Land Treatment Effects on Soil Erosion

by J. Kent Mitchell, Chittaranjan Ray, and Gregory F. McIsaac, John G. O'Brien

Soil erosion and the accompanying loss of nutrients and pesticides to surface- and ground-water systems are serious environmental concerns. In Illinois alone, 10 Mg/ha soil from cultivated cropland are washed out with rain water every year *(SCS, 1994)*. Loss of top soils in excess of soil regeneration rates causes a reduction in yield and induces further erosion. Soil erosion also causes a loss of surface applied nutrients and pesticides which eventually enter streams and reservoirs and, in some instances, ground water. Nutrient rich water in streams and reservoirs alter the trophic status of these water bodies and cause algal booms and other water-quality problems. Pesticides entering surface- and ground-water systems may contaminate our drinking water. Soil loss is also a major problem around construction sites. In addition to causing water-quality problems, soil loss from construction sites in urban environment acts as a nuisance to the general public.

High molecular weight ionic polymers (polyacrylamides - commonly referred to as PAM) have been used as soil conditioners since the 1940s. In the 1950s, PAM used in agriculture had substantially lower molecular weight than the present day PAM, the application rates were greater than 500 kg/ha, and the PAM was incorporated into the plow layer to improve the soil structure *(Sojka and Lentz, 1994)*. The PAMs used in recent years have molecular weights ranging from 100,000 to greater than 5,000,000 g/mole. PAM is composed of branched chain monomers and can have positive, negative, or neutral charge.

PAM has been demonstrated by USDA scientists to reduce sediment loss in furrow irrigation. For sprinkler irrigation, the application rates are higher because of the larger area covered and the additional detachment and transport of soils due to water droplet impact. The USDA scientists have demonstrated that PAM has been less effective when sprayed in a separate application as compared with irrigation-borne application.

A study was undertaken to evaluate the effectiveness of two PAMs in reducing soil erosion from natural rainfall on tilled erosion plots located on slopes ranging from 2.5 to 3.6% in the Midwest. Soil loss from PAM treated plots were compared with similar plots without PAM and with plots with vegetative measures at the lower end.

Literature Review

Since their introduction in early 1950s, the use of organic polymers as coagulants gained widespread acceptance in water treatment industry. Polymers are also used as coagulants in mining industry, pulp and paper making, and in wastewater treatment. Three types of polymers — nonionic, anionic and cationic — are used in the water treatment industry as coagulant aid, filter aid, and for sludge conditioning *(Montgomery, 1985)*. The use of PAM as a soil conditioner has been studied for several decades. Azzam (1980) summarized the use of polymers in agricultural research.

The use of PAM in controlling soil erosion gained widespread attention through a benchmark publication in the October 1993 issue of Science News *(Raloff, 1993)*.

Lentz et al. (1992) found that small quantities of negatively charged (anionic) PAM in irrigation water applied to 1.6% grade furrows in Portneuf silt loam in southern Idaho reduced the soil erosion rate by 97% in the return water. During the second irrigation, the residual effect of PAM from the first irrigation was even helpful in reducing soil erosion by 50%. Trout et al. (1993), Sojka and Lentz (1993), Trout and Lentz (1993), Lentz and Sojka,(1994) and Trout et al. (1995) also present data on the effectiveness of PAM in reducing soil erosion resulting from furrow irrigation.

The use of PAM in reducing surface water runoff as well as an accompanying increase in the rate of infiltration has been examined by several investigators. For example, Trout et al. (1995) reported a 30 to 110% increase in cumulative infiltration over eight hours for PAM treated furrows in three experiments. They observed that a high infiltration rate was associated with a low sediment concentration in the furrow water. The increase in infiltration may lead to over watering, salt leaching, and chemical losses if water is not managed properly. Lentz and Sojka (1994) studied net infiltration as a function of PAM application rate. They observed that mean net infiltration for PAM-treated furrows was 11% higher than controls at application rates below 0.7 kg/ha and 15% higher than control at heavier application rates. For the entire range of application rates, the net infiltration for PAM treated soil varied from 92 to 148% of that observed for the control.

