erosion, PAM, Quarter–drain, Surface ditch, Surface runoff.*

Each year in early spring, primary quarter–drains are installed perpendicular to sugarcane furrows to provide drainage of runoff water and route it to secondary quarter–drains and on to main surface drainage ditches (fig. 1). The installation of a typical quarter–drain to an average depth of 0.2 m requires removal of about 0.065 m^3 of soil per linear meter. Based on an average bulk density of 1500 kg m^{-3} for clay loam soil obtained from the study area, and measured cross–section area of the freshly installed quarter–drain, the average weight of soil removed is 94 kg m^{-1}. Intense storm events in spring commonly have rainfall energies that can erode soil from the semi–circular surface of the quarter–drains. Also, loose soil particles discharged onto the soil surface during quarter–drain installation are washed into quarter–drains and into main surface ditches causing sedimentation. The sediment fills the ditches and diminishes capacity of the surface drainage system within the field. This is especially important in the Lower Mississippi River Valley where flat agricultural land (slopes from 0 to 0.5%) provides only a limited outflow of runoff from the sugarcane fields.

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BACKGROUND

The use of soil conditioners in the United States to enhance soil structure began in 1950s, but because of the high cost of polymers their use was limited (Seybold, 1994). There is renewed interest in using polymers to reduce soil erosion with the emergence of a new family of anionic polyacrylamides (PAM) with high molecular weights. PAM have been shown to successfully reduce soil erosion in furrow irrigated fields when applied in small rates (Sojka and Lentz, 1994). According to Bavernik (1994), interest has shifted to high molecular weight (>5 × 10^6 g mole^{-1}) anionic PAM, as it better prevents soil loss from agricultural land.

For more than a decade PAM has been a focus technology for reducing soil erosion. PAM has effectively controlled soil erosion induced by irrigation water flowing in surface channels in the Northwestern region of the United States (Lentz et al., 1992; Sojka and Lentz, 1994; Lentz and Sojka, 1994; Trout et al., 1995). Sojka et al. (1998) reported that PAM, when applied to irrigation water nearly eliminated soil erosion caused by irrigation. Lilleboe (1997) reported that in 1996 approximately 150,000 ha were successfully treated

