Conclusions

This study showed that in forested watersheds with little to no slope, as found in the coastal plain of North Carolina, the increase in sediment concentrations and outflows resulting from the presence of access roads is of minor concern at the watershed outlet. Even though other studies have shown high sediment concentrations in runoff from forest access roads (as high as 850 mg/L from non-graveled road surfaces - Appelboom, 2000) in this area, the average annual sediment concentrations at the watershed outlet ranged from 4.5 to 35.9 mg/L. Concentrations observed in this study fall within the range of sediment concentrations (7.0 to 32.4 mg/L) found to occur in other drained forested watersheds without access roads. The sediment concentrations at the outlet are well below the threshold sediment concentrations (300 mg/L) that cause shifts in species diversity of aquatic life from desirable species, to undesirable species. The potential average increase of 20 mg/L (based on the average sediment concentrations of the study versus the natural wetland sediment concentrations) is below that reported in literature (increases of 20 to 80 mg/L) that decrease desirable invertebrate populations

Acknowledgments

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PAM and Straw Residue Effects on Irrigation Furrow Erosion and Infiltration

R.D. Lentz and D.L. Bjorneberg[1]

Abstract

Water soluble anionic polyacrylamide (PAM) is a highly effective erosion deterrent in furrow irrigation, but little is known about the effect of plant residue on PAM efficacy. We hypothesized that increasing plant residue in irrigation furrows may decrease PAM's ability to control erosion. Treatments included furrows with 3.2 g m^{-1} and 10 g m^{-1} straw applications irrigated with PAM or untreated water, and conventionally irrigated furrows (no PAM and no straw). Five irrigations were monitored on a field with 1.5% slope and silt loam soil *(Durinodic Xeric Haplocalcids)*. PAM was applied as a granular patch at the furrow inflow end (33 g or 1 kg active ingredient ha^{-1}). Irrigation inflows of 23 L min^{-1} were cutback to 15 after runoff began. Adding more straw, or adding PAM to straw-treated furrows decreased furrow sediment loss and increased net infiltration, but only for the first two irrigations after treatment. For fresh furrows, straw treatments reduced sediment loss an average of 86% and straw + PAM reduced sediment loss nearly 100%, compared to conventionally irrigated furrows. High-straw+PAM and low-straw+PAM treatments produced the same furrow sediment losses and net infiltration amounts, i.e. increasing plant residues in furrows did not decrease PAM's efficacy on these soils.

Keywords. Furrow irrigation, Erosion, Straw residue, Sediment discharge, Infiltration.

Introduction

Polyacrylamides have been used as settling agents in the water treating, mineral processing, and paper manufacturing industries for decades. In a more recent application, polyacrylamide-amended irrigation water was used to reduce furrow irrigation-induced erosion and sediment loss (Lentz and Sojka, 1994). Of the many forms of polyacrylamide manufactured, a water soluble anionic polyacrylamide having a molecular weight of 12 to 15 Mg mol^{-1} and charge-density of 8 to 35% has been found to be most effective for furrow erosion control (Lentz et al., 2000). In this paper, use of the terms polyacrylamide or PAM will refer to this particular type of polymer.

Lentz and Sojka (1994) demonstrated that applying 10 mg PAM L^{-1} water, i.e. 10 ppm, during the first 2 hr (during advance) of the irrigation reduced sediment loss from treated furrows by an average 94% compared to untreated furrows. The 10 mg L^{-1} PAM concentration applied during the initial irrigation period was found to be optimal (Lentz, et al., 2000). This PAM application method, adopted as the NRCS Practice Standard, also reduces runoff losses of N, P, and chemical-oxygen-demand by 80 to 90%, and pesticide losses by at least 50 to 70%, compared to that of untreated furrows (Lentz et al., 1998). General technical and practical guidelines concerning PAM application to furrow-irrigated agriculture were discussed by Sojka and Lentz (1997).

