Sediment Pond Effectiveness for Removing Phosphorus from PAM-Treated Irrigation Furrows

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Abstract. *Polyacrylamide (PAM) greatly reduces erosion on furrow-irrigated fields and sediment ponds can be constructed to remove suspended sediment from irrigation runoff. Both practices are approved for reducing phosphorus (P) loading in the Lower Boise River Pollution Trading Project in southwest Idaho, but information is not available about using both practices on the same field. The objective of this study was to measure the combined effects of PAM application and sediment ponds on sediment and P losses from a furrow-irrigated field. Small sediment ponds (5.8 m²) with a 60-min design retention time were installed on two fields to receive runoff from PAM-treated or control furrows. Pond inflow and outflow were monitored during a total of 11 irrigations on the two fields. Three crop years of data showed that applying PAM to furrows reduced sediment and total P mass transport to the ponds 50% to 80%, which reduced the mass of sediment and total P retained in the ponds. However, PAM application did not change the percentage of sediment (86%) and total P (66%) retained. The PAM-sediment pond combination reduced average total P loss by 86% to 98%, based on the difference between untreated inflow and PAM-treated outflow. PAM and sediment ponds had little or no effect on dissolved reactive P (DRP) concentrations. The mass of DRP retained in sediment ponds was directly related to the amount of water that infiltrated within the ponds. Applying PAM to irrigation furrows and installing sediment ponds at the end of the field can be an effective combination for reducing sediment and total phosphorus losses from furrow-irrigated fields, but these practices only reduced soluble P losses by decreasing the volume of water that ran off the fields.*

Keywords. Furrow irrigation, Sediment pond, Phosphorus, Polyacrylamide.

Runoff from surface-irrigated fields contains sediment and nutrients that can impair the water quality of receiving streams, lakes, and rivers. Most of the phosphorus (P) in runoff from row-crop fields is associated with eroded sediment. On fields with minimal erosion, greater than 90% of the P can be dissolved in runoff water (Berg and Carter, 1980).

Sediment ponds effectively remove suspended sediment, along with the attached particulate P, from furrow irrigation runoff. Suspended material settles as water slowly flows through a pond. Brown et al. (1981) measured that a 0.34-ha sediment pond removed 65% to 76% of the sediment and 25% to 33% of the total P over five years. Pond retention time was 2.7 h. Robbins and Carter (1975) found that a small sediment pond (0.4 ha) removed 85% of the sediment from irrigation return flow when the inflow sediment concentration was greater than 1000 mg L^{-1}.

Applying small amounts of high molecular weight, water soluble, anionic polyacrylamide (PAM) is extremely effective for controlling furrow irrigation erosion. Unlike sediment ponds, PAM stops erosion from occurring rather than removing eroded sediment after it flows from the field. Applying 10 mg PAM L^{-1} in irrigation water as it advances down the furrow can reduce soil erosion by more than 90% compared to untreated furrows (Lentz et al., 1992; Sokja and Lentz, 1997; Trout et al., 1995). PAM application can also reduce total and soluble phosphorus loss in furrow irrigation runoff (Lentz et al., 1998). The success of this practice led the Natural Resources Conservation Service (NRCS) to adopt a conservation practice for anionic PAM application for erosion control (NRCS, 2001).

A pollution-trading project has been established for the Lower Boise River Basin in southwestern Idaho to assist point and nonpoint sources with meeting phosphorus Total Maximum Daily Load (TMDL) requirements. The project allows landowners to trade phosphorus credits that exceed the required reductions for their land. Landowners earn phosphorus credits by using best management practices (BMPs), such as converting from furrow irrigation to sprinkler or drip irrigation, installing sediment ponds, using conservation tillage, or applying PAM to furrow-irrigated fields. The ability of a BMP to reduce total P loss from irrigated land was assigned based on its ability to reduce sediment loss; reducing sediment by 1000 kg would reduce total P by 1 kg. Previous research has documented the effectiveness of many conservation practices. However, little information exists about the effectiveness of combined practices. Therefore, the objective of this study was to determine the combined effectiveness of PAM application and sediment ponds for reducing sediment and P losses from furrow-irrigated fields. Results from this study will be used for future adjustments in phosphorus credits for the Lower Boise River pollution-trading program.

