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Reducing Soil and Nutrient Losses from Furrow Irrigated Fields with Polymer Applications

R.D. Lentz, R.E. Sojka & C.W. Robbins

Summary
Irrigation furrow runoff contains sediment, associated organics, and nutrients that enter surface waters as non-point source contributions. We compared the effects of anionic polyacrylamide (PAM) applications on furrow runoff losses of sediment, nitrate, ortho-phosphorus (ortho-P), total-phosphorus (total-P), and chemical oxygen demand (COD). Dry bean was planted on Portneuf silt loam (Durixerollic Calciorthids) after conventional tillage. Initial irrigation inflows of 23 L/min were cut back to 15 L/min after runoff began. Control furrow streams contained no PAM. PAM was applied continuously at 1 mg/L during the PAM **C1** treatment. In the PAM **I10** treatment, 10 mg/L PAM was applied to inflows early in the irrigation, then stopped once runoff began. Runoff from PAM-treated furrows was 37% less than for controls. Runoff, ortho-P, and total-P concentrations in control furrows were 5 to 7 times that of the pulsed-PAM treatment, and control COD levels were 4 times those of the PAM **I10** treatment. The **C1** concentration values for all components except nitrate were about twice as large as those of the **I10** treatment. Total seasonal soil loss was 3.14 Mg ha^{-1} for control furrows, 0.35 for PAM-**C1**, and 0.25 for PAM-**I10** treatments. Relative to controls, PAM markedly reduced total furrow losses of sediment, ortho-P, total-P, and COD (60 to 92%), but had little influence on runoff nitrate.

1 Introduction

Irrigation-induced erosion threatens agricultural sustainability and surface water quality worldwide. Soil losses resulting from 50 to 80 years of continuous furrow irrigation have reduced the productivity potential of some northwest U.S. farms by 25% (Carter, 1993). Furrow runoff contains sediment and associated organics and nutrients that enter surface waters as non-point source contributions and damage downstream users and environments. Alternative, more efficient sprinkler irrigation systems are usually less erosive, but are more costly. Moreover, in southern Idaho, current inexpensive water prices provide little motivation to irrigate more efficiently. Nonetheless, gradual conversion to sprinkler systems is occurring, primarily because of associated labor savings (Dennis Kincaid, personal communication, 1996). Still, 50 to 60% of farm managers in south-west and south-central Idaho use surface irrigation. An effective, economical, and favorably received erosion control practice is needed to conserve soil in this and other irrigated areas worldwide.

Lentz et al. (1992) showed that applications of a water-soluble anionic polyacrylamide (PAM) of 12-15 Mg mol^{-1} and 18% charge density reduced furrow irrigation-induced sediment losses by up to 97%. Over three years, an average soil-loss reduction of 94% was achieved by applying an initial 10 mg L^{-1} PAM pulse in irrigation water mainly during furrow advance, i.e. while water first

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traversed the length of the dry furrow. When we applied 0.5 mg L^{-1} PAM to irrigation water continuously for the entire irrigation, we used 75 to 86% less PAM, and achieved a 70 to 80% soil-loss reduction, relative to controls (Lentz and Sojka, 1996).

Both these application techniques were enthusiastically accepted by irrigators in the western US. PAM first became generally available in 1995, and was used on about 20,000 ha that year. In 1996 PAM was used on nearly 200,000 ha!

Seybold (1994), Barvenik (1994), and Barvenik et al. (1996) reviewed safety, toxicity and environmental regulation aspects of PAM-use. When PAM is employed at concentrations recommended for agriculture and other industries (1-10 mg L^{-1}), the polymer is non-toxic and no adverse environmental affects have been observed. PAM is authorized for use in treatment of potable water supplies, in food processing, and in paper products used to store food. PAM formulations used for treating irrigation water are food-grade quality and compositions are strictly regulated.

A preliminary study by Lentz and Sojka (1994) indicated that PAM-use not only reduced field soil losses, but also appeared to diminish nutrient and organic losses in furrow runoff. In their study, a continuous < 0.5 mg L^{-1} PAM treatment was applied to irrigation inflows. This less-than-optimal PAM treatment produced slight to moderate reductions of total-P, ortho-P, nitrate, and BOD (biochemical oxygen demand) in runoff.

Our objective was to compare the effects of zero, continuous, and pulsed-PAM applications on furrow runoff losses of sediment, nitrate, ortho-P, total-P, and chemical oxygen demand. The COD provides a measure of organic matter losses occurring in runoff.