During furrow irrigation, the advancing water stream inundates soil aggregates, which slake and break down, and soil particles are detached, dispersed, and transported down furrow. Some transported sediment is deposited along the wetted furrow perimeter. The resulting smoothed surface has less resistance to flowing water. These processes simultaneously promote surface seal formation, which decreases furrow infiltration (Segeren and Trout, 1991) and increases runoff and sediment loss.

PAM-amended irrigation water affects this process in two ways, it adsorbs to soil surfaces, increasing soil cohesion and aggregate stability; and it flocculates fine soil particles suspended in the furrow stream, producing larger aggregates that tend to settle out of the flow. Together these processes produce a well aggregated system that better maintains roughness and permeability of the furrow surface, compared with untreated furrows (Trout et al., 1995). Hence, PAM-treated furrows, may have greater infiltration, less runoff, lower soil detachment rates, and reduced sediment transport rates compared to untreated furrows.

Crop residues occur in furrows as a result of incomplete incorporation or are placed there to control erosion (Aarstad and Miller, 1981) or increase infiltration rates (Miller and Aarstad, 1971). Sediment and unincorporated straw at inflow-ends of furrows can be detached and transported down furrow. This sediment and residue can eventually settle or be trapped in the downstream residue-laden furrow, potentially filling and blocking it, and can

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cause the stream to overtop and escape the furrow (Berg, 1984). Dissolved organic matter from soil or plant residue can reduce PAM's capacity to flocculate dispersed mineral particles (Lentz et al., 1996).

Little published information is available that describes the influence of crop residue on PAM's furrow irrigation erosion control efficacy. No PAM/residue interaction was observed when PAM was used with a straw application of >130 kg ha^{-1} (C. Shock, personal communication, 2000). Here we tested the hypothesis that increasing crop residue decreases PAM's capacity to inhibit furrow irrigation-induced erosion.

Materials and Methods

The 0.4-ha field plot was located at the USDA-ARS Northwest Irrigation and Soils Research Laboratory at Kimberly, ID on Portneuf silt loam, coarse-silty, mixed superactive, mesic *Durinodic Xeric Haplocalcids*. Surface soil included 14% clay and 68% silt. Soil organic matter was 14 g kg^{-1}, cation exchange capacity was 18 $cmol_c$ kg^{-1}, electrical conductivity (EC, saturated paste extract) was 0.07 S m^{-1}, ESP was 1.5, pH was 7.8, and calcium carbonate equivalent varied from 2 to 8%. Slope was 1.5%. The seedbed was disked, roller-harrowed, premergence herbicide applied, and planted to corn (*Zea mays L.*). Electrical conductivity of irrigation water was 0.05 S m^{-1}, and SAR was 0.7. Furrows were shaped with a weighted furrow-forming tool. Irrigation water was applied from adjustable spigots on gated pipe. Furrow length was 175 m.

Treatments consisted of low-residue (3.2 g m^{-1} of furrow or 21 kg ha^{-1} on whole field basis) and high-residue (10 g m^{-1} or 65 kg ha^{-1}) furrows, with or without PAM treatment, and an untreated control. Wheat straw was applied by hand along the entire length of the furrow. We applied a 12 to 14 Mg mol^{-1} anionic PAM with 18% charge density, manufactured and marketed under the trade name Superfloc 836A by CYTEC Industries, Wayne, NJ. The white granular crystals were 80% PAM (AI). Thirty-three grams of granular PAM were placed in a 0.1 m^2 patch at the head of each PAM treated furrow (equivalent to 1 kg PAM (AI) ha^{-1}). The patch was positioned so that impinging turbulence from incoming water would promote PAM hydration and solution.

We measured irrigation furrow inflow and outflow rates, and collected runoff samples to determine sediment concentration. Furrow monitoring procedures were identical to those of Lentz et al. (1994). Furrow soil loss and infiltration were computed from field data with WASHOUT, an analytical computer program (Lentz et al., 1998). Soil loss reduction was computed as percent difference between the control and treated-furrow values.