PAM application techniques and its mobility in soil has been addressed by Nadler et al. (1994). PAM penetration in sand loam as well as clay loam soils was limited to top 25 cm after 10 months application at three application rates. Sorption was attributed to be the key factors in retaining the PAM at the soil surface. The salt content of the solution was found to reduce the viscosity. Loamy soil leached with calcium chloride or sodium chloride was used by Nadler et al. (1994) to study aggregate stability and water holding capacity. Sodium leached loam showed improved aggregate stability compared with original soil. PAM application rate and polymer type was found to have a pronounced effect on water holding capacity of the two soils tested. Bicerano (1994) outlines some key properties of the PAM for erosion control in irrigation. They include: water solubility and water absorption capacity, dilute solution properties and stability under prevailing environmental conditions. Bicerano (1994) also presented methods to predict such properties. Often it is important to know such properties from the point of view of synthesis and modeling.

Shainberg and Levy (1994) discuss the effect of organic polymers in preventing seal formation of surface soil due to rain or sprinkler drops. Soil sealing reduces infiltration rate and enhances surface ponding which often leads to soil erosion on steep slopes. High or low charge cationic polymers were more effective in maintaining a higher rate of infiltration than anionic or nonionic polymers at three application rates. All these experiments were conducted using distilled water. Gabriels et al. (1973), quoted by Shainberg and Levy (1994), found that anionic PAM surface applied at a rate of 38 kg/ha to the soil was effective in preventing surface runoff and maintaining high infiltration rates. Shainberg et al. (1990) used a low charge density high molecular weight anionic PAM at 10, 20 and 40 kg/ha to study infiltration and runoff. Although a PAM application rate of 20 kg/ha was sufficient to maintain a high rate of infiltration, application rates above 20 kg/ha were effective in reducing surface seal. Shaviv et al. (1986), cited by Shainberg and Levy (1994) found that for medium molecular weight PAM, a corresponding application rate of 80 kg/ha was the most effective treatment. Shainberg et al. (1990) found that tap water with an electrical conductivity of 0.97dS/m had a "beneficial" effect on PAM. Using distilled water, PAM applied at 10 and 20 kg/ha increased the infiltration rate in loess soils. However, when 5000 kg/ha of phosphogypsum was added to this soil, the infiltration rate was nearly 10 times higher. The authors suggest that phosphogypsum maintains a higher electrical conductivity in soil solution. They concluded that clay flocculation was a precondition for cementing and stabilization of aggregates at the soil surface by anionic PAM.

Fox and Bryan (1992) used the PAM SEPARAN AP30 (Dow Chemical) under a field rainfall simulator in Northern Kenya. The PAM was applied with water to undisturbed and tilled plots at two locations at a rate of 25 kg/ha. After PAM solution application, the plots were allowed to dry. The first rainfall simulation of 15 min. was conducted one to two days after application and a second simulation was conducted three to six weeks later. In the interim, approximately 70 mm of natural rainfall occurred. They credit the tillage treatment and PAM application with providing a significant level of reduction in runoff and soil loss.

Ben-Hur (1994) addressed the issue of surface runoff and seal formation from self-propelled moving sprinkler systems. Application of 20 kg/ha of PAM and 40 kg/ha of Polysaccharide (PS) on the soil surface prior to sprinkler irrigation reduced runoff and erosion levels significantly and increased the yield of cotton and potato. The author used a sprayer to spray PAM on the soil surface after completion of cultivation which was allowed to dry before the first irrigation. PS application in the field was more convenient than PAM application due to its higher dissolution rate and lower viscosity. The author also pointed out that field PAM application is a problem because of PAM's low solubility in water (2 kg/m^3) and high viscosity. At this solubility, 1.0 mm depth of application of PAM solution must be applied to achieve a rate of 20 kg/ha. Because of the high solubility of PS, only 0.08 mm of PS solution is needed to be applied to retain an application rate of 40 kg/ha. This application of PAM and PS was said to reduce runoff and erosion levels significantly, and it, in fact did, on 5 of 16 comparisons.

Stern et. al. (1992) treated plots with phosphogypsum (PG), PAM and

PG. and a tillage treatment plus PG. PAM was applied at 20 kg/ha and the plots were sprinkler irrigated five times for a total of 289 mm of applied water. Runoff from all of the treatments was significantly less compared to the check plots.

Vegetative filter strips (VFS) are bands of vegetation located between the pollutant source and the receiving waters to remove sediment and chemical pollutants. Dillaha (1989) presented an extensive review of the literature concerned with the effect of VFS in reducing sediment and nutrient transport from cropped areas. Dillaha et. al. (1989), Magette et. al. (1989) and Flanagan et. al. (1989) also presented the results from other authors as well as results from their own studies on VFS. In all cases, VFS significantly reduced the sediment transported to receiving waters downstream.