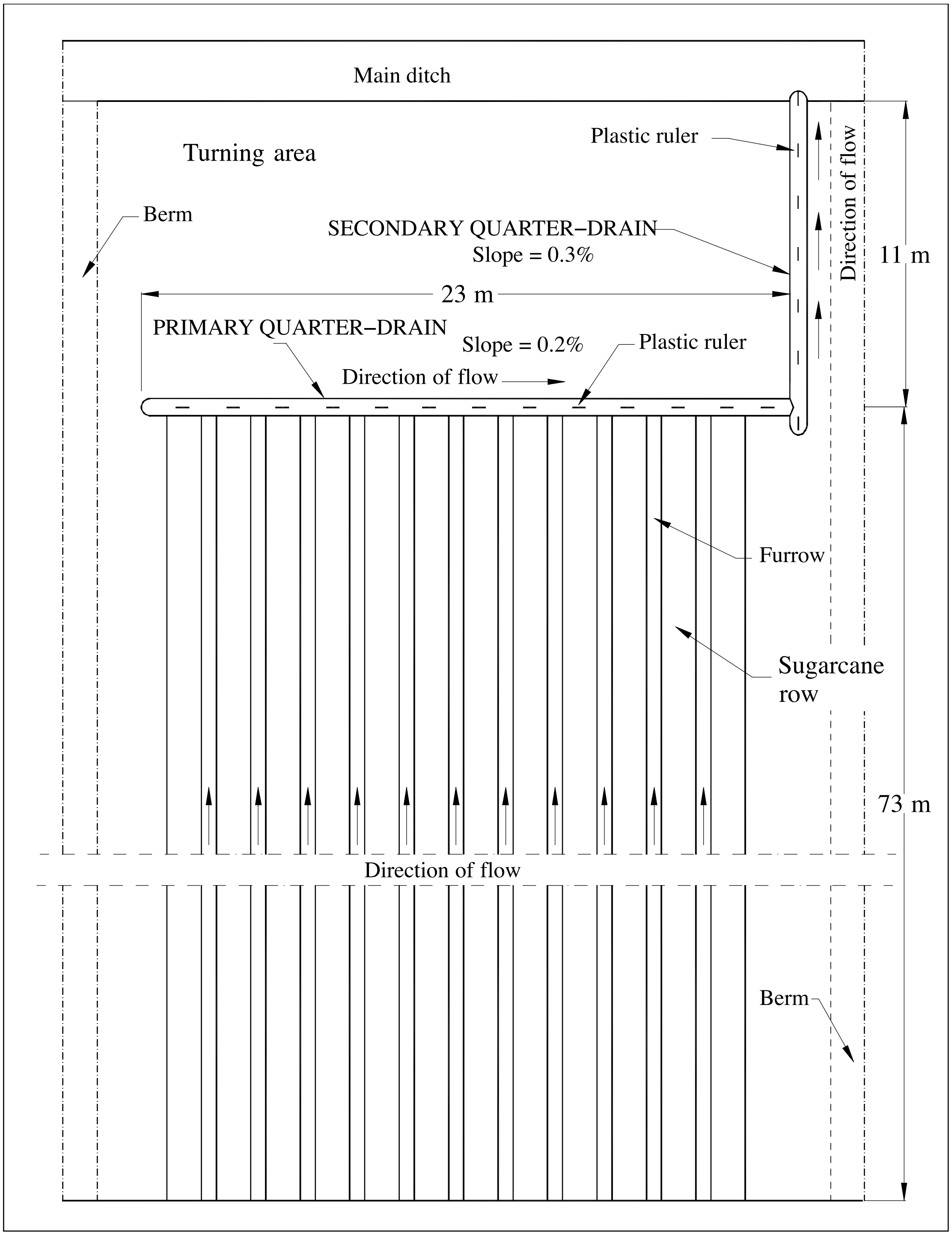

Figure 1. Experimental plot design for soil erosion study using PAM.

by PAM in the western United States. According to the USDA−NASS (1998) over 140,000 ha was treated with PAM nationally, mostly in the western United States with Idaho having the maximum area of 35,500−ha PAM treated.

There have been many reports related to PAM application rates and methods. Bjorneberg et al., (2000) studied combined effects of residue cover and PAM on soil erosion. They stated that applying PAM to straw−covered soil−controlled runoff, erosion and phosphorus losses better than using either PAM or straw residue alone. In the early 1970s, Gabriels et al. (1973) showed that adding 38 kg ha^{-1} of anionic PAM to soil resulted in a greater infiltration rate and prevented runoff. Shainberg at al. (1990) concluded that applying 20 kg ha^{-1} was most efficient in maintaining high infiltration rates, thus minimizing sealing and runoff. Shainberg and Levy (1994) studied several aspects of polymer influence on infiltration rate in terms of soil surface sealing. They stated that PAM applied as a dry material tends to produce a surface seal and reduce infiltration rates, thus aqueous PAM solution is the better way to prevent sealing. They concluded that the addition of small amounts of polymers (10−20 kg ha^{-1}) either sprayed directly on the soil surface or added to the applied water stabilizes and cements together aggregates at the soil surface and thus increases their resistance to seal formation. Letey (1994) reported that adsorption of PAM to soil clay particles increases with increasing molecular weight of polymer. He stated that there is very limited desorption of PAM from soil since the polymer becomes irreversibly bonded to soil by drying the soil as long as there is moisture in the soil. According to Letey (1994) PAM adsorption occurs mainly on the external surface of clay particles. Because of the high molecular weight of PAM it does not penetrate soil aggregates. PAM adsorption on soil particles is related to soil aggregate size and molecular conformation of PAM rather than whole soil surface area.

With the regular occurrence of intense storm events on slowly permeable alluvial soils in southern Louisiana planted to sugarcane, the sediment carried with runoff waters (up to 60% of rainfall) has been a big concern for farmers. Nutrients and pesticides are washed from the field and sediment fills surface drainage channels within the field and increases the cost of maintaining the ditch system. To address the soil erosion problem from quarter–drains, a field experiment was conducted at the USDA–ARS research site in St. Gabriel, Louisiana, to determine the effect of PAM on soil erosion reduction from quarter–drains.