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MATERIAL AND METHODS

Inflow and outflow were measured on small sediment ponds constructed on two fields in 2001 and one field in 2002 at the Northwest Irrigation and Soils Research Lab (Kimberly, Idaho). Both fields were Portneuf silt loam (coarse-silty, mixed superactive, mesic *Durinodic Xeric Haplocalcids*). Field 1 was planted to spring wheat (*Triticum aestivum* L.) in 2001 and dry bean (*Phaseolus vulgaris* L.) in 2002. This field was 120 m long with 1.3% slope. Field 2 was planted to dry bean and was only monitored in 2001. Field 2 was 180 m long and furrow slope was 1.5%. We monitored the first three of five irrigations on field 1 in both 2001 and 2002 and all five irrigations on field 2 in 2001.

Each field had six sediment ponds. Three ponds received runoff from PAM-treated furrows and three received runoff from untreated furrows in a randomized complete block design. Runoff from five furrows (0.76-m spacing) flowed into each pond on the spring grain field in 2001 and four furrows (1.12-m spacing) for dry bean fields in 2001 and 2002. Sediment ponds were designed with 4:1 length-to-width ratio and 60-min retention time (Idaho NRCS, 1999). Pond design was an iterative process of selecting a width and calculating the length and depth. Pond inflow rates were estimated from typical furrow runoff rates for these fields. Pond depth was calculated as the depth required to contain the inflow rate in the pond of a given width and length for 60 min. The resulting sediment pond design was 1.2 m wide, 4.8 m long, and 0.6 m deep (3.5 m^3). Sediment ponds were roughly constructed with a backhoe and then uniformly sized by hand.

The irrigation water source was the Snake River (sodium absorption ratio <1, electrical conductivity <0.5 dS m^{-1}). Furrow inflow was supplied by siphon tubes from a concrete ditch on field 1 and by gated pipe on field 2. Inflow rates were measured by recording the time required to fill a known volume (4-L bucket). Equal inflow rates were set for both PAM and control furrows. We did not attempt to compensate for the increased infiltration that would likely occur from applying PAM.

Granular PAM (10 to 20 g) was applied at the inflow end of each PAM-treated furrow immediately before each irrigation. The PAM was spread over approximately 0.5 m of furrow soil so it would slowly dissolve as water flowed over the area during irrigation. The PAM was a high molecular weight (12 to 15 Mg mol^{-1}), water soluble, anionic (18% charge density) polyacrylamide.

Small trapezoidal flumes were installed to measure pond inflow and outflow. We measured flow rate and collected water samples at 15-, 30-, and 60-min intervals after water began to flow into the pond and 15-, 30-, and 60-min intervals after water flowed from the pond. Samples were collected at 2- to 3-h intervals during the remaining irrigation time. Total irrigation time was 12 to 24 h. Once outflow began, pond inflow samples were collected every time outflow samples were collected. Sediment concentration was measured by pouring a 1-L water sample into an Imhoff cone and reading the volume of settled sediment after 30 min (Sojka et al., 1992). Two, 50-mL water samples were collected for phosphorus analysis. One sample was filtered in the field (0.45 micron) within 15 min of collection, stabilized with 0.5 mL of H_3BO_3, and refrigerated until analysis for dissolved reactive P (DRP) (Murphy and Riley, 1962). The second sample was unfiltered and refrigerated until analysis for total P by persulfate digestion (American Public Health Association, 1992).

Flow rates were integrated with time to calculate flow volume into the furrows, into the ponds, and out of the ponds. Infiltration volume was calculated by subtracting outflow from inflow for the field and the ponds. Sediment and phosphorus loads were calculated by multiplying sample concentrations by the flow volume that occurred during the time interval between sample collection. The retention percentage in a pond was calculated by dividing the mass of sediment or phosphorus retained in the pond by the total mass that flowed into the pond. Retention time was calculated by pond volume (3.5 m^3) divided by the average flow rate through the pond. Flow-weighted concentrations were calculated by dividing the total mass load by the total flow for an irrigation.

A randomized complete block design was used with two treatments and three reps. Paired T-tests were used for statistical comparisons between treatments ($P < 0.05$). Total mass or flow-weighted concentration for each pond and irrigation were used for statistical comparisons for each field-year. Values reported in tables are annual averages of values from each pond and each irrigation.