2 Methods

The field study was conducted at the USDA-ARS Northwest Irrigation and Soils Research Laboratory at Kimberly, Idaho, USA. Dry bean (*Phaseolus vulgaris* L .'Viva Pink') was planted on Portneuf silt loam, coarse-silty, mixed, mesic Durixerollic Calciorthids. The seedbed was prepared with disk and roller harrow. Surface soil texture was silt loam (10% clay, 70% silt), organic matter was 10-13 g kg^{-1}, cation exchange capacity was 190 $mmol_c$ kg^{-1}, saturated-paste-extract electrical conductivity (EC) was 0.7 dS m^{-1}, ESP was 1.5, pH was 7.7, and calcium carbonate equivalent was 5%. Furrows were 175 m long, with a 1.6% slope. Furrows were shaped with a weighted wedge-shaped forming tool. To avoid infiltration differences between wheel-tracked and nonwheel-tracked furrows, only trafficked furrows were irrigated and monitored.

Irrigation water was from the Snake River. Its electrical conductivity was 0.5 dS m^{-1} and its SAR was 0.5. A gated pipe conveyed water to the each furrow, and adjustable spigots controlled inflow rates. A cutback irrigation strategy was employed. Initial irrigation inflows were relatively high at 23 L min^{-1} to move water across the field quickly, then flows were cut back to 15 L min^{-1} to reduce runoff. Irrigations were 8 to 24 hours in duration. The field was irrigated five times during the season.

Furrow inflows and outflows were monitored, and runoff sediment concentrations were measured throughout each irrigation. Measurements were made at one-half hour intervals early in the irrigation, and every hour or every several hours in the later half of the irrigation, after outflows and sediment loads had stabilized. Inflow was measured by filling a known volume, and outflows were measured with v-notch flumes (Trout and Mackey, 1988). Sediment was measured using Imhoff cones (Sojka et al., 1992). Details of the flow and sediment monitoring procedure were given by Lentz et al. (1992).

The study compared three treatments. Control furrow-streams contained no PAM. PAM was applied continuously at 1 mg L^{-1} in a continuous PAM treatment (**C1**), and was applied at 10 mg L^{-1} during the advance phase only in a pulsed-PAM treatment (**I10**). PAM injection in the pulsed treatment was curtailed at an average 111 min after the irrigation began, ie. shortly after the end of the advance phase, and untreated water was used for the remainder of the irrigation set. PAM stock solutions, prepared one to two days prior to the irrigation (Lentz and Sojka, 1996), were metered into the head of each furrow with positive displacement pumps. Turbulence created by the incoming water stream mixed and dispersed the aqueous PAM concentrate into the flow.

Three runoff samples were collected from each furrow during an irrigation. Samples were taken from outflow monitoring flumes. Runoff nutrient content was not determined for the last irrigation. Since 97% of the field's sediment losses occurred in the first four irrigations, we believed nutrient losses produced by the final irrigation were also very small. One runoff sample was collected at 1 to 2 h into irrigation, a second at 5 to 6 h, and the third at 8 to 10 h into the irrigation. Samples were analyzed for total-P (Greenberg et al., 1992), ortho-P (Watanabe and Olsen, 1965), chemical oxygen demand, COD (American Public Health Association, et al., 1971), and NO_3-N (2.0 mM potassium benzoate eluent and liquid ion chromatography). Runoff samples were stored in a refrigerator for <8 days before being analyzed.

The experimental design was a complete randomized block, with three replications. Furrow infiltration and field loss calculations were made with the computer program, WASHOUT (Lentz and Sojka, 1995). The program integrated runoff and pollutant losses over the duration of the irrigation. Net infiltration was calculated as the difference between total inflow and total outflow. Total nutrient and COD losses were computed assuming that runoff constituent concentrations were constant between sampling intervals. Treatment means were compared using the Duncan multiple range test (Snedecor and Cochran, 1980).

3 Results and discussion

The **C1** and **I10** PAM treatments influenced both material concentrations and hydraulic characteristics of the furrow streams. PAM's significant impact on total field-loss values reflected the combined effect of these factors.

Net infiltration for **C1** was 1.5 times that of control furrows and net infiltration for **I10** was 1.3 times that of control values (Table 1). Therefore, runoff from PAM-treated furrows was smaller than that of the control furrows. On average, the outflow rate of PAM-treated furrows was 37% less than that for control furrows (Table 1). By reducing runoff, PAM applications decrease field soil and nutrient losses, assuming furrow-stream material concentrations remained unchanged, or decline.

	Control	**I10**	**C1**
Mean Outflow (L/min)	8.9 a†	5.9 b	5.3 b
Total Outflow (mm)	44 a	30 b	22 c
Net Infiltration (mm)	49 c	63 b	71 a

† similar letters across rows indicate nonsignificant differences ($P < 0.05$).

Table 1: Outflow and infiltration values, averaged over all irrigations.

PAM applications reduced concentrations of sediment, ortho-P, total-P, and COD in furrow runoff (Table 2). Runoff nitrate concentrations did not differ among treatments. Runoff ortho-P and total-P concentrations in control furrows were 5 to 7 times that of the PAM-**I10** treatment, and control COD levels were 4 times those of the PAM-**I10** treatment (Table 2). Material concentrations in PAM-**I10** furrows were about one-half those of PAM-**C1**.