Plot furrows were formed on May 17, 1999. An initial nonmonitored irrigation was applied to freshly formed furrows. The field was then cultivated, furrows were reformed, and straw residue treatments were applied. Five monitored irrigations followed, the first on fresh furrows, and four repeat irrigations on these same furrows which were not subsequently disturbed by tillage. We refer only to monitored irrigations here, numbering them from one to five, with irrigation #1 being the first irrigation applied after straw was placed in the furrows. Irrigations were two weeks apart, except for one and two, which were one week a part. Irrigation duration was 24 h. Inflow rate during furrow advance was 23 L min^{-1}, which was cutback to 15 L min^{-1} after runoff began.

The study employed a split plot design with residue application rate as the main plot and PAM application rate as the subplot, with four replicates. Additional conventionally-irrigated control furrows were included in each block. Residue and PAM treatments were analyzed in a split block analysis. An additional analysis used a complete block approach to compare the control treatment with the others. Hypotheses and mean separations were determined with a probability of $P = 0.05$.

Results and Discussion

Relative to untreated control furrows, the addition of straw or straw+PAM greatly reduced sediment loss for all irrigations, and increased net infiltration and advance time for freshly formed furrows in irrigation one (Table 1). Analysis of variance showed that main effects, straw and PAM application rate, significantly influenced several irrigation parameters during irrigation one on fresh furrows (Tables 1 & 2). In subsequent irrigations, however, straw or PAM rate had less effect on irrigation parameters. In the last three irrigations (3,4,5), straw rate affected only furrow advance time, while PAM rate influenced sediment loss, mean sediment concentration, and advance time (Table 2). Significant interactions (straw X PAM) occurred for sediment loss and mean runoff sediment concentration, but only for irrigations one and two.

Comparison With Untreated Controls: In irrigation one, straw application on average reduced sediment loss 86%, reduced mean sediment concentration 81%, and increased infiltration 1.3x, compared to untreated control furrows (Tables 1 and 2). In irrigation two on average, straw alone reduced sediment loss 76% and sediment concentration 77% relative to controls. In the last three irrigations, the straw-induced reduction in sediment loss

Table 1. Irrigation parameters for irrigations one and two, and 3, 4 and 5 combined for monitored irrigations. Furrow length was 175 m

		------ Low Straw ------		----- High Straw ----	
	Control	No PAM	PAM	No PAM	PAM
Irrigation 1 (fresh furrows)					
Mean Outflow (mm)	13.8 c[†]	12.2 c	6.8 a	9.6 b	5.7 a
Sediment Loss (Kg ha^{-1})	3000 d	636 c	3 a	212 b	0.5 a
Infiltration (mm)	54 a	63 b	92 d	77 c	96 d
Mean Sediment Conc. (g L^{-1})	4.3 d	1.0 c	0.02 a	0.45 b	0.00 a
Furrow Advance (min)	102 a	129 a	228 b	168 ab	250 b
Irrigation 2 (repeat irr. furrows)					
Mean Outflow (mm)	10.7 a	11.3 a	8.4 a	10.2 a	8.5 a
Sediment Loss (Kg ha^{-1})	2807 d	951 c	2.8 a	418 b	1.4 a
Infiltration (mm)	49 a	49 a	63 a	53 a	61.6 a
Mean Sediment Conc. (g L^{-1})	4.8 d	1.6 c	0.01 a	0.7 b	0.00 a
Furrow Advance (min)	51 a	59 a	65 a	67 a	83 b
Irrigation 3, 4, 5 (repeat irr. furrows)					
Mean Outflow (mm)	10.4 a	9.3 a	9.4 a	9.1 a	9.3 a
Sediment Loss (Kg ha^{-1})	1078 c	80 b	3 a	41 ab	1 a
Infiltration (mm)	56 a	60 a	63 a	61 a	62 a
Mean Sediment Conc. mg L^{-1})	1.9 b	0.2 a	0.00 a	0.1 a	0.01 a
Furrow Advance (min)	85 a	99 ab	138 c	112 bc	164 c

[†] Values within a row with the same letter are not significantly different.

and concentration was nearly 94%. The straw + PAM treatment had a greater impact than straw alone. In irrigation one, straw + PAM reduced sediment loss and mean sediment concentration by nearly 100%, reduced mean outflow rate 54%, and increased infiltration 1.7x and furrow advance time 2.3x, compared to untreated control furrows. A similar 100% reduction for sediment loss and concentration was observed in irrigations 2,3,4, and 5.