Narrow strips of stiff grasses nearly on the contour have been used worldwide for many years for soil erosion control *(National Research Council, 1993)* and more recently have been studied to develop quantitative results and design recommendations *(Dabney et. al, 1993; Dewald et. al., 1996; McGregor and Dabney, 1993)*. It has been demonstrated in the few studies conducted that these stiff grass rows also significantly reduce sediment transport. Most of these studies have been in warm climates.

Method and Materials

The study was conducted on small erosion plots located within the University of Illinois farm south of Champaign in East Central Illinois. A total of 20 plots, ranging in slope from 2.5 to 3.6% were established on Catlin silt loam soil (fine-silty, mixed, mesic Typic Argiudolls) with pH of 5.1-7.3 and organic matter content of 3-4%.

A completely randomized block design was chosen which would test the five main effect treatments: PAM1 application, PAM2 application, grass strip, switch grass row and check (control). A diagram of the experimental site is illustrated in Figure 1.

Plot dimensions were 3 m by 11 m, with the major axis aligned with the maximum slope gradient. Plots were grouped in tandem to facilitate col-

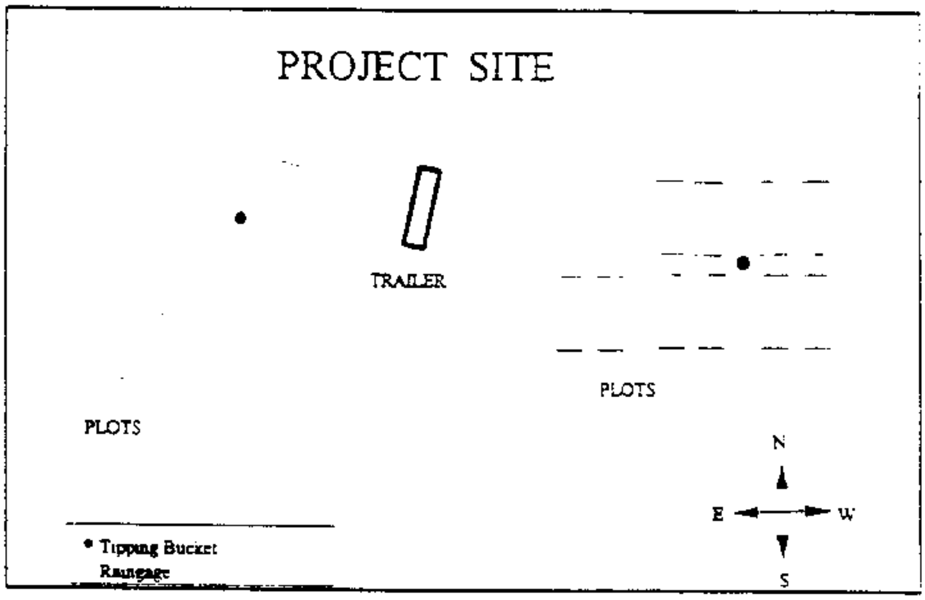


Figure 1. Experimental Site

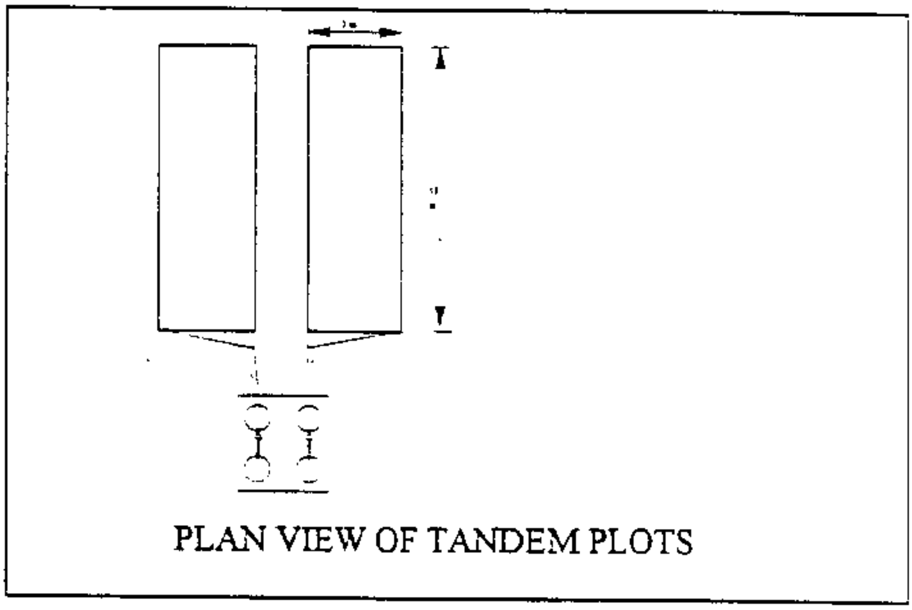


Figure 2. Illustration of tandem plots

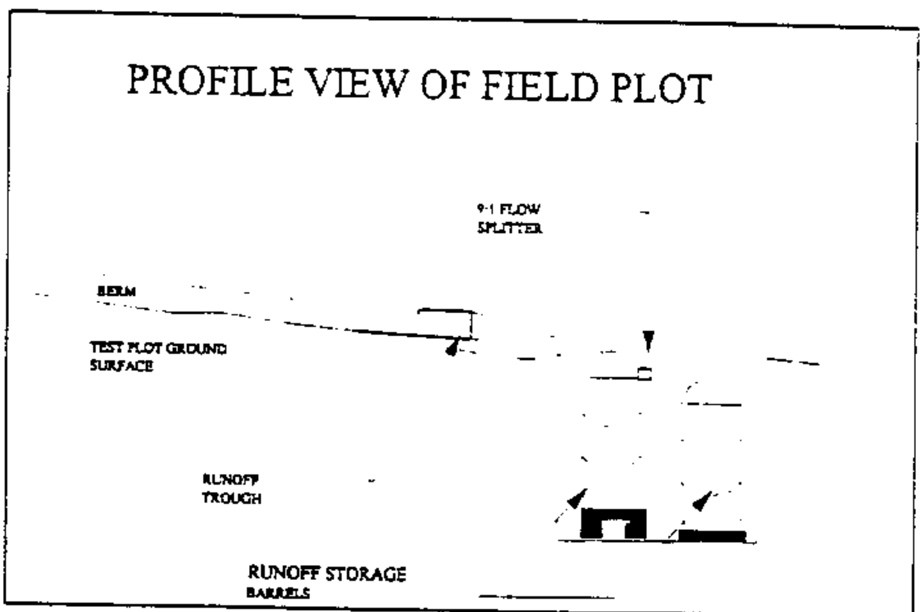


Figure 3. Profile view of field plot.

Table 1. Chemical characteristics of Urbana-Champaign tap water

Cations	mg/L	Anions	mg/L
Sodium	34	Chloride	6
Magnesium*	45	Sulfate	35-40
Potassium	<1	Fluoride	1
Calcium*	35		
Iron	<.01		
Manganese	<.01		

Alkalinity:*	110 mg/L
pH:	8.7 - 8.9
TDS:	153 mg/L
Electrical Conductivity:	219 S/cm (calculated)

*As $CaCo_3$ equivalent

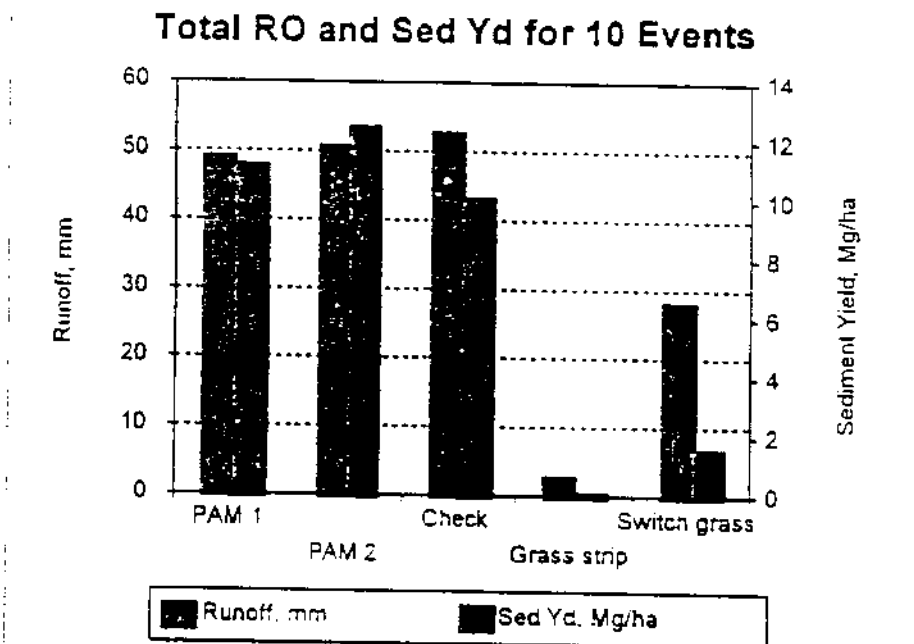


Figure 4. Cumulative runoff and sediment yield for each treatment over the ten events sampled after pam application.

lection of surface runoff water in storage barrels. The relative locations of plots and the storage pits which contained four storage barrels are illustrated in Figure 2.