The objective of this experiment was to measure relative depth of erosion in the quarter–drains to determine the effectiveness of a single PAM application in reducing soil erosion from quarter–drains on sugarcane fields over a 4–month period. PAM was applied directly to quarter–drains, and the experiment was conducted under typical weather and field conditions in southern Louisiana.

Materials and Methods

A replicated experiment was initiated to determine the effectiveness of PAM by the direct application of a PAM–water solution to freshly constructed quarter–drains on 0.2–ha plots planted to sugarcane. The experiment was a randomized complete block design: two treatments (PAM, no–PAM) with three replications for each treatment with measurements of erosion depth following each storm event. Statistical analyses were preformed using SAS system, GLM procedure (SAS, 2001). Treatment means were compared using Least Significance Difference (LSD) Fisher test at $\alpha = 0.1$ significance level (Steel and Torrie, 1980).

Six identical plots were used. One primary and one secondary quarter–drain served each plot to remove surface runoff water to the main ditch (fig. 1). To provide sufficient removal of runoff water to the main ditch, and to avoid backing–up of runoff water, secondary quarter–drains were installed on 0.3% slope and 3 cm lower than primary quarter–drains. On three plots, primary and secondary quarter–drains were treated with PAM (treatment 1). Comparison was made with similar quarter–drains on three plots, which had received no PAM application (treatment 2). Following the 2001 fall harvest of sugarcane, residue discharged by the chopper harvester was left on the study area. The residue was swept to the furrows using a one–row mechanical rotating brush to minimize the travel of soil particles with runoff through furrows and minimize the deposition of the sediment from furrows into the quarter–drains. The sweeping of residue from row tops to furrows was also necessary to provide a higher soil temperature for proper emergence of the next ratoon from already established root system of LCP85–384 variety of sugarcane, typically grown in Louisiana. In early March 2002, 30–cm long plastic rulers were inserted at 1.8–m intervals into the bottoms of the quarter–drains and quarter–drain transitions to main ditches. The rulers were carefully inserted in the depth of 15 cm using a custom made tool so that 15 cm of the ruler was initially above the soil surface and provided a benchmark for soil erosion depth measurements in the quarter–drain. Eroded depth was measured at each ruler after each storm event to observe erosion changes in quarter–drains along its length.

On 15 March 2002, PAM was sprayed directly on the bare soil in the quarter–drains at a rate of 18 kg ha^{-1} (two passes of 9–kg ha^{-1} applications). A high molecular weight powder of Anionic PAM (Floeger AN 934 SH) was used. The PAM was donated from Chemtall Incorporated (Riceboro, Ga.). This commercially available, high molecular weight (14 million g mole^{-1}), anionic PAM has been commonly used to control soil erosion from irrigated agriculture in the western Unites States. PAM was applied to a Commerce silt loam soil (fine–silty, mixed, nonacid, thermic Aeric Fluvaquents) located at the St. Gabriel research site (Iberville Parish, La.). The top 30 cm of this soil (at which quarter–drains are installed) has a clay loam texture, which contains 36% sand, 37% silt, and 27% clay.

The PAM was mixed with water to a concentration of 500 ppm (mg L^{-1}). This was the maximum concentration in terms of viscosity to be handled by the spray system and still provide an optimum coverage spray pattern. A three–point–hitch 115–L sprayer was used to apply PAM into quarter–drains, and the sprayer had two nozzles (discharge of 5.5 L min^{-1} per nozzle) mounted on the end of the square steel boom (on the opposite sides) to double the amount of PAM solution discharged.

To quantify the average soil loss, a template of the original cross–sectional area of the quarter–drain was used in conjunction with ruler grid (fig. 2) After each storm 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 the actual perimeter of the cross section. The depth of erosion and the template's geometry of the non–eroded quarter–drain were used to calculate mass of erosion. The void/deposition area was calculated using depth of erosion, the circumference for curved section of the template, and the circumference for the eroded quarter–drain. The area of the eroded cross–section is the area of a trapezoid, where lower and upper bases are the curved circumferences for the template and eroded quarter–drain, respectively; the depth of erosion is the trapezoid's height (fig. 2).