Thus, PAM treatments both decreased furrow outflows and, with the exception of NO_3-N, reduced furrow-stream pollutant concentrations. The combined effect decidedly reduced material field losses.

Total soil loss for the five irrigations was 3.14 Mg ha^{-1} for control furrows, 0.35 for PAM-**C1**, and 0.25 for the PAM-**I10** treatments. That is, PAM-**I10** reduced total soil loss 92%, and PAM-**C1** 89%, as compared to control furrows. When computed on a per irrigation basis, soil-loss reduction for the PAM-**I10** treatment was 91% vs. 85% for PAM-**C1** (Fig. 1D). The per-irrigation **C1** value was smaller than the total-season value because PAM-**C1**'s control of soil erosion was less consistent among irrigations than that of PAM-**I10**.

Runoff component	Control	I10	C1
Ortho-P (mg/L)	0.43 a†	0.09 c	0.20 b
Total-P (mg/L)	0.88 a	0.12 b	0.24 b
NO3-N (mg/L)	0.05 a	0.07 a	0.06 a
COD (mg/L)	119.7a	31.5 b	88.5 a
Sediment (mg/L)	1800 a	300 b	500 b

† similar letters across rows indicate nonsignificant differences ($P < 0.05$).

Table 2: Mean material concentration in furrow runoff

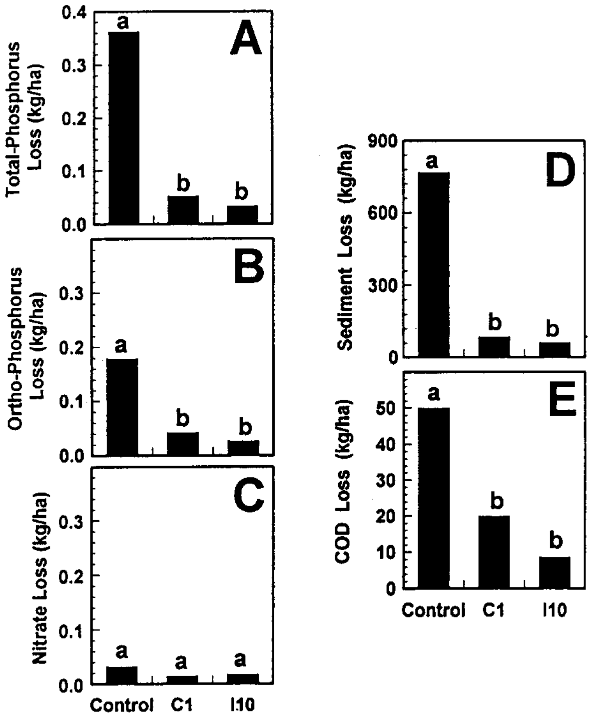

Fig. 1: Total-P (A), ortho-P (B), NO3-N (C), sediment (D), and COD (E) losses per irrigation from nontreated and continuous 1 mg L-1 (C1) and pulsed 10 mg L-1 (I10) PAM-treated furrows. In each graph, columns with common letters do not differ (P=0.05)

Total-P and COD losses from the first four irrigations were 60 to 91% lower from PAM-treated furrows than from control furrows (Figs. 1A, 1B, 1E). Total NO_3-N losses from all furrows was uniformly low. Total NO_3-N losses from PAM-treated furrows were one-half that of controls, although the difference was significant at P = 0.24 (Fig. 1C). Again, **PAM-I10** most effectively reduced total nutrient losses. Relative to controls, the **PAM-I10** application reduced total-P losses by 89% vs. 83% for **PAM-C1**, and reduced total COD losses by 83% vs. 60% for **PAM-C1** (Fig. 1).

4 Conclusions

1. PAM additions to furrow inflows substantially reduced furrow-irrigation field-losses of sediment, total-P, ortho-P, and organic matter, compared to untreated furrows.
2. The most effective treatment for reducing sediment and nutrient losses was **PAM-I10**, where 10 mg L^{-1} PAM was metered into furrow irrigation inflows during the furrow advance (during water's initial advance down furrow). **PAM-I10** reduced total field losses of sediment by 92%, total-P by 91%, ortho-P by 86%, and organic matter (COD) by 83%, compared to untreated furrows.
3. The PAM treatment reduced field losses by decreasing material concentrations in runoff and by reducing runoff volume. PAM accomplished the latter by maintaining higher net infiltration rates in treated furrows than was present in nontreated furrows.

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Addresses of authors:
R.D. Lentz
R.E. Sojka
C.W. Robbins
USDA-ARS
Northwest Irrigation and Soils Research Laboratory
3793 N. 3600 E.
Kimberly, ID 83341, USA