A small earthen berm was constructed around the plots to prevent surface runoff from other areas of the site from entering into the plot and to direct all runoff within the plot to the collection device. Individual plot runoff flowed naturally down slope toward the collection trough which conducted the flow to the storage barrels. The profile of an individual plot is illustrated in Figure 3. All surface runoff from the plot flowed into the primary storage barrel. Runoff which overflowed the primary storage barrel was directed through a 9 to 1 flow splitter, and one-ninth of the overflow was directed into the secondary storage barrel. The remaining eight-ninths of the runoff was discharged to a drain.

Two types of PAM were evaluated in this study. Both PAMs were obtained as samples from Cytec Industries, a Division of American Cynamid Corporation, located in West Patterson, New Jersey. The first PAM (PAM1) is a high molecular weight polymer (10 x 106 g/mol) called Superfloc A-836. The second PAM (PAM2) is a lower molecular weight (0.25 x 106 g/mol), highly anionic polymer called Aerofloc 550. PAM1 was available in granular form and PAM2 as a translucent liquid. PAM1 and PAM2 were applied to four test plots each after tillage. Four test plots were used as control. Additionally, four test plots had a grass strip 3m long at the lower end of the plot below the 3m x 11m bare plot. The 3m long section was planted with Redtop in the Fall of 1992. The remaining four plots had a single row of Switch Grass at the lower end of the plot just before runoff entered the collection system. No PAM was applied to the plots with grassed outlets. The check, grass strip and switch grass plots have been monitored for three years to compare the effectiveness of the two vegetative treatments in removing sediment.

All the plots were roto-tilled prior to PAM application. PAM1 was applied at a rate of 1.1 kg/ha and PAM2 was applied at a rate of 15.7 L/ha (17.6 kg/ha). The actual quantity of PAM1 applied to each plot was 3.65 g. Similarly, the quantity of PAM2 applied per plot was 50 mL. The first year, PAM1 was added to 19 L of water and mixed. Attempts were made to apply this mixture with a hand-held watering can. However, the mixture did not move through the perforations on the outlet end of the watering can. Finally, this material had to be applied by hand using a jug. As a result, the uniformity of application was poor. PAM2 was mixed with 11 L of water and uniformly applied over the plot using a garden sprayer. Potassium bromide was mixed at the rate of 113g in 4 L of water and applied to each PAM plot and to the four control plots to estimate water movement as infiltration and as runoff. No surface runoff was produced during the application processes.

The second year the same measured amounts of PAM1 and PAM2 were mixed with 38 L to 75 L of tap water and pumped through a garden hose to a nozzle that was oscillated by hand to spread the material evenly.

Table 2. Average slope, cumulative runoff and sediment yield over ten events

Yield* Treatment	Average Slope* (%)	Runoff* (mm)	Sediment (Mg/ha)
PAM1	3.3a	49.3ab	11.2a
PAM2	2.8a	50.8ab	12.5a
Check	3.1a	52.8a	10.1a
Grass Strip	2.8a	2.9c	0 . 1 b
Switch Grass	3.0a	28.3b	1.6b

*Slope, runoff or sediment yield values with the same lower-case letter are not significantly different at the 0.05 level.