To measure depth of erosion/deposition and calculate cross–sectional area for each depth, 18 rulers were installed for each primary quarter–drain. The first 12 rulers were spaced 1.8 m apart and placed in the quarter–drain in line with the center of each row to prevent damaging rulers with the tractor and other equipment tires. The other six rulers were spaced at 0.3 m to provide better resolution at the transition between primary and secondary quarter–drains. For secondary quarter–drains, 36 rulers were spaced equally at 0.3 m. If the difference between the original depth and depth measured after a storm event (or between storm events) was positive, then deposition occurred, and if this difference

Figure 2. Effect of PAM in reducing soil erosion (top), and visible soil erosion in quarter−drain with no PAM applied (bottom) after six storm events.

was negative, then erosion occurred. The average erosion/deposition depth in the quarter−drain was calculated by adding negative and positive numbers and dividing by number of rulers.

Average void/deposit area was calculated for the full length of quarter−drain by summing all areas and dividing by the number of rulers in the quarter−drain. The erosion volume was calculated by multiplying average void/deposit area by the length of the quarter−drain. To obtain mass of soil loss, average erosion volume was multiplied by soil bulk density obtained at the site from 36 undisturbed soil core samples (Blake and Hartge, 1986). Depth of erosion at the transition between primary and secondary quarter−drains was computed by averaging depth from three replications for each treatment and plotting against location on the quarter−drain.

Results and Discussion

Cumulative Soil Loss

PAM significantly reduced soil erosion in primary quarter−drains after six storm events (table 1). The overall cumulative average depth of erosion with PAM treatment was 1.3 mm for the primary quarter−drains versus 5.4 mm for the untreated quarter−drains. These differences were significant ($P < 0.001$). Cumulative average erosion depth for secondary quarter−drains was 1.9 mm for PAM treated versus 5.4 mm for the untreated quarter−drains ($P < 0.0043$) (table 1). Significant differences in erosion depth were found between PAM and no−PAM treatments for primary quarter−drains for storms 1, 2, and 3. However, there were no significant differences in erosion depth after storms 4, 5, and 6. For secondary quarter−drains significant differences between PAM and no−PAM treatments were found for first, fourth, fifth, and sixth storm event (table 1).

Visual observations also showed that PAM helped to preserve the original shape of the semicircular quarter−drain after the six storm events. The cumulative rainfall depth from these storms amounted to 368 mm. After the sixth storm event, pictures were taken to compare visual differences between PAM and no−PAM treatments. In quarter−drains where PAM was not applied, a gradual deterioration of the side walls was visible (fig. 2). However, where PAM was applied, the original shape was preserved. The PAM was most effective during the first three storm events with accumulative rainfall of 160 mm, in which period soil loss reduction was 88% for the treated primary quarter−drains compared to non−treated. As shown in figure 3, the maximum erosion reduction was observed after the third storm event, which amounted to 15 kg of soil loss reduction per 23 m of the primary quarter−drain. The data suggest that cumulative soil erosion for PAM treated and untreated quarter−drains were well correlated with the cumulative rainfall amount during first three storm events. The coefficients of determination R^2 for these eventswere 0.99 and 0.95 for PAM treated and untreated quarter−drains, respectively (fig 3).

Table 1. Cumulative treatment effects on depth of erosion from primary (P), and secondary (S) quarter−drains for six storm events.

Storm No.		1	2	3	4	5	6	Mean Depth of Erosion
Rainfall depth (mm)		40	30	90	86	60	62	
Date		3/28/02	4/02/02	4/11/02	6/20/02	6/20/04	7/01/02	
Erosion depth (mm)								
P[a]	PAM	0.2a[b]	0.4a	0.9a	2.4a	2.0a	1.9a	1.3a
	No−PAM	4.3b	6.2b	8.1b	5.0a	4.3a	4.3a	5.4b
S[c]	PAM	2.0a	3.4a	4.5a	0.6a	0.4a	0.2a	1.9a
	No−PAM	5.3b	5.8a	6.8a	3.1b	4.4b	3.4b	4.8b

[a] LSD value = 2.7 for main effects (PAM and no−PAM treatments) at a = 0.1 level of significance for primary quarter−drains.

[b] Values followed by the same letter are not significantly different between PAM and no−PAM treatments, with comparisons valid only within a storm event and quarter−drain.

[c] LSD value = 2.5 for main effects (PAM and no−PAM treatments) at a = 0.1 level of significance for secondary quarter−drains.