Straw Effects: This main effect examined the influence of the high-straw treatment relative to that of the low-straw. When averaged over both PAM rates in irrigation one, increasing straw rate increased net infiltration 1.1x, decreased mean outflow by 20%, and decreased sediment loss by 70% and mean sediment concentration by 60% (Table 2). In later irrigations, increasing straw rate affected only the furrow advance period, increasing it by 1.2x.

PAM Effects: This main effect examined the influence of the PAM+straw treatment relative to that of the straw-only. When the two straw rates are combined in irrigation one, PAM+straw increased net infiltration 1.3x, decreased mean outflow by 42%, and increased the furrow advance time 1.6x. PAM+straw also decreased sediment loss by 100%, and mean runoff sediment concentration by 88%. For irrigations 3,4,and 5, PAM application to strawed furrows significantly decreased sediment loss (97%) and mean runoff sediment concentration (100%) and increased furrow advance time (1.4x); but because furrow erosion rates were generally lower in repeat irrigations, the numerical differences between treatments (straw alone vs straw+PAM) were small.

Straw X PAM Interaction: Without PAM, low-straw produced greater sediment losses than the high-straw treatment for irrigations one and two. The low-straw+PAM and high-straw+PAM treatments both reduced sediment losses by nearly 100%, sediment losses were < 1/100th that of untreated furrows. Thus, PAM had a greater relative impact on sediment losses in low-straw furrows than in high-straw furrows (Tables 1 and 2).

Conclusions

Applying either PAM (Lentz and Sojka, 1994) or straw residue to freshly-formed furrows increased net infiltration and reduced sediment losses, relative to untreated furrows. During the first two irrigations after straw was applied, the straw+PAM treatments produced greater net-infiltration increases and sediment-loss reductions than did straw-only treatments. After two irrigations on the otherwise undisturbed strawed furrows, no effect of adding PAM or increased straw residue on net infiltration was observed, though all straw and PAM treatments

Table 2. Irrigation parameter comparisons between levels of straw or PAM treatments, and significance of the straw-PAM interaction. Furrow length was 175 m

	Low Straw	High Straw	Straw Alone	Straw + PAM	Signif. Straw X PAM Interaction
Irrigation 1 (fresh furrows)					
Mean Outflow (mm)	9.5 b†	7.6 a	10.9 b	6.3 a	NS
Sediment Loss (Kg ha^{-1})	319 b	106 a	424 b	1.7 a	***
Infiltration (mm)	78 a	86 b	70 a	94 b	NS
Mean Sediment Conc. (g L^{-1})	0.5 b	0.2 a	0.8 b	0.1 a	***
Furrow Advance (min)	178 a	209 a	148 a	239 b	NS
Irrigation 2 (repeat irr. furrows)					
Mean Outflow (mm)	9.9 a	9.4 a	10.8 b	9.5 a	NS
Sediment Loss (Kg ha^{-1})	477 b	209 a	684 b	2 a	***
Infiltration (mm)	56 a	57 a	51 a	62 b	NS
Mean Sediment Conc. (g L^{-1})	0.8 b	0.4 a	1.1 b	0.0 a	***
Furrow Advance (min)	62 b	75 a	63 a	74 a	NS
Irrigation 3, 4, 5 (repeat irr. furrows)					
Mean Outflow (mm)	9.4 a	9.2 a	9.3 a	9.4 a	NS
Sediment Loss (Kg ha^{-1})	42 a	21 a	61 b	1.9 a	NS
Infiltration (mm)	61 a	61 a	60 a	62 a	NS
Mean Sediment Conc. (g L^{-1})	0.1 a	0.0 a	0.1 b	0.0 a	NS
Furrow Advance (min)	119 a	138 b	106 a	151 b	NS

† For a given straw-level or PAM-level comparison, values within a row with the same letter are not significantly different.

continued to inhibit sediment losses, compared in untreated furrows. High-straw+PAM and low-straw+PAM treatments affected furrow infiltration and erosion similarly. Increasing straw residue in irrigation furrows did not decrease PAM's erosion control effectiveness. When both PAM and straw were applied, straw rates exceeding 3.2 g m^{-1} of furrow (21 kg ha^{-1} whole field basis) produced no additional erosion control benefit.