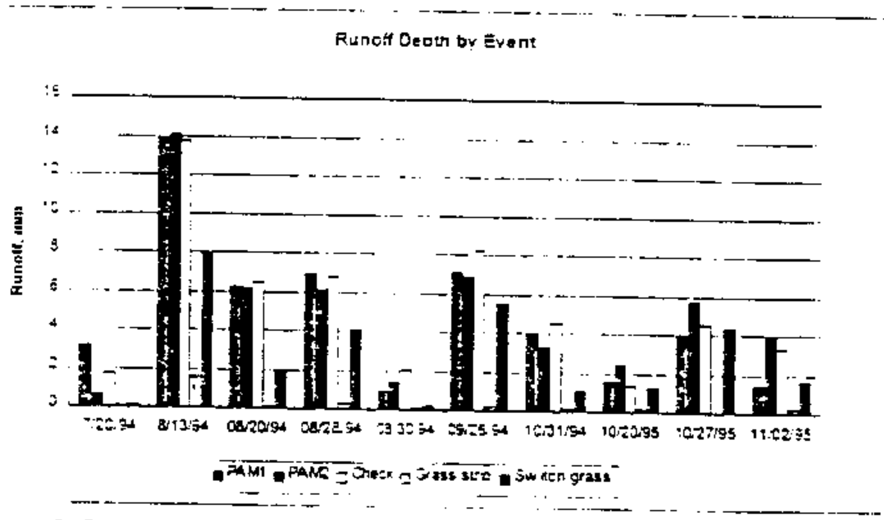


Figure 5. Runoff for each treatment and for each of the ten events sampled after PAM application.

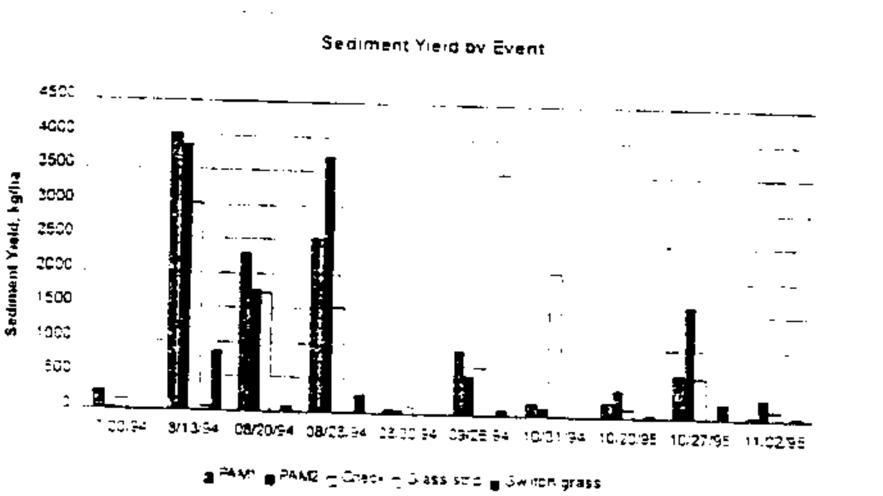


Figure 6. Sediment yield for each treatment and for each of the ten events sampled after PAM application.

The tap water has the chemical characteristics shown in Table 1.

Following each runoff event, the depth of runoff in the barrels was measured so that runoff volume could be calculated. Before taking a water sample from a barrel, the contents were thoroughly mixed. Two sample bottles were collected to determine sediment concentration from each barrel. If runoff was sufficient to overflow the primary storage barrel, two samples were also taken from the completely mixed contents of the secondary storage barrel. Additional samples were collected for bromide determinations.

Total plot runoff was calculated by adding the volume of water in the primary barrel to nine times the volume of water in the secondary barrel. This multiplication factor was used to account for the effect of the 9:1 flow splitter. Sediment concentration was determined gravimetrically in the laboratory. The average of the two samples from each barrel was used as the sediment concentration of each barrel. Sediment mass in each barrel was calculated by multiplying the volume of the runoff in the barrel by the sediment concentration of that barrel. Total sediment mass in direct surface runoff from each plot was calculated in the same manner as total plot runoff.

Water samples taken for bromide analysis were analyzed using an Orion ion-selective electrode. This electrode was tested to be accurate to 0.1 mg/L using standard modes of analysis. Since bromide was uniformly applied to the soil, it was presumed that the plots producing greater amounts of sediment load to runoff water would have higher concentrations of bromide in the runoff water.

There were seven runoff producing events after PAM was applied in 1994 and three events in 1995. Analysis of variance and multiple comparison of means were conducted to identify statistically significant differences in runoff and sediment yield from the different treatments. Analyses were conducted for individual events and for cumulative runoff and sediment yield for the ten events. Additionally, cumulative runoff and sediment from the 28 events on the check, grass strip and switch grass treatments were compared.

Treatment means were compared using Scheffe's test for least significant difference with a significance level of 0.05 *(SAS, 1992)*. This test controls the overall probability of a type II error (declaring a difference in means a treatment effect when in fact it is due to random variation) at

0.05. In order to accomplish this, the pairwise type II error rate is controlled at less than 0.05. Thus, this is a relatively conservative test in that a pairwise differences must be significant at the 0.05 level may not be indicated as significant in the multiple comparison of means in order to maintain the overall error rate at 0.05.