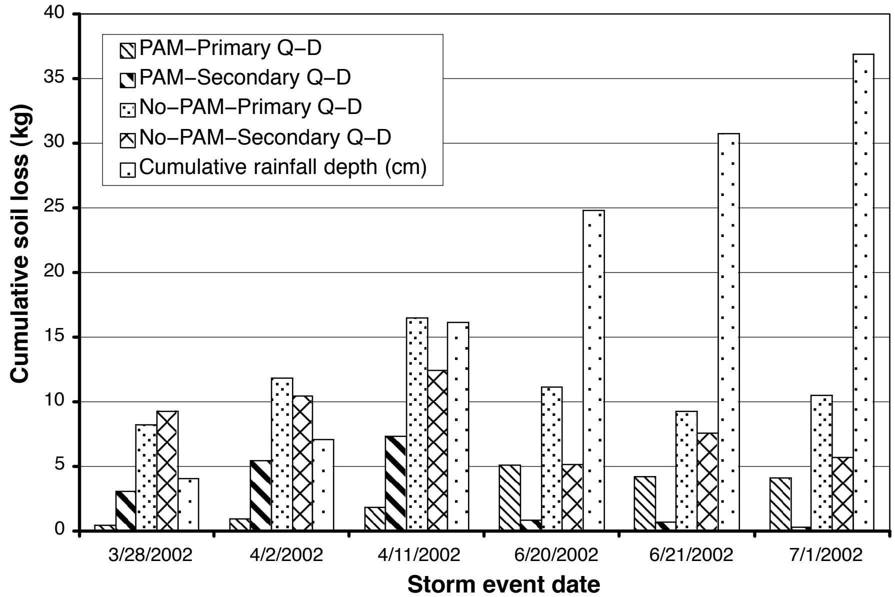

Figure 3. Cumulative rainfall amount and soil loss for PAM treated and non–treated primary and secondary quarter–drains (Q–D) for six storm events.

Similarly, for the first three storm events, cumulative soil loss from the secondary quarter–drains was also proportional to the cumulative rainfall amount for both treatments (fig. 3). For these rainfall events coefficients of determination R^2 were 0.88 and 0.98 for PAM treated and untreated quarter–drains, respectively. Deposition occurred during storms 4, 5, and 6 for PAM treated quarter–drains, and during storms 4 and 6 for untreated secondary quarter–drains. Based of visual observations, sediment from both quarter–drains migrated and accumulated in main ditches. In terms of mass, the greatest reduction of soil loss was 10 kg from 11 m (full length) of the secondary quarter–drain after the fifth storm event (fig. 3). Overall, for secondary quarter–drains, PAM reduced soil erosion by 60%.

There were 69 days without rainfall between the third and fourth storm, during that period some loss of PAM effectiveness occurred. This loss of effectiveness can be explained by PAM gradual degradation processes associated with ultraviolet light, chemical and biodegradation. According to Tolstikh et al. (1992), PAM degradation in soil systems occurs over time as a result of chemical hydrolysis, sunlight, and temperature at rate of 10% per year. After the fourth storm the soil erosion reduction dropped 12% to 76% when compared with first three storms, however PAM treatment was still effective. It appears that under southern Louisiana's climate conditions, PAM would be most effective for about 6 to 7 weeks following application. Similarly, Fox and Bryan (1992) reported a beneficial effect of PAM in reducing soil erosion up to 6 weeks under normal weather conditions.

Soil Loss at Transitions Between Primary and Secondary Quarter–Drains

The relationship between soil erosion depth and location on the primary and secondary quarter–drains after three and six storms was also examined. The lesser erosion depth at transitions was found after the sixth storm when compared to the third storm event for both treatments, and can be explained by sediment re–deposition process. It appears that sediment from the sugarcane rows and from upslope sections of primary quarter–drain moved with the runoff and was deposited in the previously eroded soil depressions (figs. 4 and 5). The greatest erosion in the primary quarter–drains occurred at the transition with the secondary quarter–drains for both treatments. The most erosion for untreated primary quarter–drains occurred between 2.3 and 0.2 m from the transition with the secondary quarter–drain. After the sixth storm event the maximum average erosion depth was 6 mm and was found at 0.7 m from the transition for PAM treatments, and 9 mm at 0.2 m from the transition for no–PAM treatments (fig. 4). Similarly as for the primary quarter–drains, the lesser erosion depth in secondary quarter–drains was observed after the sixth storm compared to the third storm event. The most erosion for untreated secondary quarter–drains occurred between 5.5 and 3.5 m from the transition with the primary quarter–drain, with a maximum erosion depth of 11 mm at 1.5 m from the transition. The depth of erosion for PAM treatment was only 2 mm at 3.6 m from the transition (fig. 5).