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Effects of PAM Application Method and Electrolyte Source on Runoff and Erosion

J.R. Peterson, D.C. Flanagan, J.K. Tishmack[1]

Abstract

Previous research has indicated that polyacrylamide (PAM) soil amendments can be effective in reducing runoff volume and soil erosion by reducing soil sealing and stabilizing soil structure. Furthermore, the application of an electrolyte in addition to PAM has been shown to further reduce runoff volume and sediment yield on some soils. A field study was conducted using simulated rainfall to test the effectiveness of method of PAM application (dry or in solution), the effectiveness of two sources of electrolytes, and effectiveness of a synthetic soil. Treatments using an application of a liquid PAM solution that was allowed to dry on the soil surface were the most effective in reducing total runoff (62% to 76% reduction compared to control) and total sediment yield (93% to 98% reduction compared to control). Spraying of PAM in solution was significantly more effective in controlling runoff and erosion than was the dry granular application.

Keywords. Runoff, Soil erosion by water, Soil amendments, Polyacrylamide, PAM.

Introduction

Agriculture is a leading source of pollution to surveyed streams, rivers, and lakes in the United States. According to the US EPA (1996), agricultural pollution affects 25% of streams and 19% of lakes and contributes to 70% of all identified water quality problems in streams and 49% in lakes. Sediments are the most common pollutant affecting rivers and streams (US EPA, 1996). Sediment contributes to 51% of water quality problems in rivers and streams and to 25% in lakes. The problem of erosion is not only an agricultural one. The construction and forestry industries also contribute to accelerated erosion rates.

During a precipitation event the impact of individual raindrops can cause breakdown of soil aggregates. Individual soil particles are then free to migrate to pore spaces, which results in sealing of the soil surface. Surface sealing results in reduced infiltration rates and consequently to increased runoff and erosion and may also interfere with seedling germination (Shainberg and Levy, 1994). In the early 1950's the use of a synthetic organic polymer known as Krilium to stabilize soil aggregates was introduced (Wallace and Wallace, 1986). However, prohibitive costs and difficulty of use limited its utility. More recently, the cost and effectiveness of synthetic polymers as soil conditioners have become more attractive because of advances in chemistry (Seybold, 1994). One such polymer is polyacrylamide (PAM).

PAM is a synthetic organic polymer high in molecular weight and is water soluble. PAM primarily interacts with the clay fraction of soils (Seybold, 1994). PAM can be synthesized in cationic, nonionic, or anionic forms, though anionic PAM has been found to be the most effective for erosion control (Shainberg and Levy, 1994). Shainberg et al. (1990) reported that the benefits of PAM were enhanced by the introduction of an electroyte source that helps to create a cation bridge for the polymer to adsorb to the soil. Typically, the electrolyte is introduced in the form of phosphogypsum. PAM is being used extensively for erosion control in furrow irrigation systems.

Reduction of erosion and runoff through the use of PAM and gypsiferous material has been well documented. Objectives of this study were to determine the effect of application method of PAM on runoff and erosion and to test the effectiveness of alternatives to gypsum as a means to increase electrolyte concentrations in runoff for a worst case scenario of a large storm event on a newly disturbed soil.

Materials and Methods

Fifteen field plots measuring 3.0 m wide by 9.1 m long were constructed on a hillslope one-mile south of the Purdue University campus in West Lafayette, Indiana. The hillslope was first graded to an approximate 20% slope. Plot locations were staked and enough soil to fill the plot area to a depth of 25 cm to 35 cm was placed at

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