Results and Discussion

Mean cumulative runoff depth and sediment yield over the ten events sampled after PAM applications in two years are illustrated in Figure 4 and presented in Table 2. Mean plot slopes for the different treatments were not statistically different, although slight differences by treatment did exist. Runoff was significantly reduced by the switch grass row treatment as compared to the check. Runoff from the PAM treatments, was not significantly different from the check. However, runoff from the switch grass treatment was not significantly different than either PAM treatment even though it was different from the control. A similar result was obtained with regard to sediment yield from the plots. The PAM treatments are not significantly different from the control, but the switch grass and grass strip treatments were significantly less than the PAM and control treatments.

The runoff depth and sediment yield results for each event are demonstrated in Figures 5 and 6, respectively. These figures indicate and the results shown in Table 3 indicate that runoff and soil loss from the PAM treatments are not significantly different from the control, even for the first one or two events, as might be expected. The PAM was applied on July 12, 1994, and the first event was monitored on July 20, 1994. PAM1 was applied at a very low rate but the PAM2 application rate was near that described by Shainberg et. al. (1990), Fox and Bryan (1992), Ben-Hur (1994), and Stern (1992). Yet no significant differences were found. However, PAM2 was a lesser molecular weight and, thus, may require a greater application for a similar effect as PAM1.

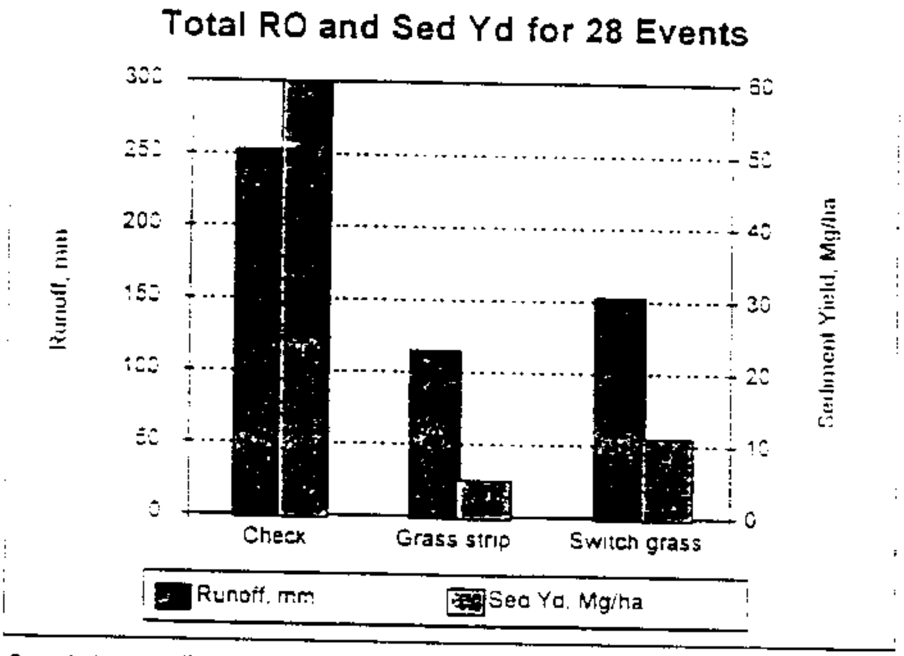
Differences may not have occurred after the PAM application on August