The greatest erosion at the transitions between primary and secondary quarter–drains can be explained by the difference in elevation between the bottom of primary and secondary quarter–drains (3–cm drop). It appears that the drop of the transition created higher runoff velocity at the end of the primary quarter–drains and caused greater erosion in secondary quarter–drains because of turbulence of runoff water.

Net Soil Loss

When comparing average net erosion depth produced by each storm event for primary quarter–drains, which received PAM, erosion occurred during 1st through 4th storm events. Most erosion (2 mm) occurred during the fourth storm event. Deposition occurred during storms 5 and 6 with highest deposition (1 mm) in the fifth storm. For non–treated primary quarter–drains, erosion occurred during storms 1 through 3, with the most erosion (4 mm) produced by the first storm, and greatest deposition (3 mm) occurred during the fourth storm (fig. 6).

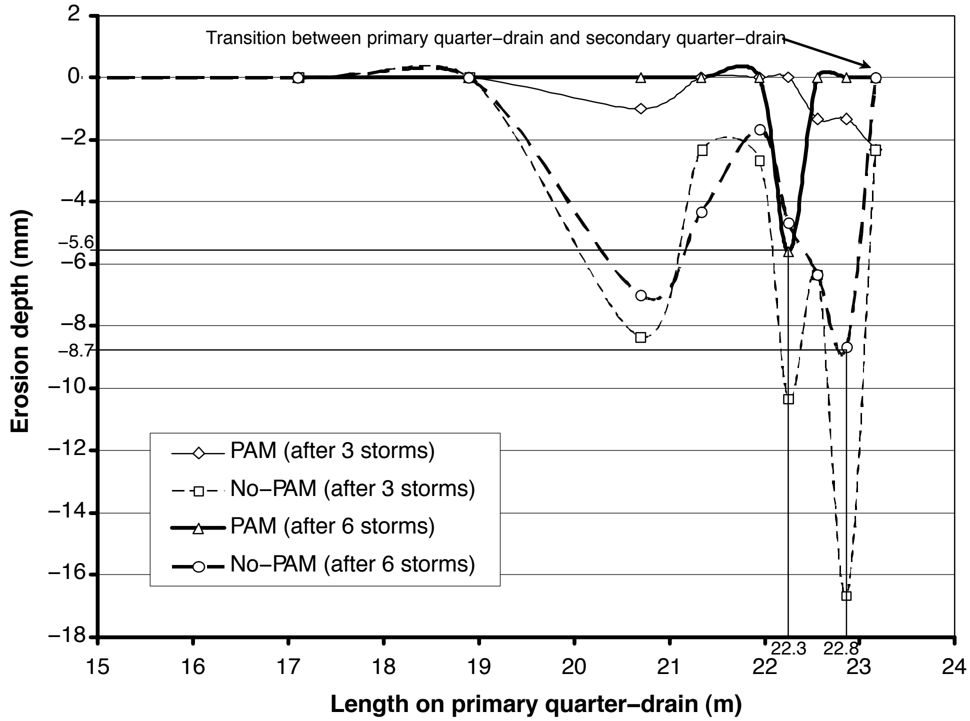

Figure 4. Average erosion depth and location on primary quarter−drain for PAM and no−PAM treatments after three and six storm events.

For secondary PAM treated quarter−drains, comparison of average net erosion depth during each storm showed that erosion occurred during storm events 1 through 3. The most erosion (2 mm) was produced by the first storm event. Deposition occurred during storms 4 and 6 with most deposition (4 mm) in the fourth storm. For non−treated secondary quarter−drains erosion occurred during storms 1 through 3 and 5, with most erosion (5 mm) occurred during the first storm and most deposition (4 mm) produced by the fourth storm (fig. 6).