Table 3. Runoff and sediment yield for individual events

Date	Rainfall (mm)	Treatment	Mean* Runoff (mm)	Mean* Sediment Yld (kg/ha)
07/20/94	23.4	PAM1	3.2a	280.8a
		PAM2	07cb	29.0b
		Check	1.7b	156.2ab
		Grass Strip	0.1c	0.2b
		Switch Grass	0.2c	1.0b
8/13/94	25.6	PAM1	13.9a	4002.2a
		PAM2	14.1a	3868.8a
		Check	13.7a	5007.8ab
		Grass Strip	1.6b	70.2c
		Switch Grass	8.0ab	873.2bc
8/20/94	20.8	PAM1	6.2a	2290.2a
		PAM2	6.2a	1757.5a
		Check	6.5a	1712.8a
		Grass Strip	0.1c	0.8b
		Switch Grass	1.9b	87.8b
08/28/94	16.3	PAM1	6.9a	2515.5ab
		PAM2	6.1a	3714.8a
		Check	6.8a	1531.0ab
		Grass Strip	0.3c	6.2b
		Switch Grass	4.1b	268.2b
08/30/94	24.6	PAM1	1.0ab	69.5a
		PAM2	1.4ab	71.0a
		Check	2.1a	101.0a
		Grass Strip	0.1b	0.2a
		Switch Grass	0.2b	0.2a
09/26/94	43.2	PAM1	7.1a	931.8a
		PAM2	6.9a	566.8ab
		Check	8.2a	691.5ab
		Grass Strip	0.2b	1.0b
		Switch Grass	5.5ab	78.0b
10/31/94	25.4	PAM1	4.0ab	201.5a
		PAM2	3.3abc	122.2a
		Check	4.6a	2087.5a
		Grass Strip	0.2c	0.8a
		Switch Grass	1.0bc	6.8a
10/20/95	27.7	PAM1	1.6a	219.5ab
		PAM2	2.4a	397.8a
		Check	1.4a	127.5ab
		Grass Strip	0.2a	1.5b
		Switch Grass	1.3a	37.0b
10/27/95	17.0	PAM1	4.0a	640.ab
		PAM2	5.8a	1642.0a
		Check	4.6a	603.8ab
		Grass Strip	0b	0b
		Switch Grass	4.4a	242.0ab
11/02/95	20.1	PAM1	1.4ab	51.2ab
		PAM2	4.0a	292.5a
		Check	3.3ab	121.0ab
		Grass Strip	0.3b	0b
		Switch Grass	1.6ab	47.8b

**Runoff or sediment yield values for a given date with the same lowercase letter are not significantly different at the 0.05 level within each event*

Figure 7



Cumulative runoff and sediment yield for the check and two vegetative treatments over 28 events during three years.

Table 4. Bromide concentration and mass in runoff for the first two events

Treatment	Concentration* mg/L	Mass* gm
First Event after Application		
PAM1	2.62a	0.303a
PAM2	1.38a	0.076a
Check	1.30a	0.031a
Second Event after Application		
PAM1	0.16a	.078a
PAM2	0.14a	.060a
Check	0.10a	.045a

*Concentration or mass values for a given event followed by the same lower-case letter are not significantly different at the 0.05 level.

Table 5. Cumulative runoff and sediment yield over 28 events

Treatment	Runoff* (mm)	Sediment Yield* (Mg/ha)
Check	253a	60a
Grass Strip	115b	5b
Switch Grass	153b	11b

*Runoff or sediment yield values with the same lower-case letter are not significantly different at the 0.05 level.

29, 1995, because the plots were tilled for weed control on September 25, 1995, before the first runoff event on October 20, 1995.

Bromide was applied to the PAM and control plots in 1994 in an attempt to determine the distribution of water movement to runoff and infiltration. The soil water sampling devices failed and, as with runoff depth, bromide concentration and mass are not different between treatments (Table 4).

The control and two vegetative treatments were monitored beginning June 18, 1993. The cumulative runoff and sediment yield benefit of those treatments over 28 events are illustrated in Figure 7 and presented in Table 5. The runoff and sediment yield from the grass strip and switch grass row treatments are significantly less than the bare plot control, but not different from each other.

Conclusions and Future Work

This study has demonstrated that grass filter strips and stiff grass rows reduce sediment yield and runoff. However, the value of the application of PAM to the soil surface has not been demonstrated.

The very low application rate of PAM1 and slightly lower application rate of PAM2 may not provide a good situation for demonstrating the erosion control value of these products. The tillage before events in 1995 may have interrupted the value of that application. However, during the two months from application to runoff event the PAM products may have decomposed and/or lost effectiveness in reducing runoff and erosion control.

Events will be monitored in 1996 if costs of application and monitoring can be kept to the low level of funding allocated to this project. The authors welcome advise as to the level of PAM application to attempt. If applications of 20 to 40 kg/ha are desired, can the material be raked into the surface as a powder? Otherwise, a very large amount of water will have to be used, either causing runoff during application or application over a long time.

If liquid application is used, is the chemical composition of the tap water interfering with the intended reaction of the PAM with the soil? Did KBr, used as a tracer in this study, have any detrimental effect on the action of PAM? Did the time gap between the application of PAM and the first or subsequent rainfall event cause any biotic/abiotic degradation of PAM? Perhaps PAM has little effect on soils with high organic matter content, if this organic matter is already providing a high degree of aggregate binding.

It appears that in the semi-humid cornbelt, PAM application is not practical for erosion control in row crop production because of cost. However, it may be useful for temporary erosion control at construction sites or similar settings. Additional field tests are necessary to test that hypothesis.

Acknowledgements

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