Combined Cumulative Soil Loss

PAM was effective at reducing soil erosion from both primary and secondary quarter−drains throughout the

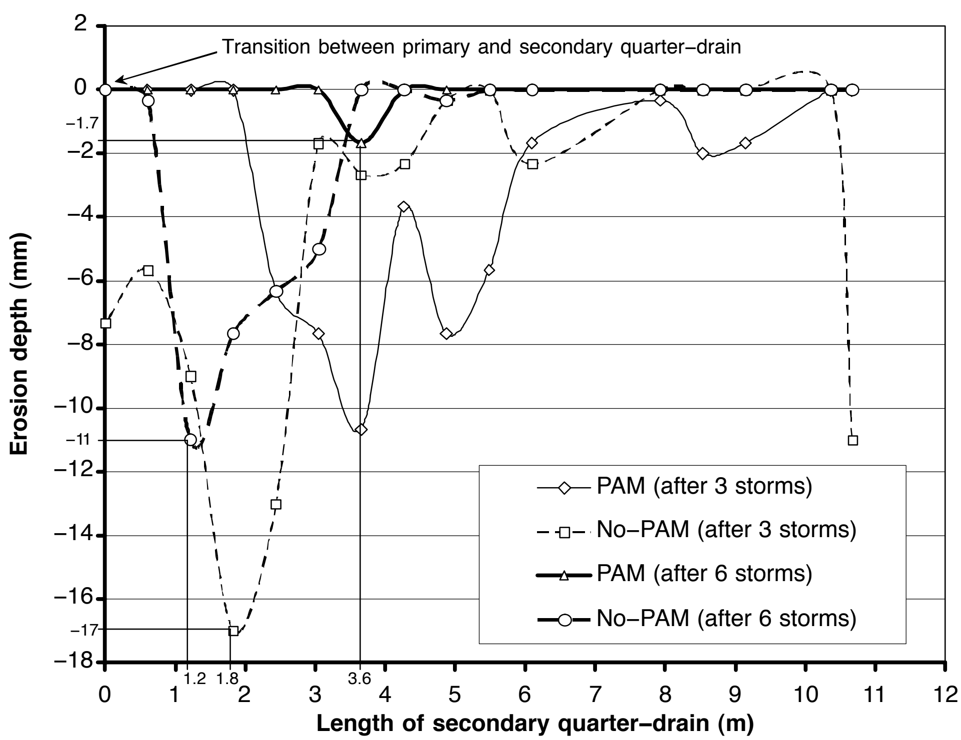

Figure 5. Average erosion depth and location on secondary quarter−drain for PAM and no−PAM treatments after three and six storm events.

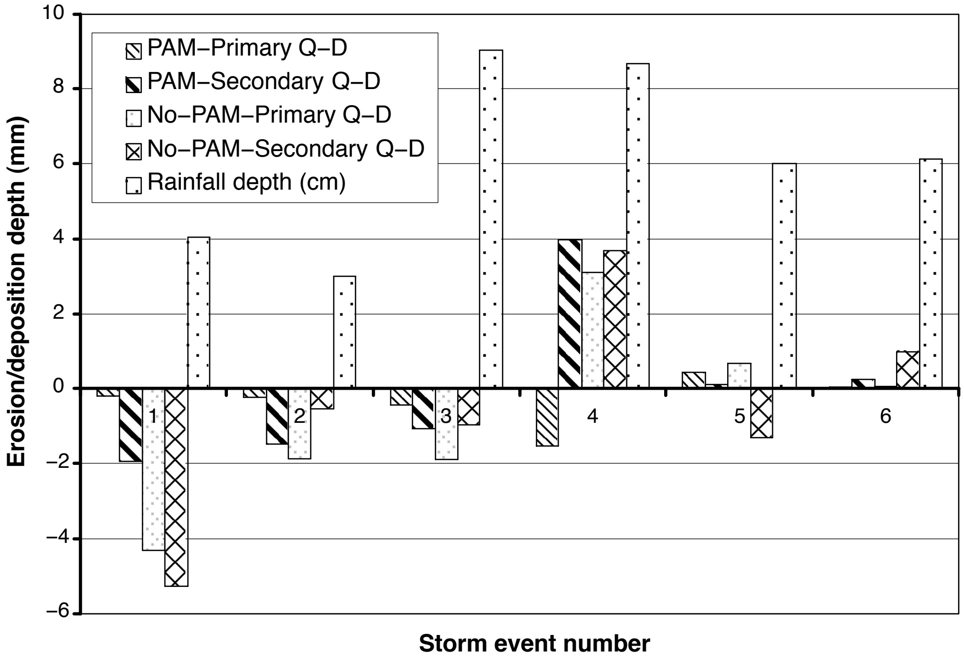

Figure 6. Average net erosion/deposition depth from the primary and secondary quarter−drains (Q−D) and rainfall depth for each storm event.

experiment (fig. 7). For untreated primary and secondary quarter−drains (full length of 34−m), the average cumulative soil loss was 18 kg. For both similar quarter−drains treated with PAM, the average reduction of soil loss was 12 kg, which represents a reduction of 67%. Therefore an aqueous solution of PAM sprayed directly to freshly constructed quarter−drains consistently reduced soil erosion in every storm event during the 4 months of this experiment.

CONCLUSION

Based on one year of study at one location, after six storm events with total rainfall of 368 mm, PAM significantly reduced erosion depth in primary quarter−drains about 76% compared with no PAM application. For soil with an average bulk density of 1500 kg m^{-3}, the average soil loss reduction for PAM treated quarter−drain was 0.65 kg m^{-1} of the primary quarter−drain. During the first three storm events cumulative soil erosion for PAM treated and untreated primary and

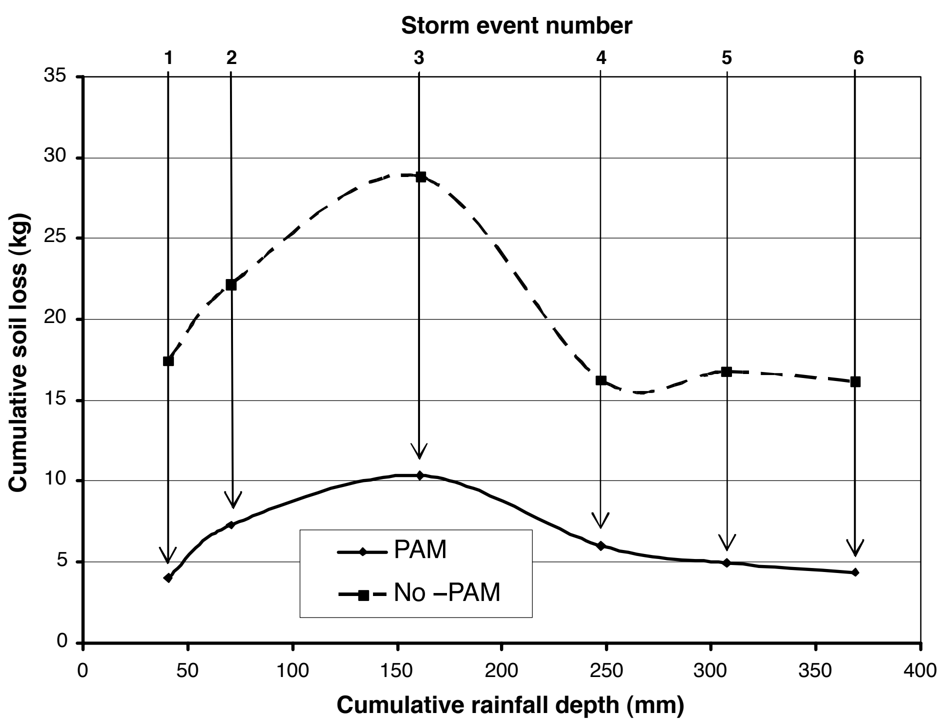

Figure 7. Average estimated soil loss (kg) for PAM and no−PAM treatments from both primary and secondary quarter−drains with total length of 34 m for all six storm events. The assumed bulk density = 1.500 kg m^{-3}.

secondary quarter–drains were highly correlated to the cumulative rainfall amount. The greatest erosion for both treatments occurred at transition areas between the primary and secondary quarter–drains. At the transition the average erosion depth for untreated quarter–drains was six times greater than with PAM treated quarter–drains. The average cumulative soil loss reduction from both primary and secondary quarter–drains was 12 kg (67%). Based on these results, PAM sprayed as an aqueous solution in March 2002 in a single application was effective in reducing soil erosion for the quarter–drain systems during the 4–month period after PAM application under normal Southern Louisiana weather condition.

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