RESULTS AND DISCUSSION

Furrow inflow volume was not different between PAM-treated and control furrows (data not shown). PAM treatment increased infiltration on both dry bean fields, resulting in significantly less inflow into these sediment ponds. However, PAM did not increase infiltration within the ponds (table 1). Average retention time in both PAM and control sediment ponds exceeded the design criteria of 60 min for all three field-years. Longer retention time should allow more sediment to settle in the ponds or allow smaller ponds to be used. The longest retention times occurred during the first irrigation each year, when pond inflow rates (i.e. furrow runoff rates) were the lowest. Retention times were 40% to 60% longer in ponds with flow from PAM-treated furrows than from control furrows (table 1), because PAM-treated furrows had slower pond inflow rates due to greater infiltration on the field. Increased retention times were not caused by greater infiltration within the ponds (table 1). Sediment deposition also had a minor influence on retention time. Assuming a bulk density of 1.3 g cm^{-3} for the deposited sediment, 100 kg of sediment would reduce pond volume by only 2.2%, which was the approximate difference in retained sediment between the control and PAM ponds for field 1 dry bean in 2002 (table 1).

Applying PAM to irrigation furrows greatly reduced erosion, which significantly reduced the concentration of sediment flowing from the PAM-treated furrows into the ponds (table 2). Reduced sediment concentrations and inflow volume consequently reduced the mass of sediment flowing from PAM-treated furrows into ponds (table 3). Total P mass and concentration followed similar trends as sediment mass and concentration. The mass of total P retained in the ponds was directly related ($R^2 = 0.95$) to the mass of sediment retained (total P [g] = 0.0010*sediment [g] − 0.082). According to this relationship, the average total P concentration of the sediment trapped in the ponds was about

Table 1. Average retention time, pond inflow volume and water, sediment and phosphorus retention in sediment ponds.[I]

	n[a]	Retention Time (min)	Pond Inflow (m³)	Pond Infiltration (m³)	Pond Infiltration (%)[b]	Sediment Retention (kg)	Sediment Retention (%)	Total P Retention (g)	Total P Retention (%)	DRP Retention (g)	DRP Retention (%)
2001 Spring Wheat, Field 1											
Control	9	75	39	17	40	8.5	75	5.2	47	0.37	22%
PAM	9	103	28	13	46	1.1	87	0.7	36	0.55	37%
		*[c]	ns	ns	ns	*	ns	*	ns	ns	*
2001 Dry Bean, Field 2											
Control	15	97	28	4.4	22	95	87	98	76	0.29	19%
PAM	15	158	15	6.6	53	19	88	20	84	0.74	61%
		*	*	ns	*	*	ns	*	ns	*	*
2002 Dry Bean, Field 1											
Control	9	69	58	31	52	180	94	188	88	3.3	48%
PAM	9	108	46	28	57	87	79	95	45	2.8	47%
		*	*	ns	ns	*	ns	*	ns	ns	ns

[a] Number of values averaged (irrigations × reps).
[b] Retention percent is the average of the percentages for each pond during each irrigation.
[c] * and ns indicate significantly different and not significant, respectively, at P < 0.05 based on paired T-test comparison between control and PAM.

1000-mg P kg^{-1} sediment, which matches the assumption used for the Lower Boise River Pollution Trading Program.

The mass of sediment and total P flowing into the ponds was reduced 50% to 80% by applying PAM (table 3), which significantly reduced the sediment and total P masses trapped in the ponds (table 1). Although less sediment was trapped, the mass of sediment in pond outflow was similar or less when PAM was applied to furrows (table 3). Reduced sediment load into ponds should increase the effective life by increasing the time between pond cleaning and decrease the gradual decline in effectiveness caused by reduced retention time as the pond fills with sediment.

The retention percentages of sediment and total P in ponds were not significantly different between PAM and control (table 1). For field 1 dry bean in 2002, average total P retention was 88% for the control and only 45% for the PAM treatment. The low value for the PAM treatment was caused by negative retention percentages for two ponds during the first irrigation when total P load into the ponds was very low. Less than 1 g of total P was measured in pond inflows while pond outflows were 1.3 to 1.8 g, thus retention percentages were negative. Inflow total P loads ranged from 20 to 425 g for the other two irrigations on this field. Eliminating the two

negative values increased the average retention from 45% to 89%. The average retention percentages for both treatments during the eight irrigations on the two dry bean fields was 87% for sediment and 75% for total P. Average sediment retention percentages in ponds on the wheat field were 75% for control and 87% for PAM, however, average total P retentions were only 47% for control and 36% for PAM (table 1) because a greater percentage of the total P from the wheat field was dissolved P, which was not reduced by removing sediment in a pond. On average, sediment ponds trapped 86% of the sediment and 66% of the total P for the three field-years.

Sediment and total P loading to the ponds was considerably less for the spring wheat compared to the dry bean (table 3) because furrow erosion was less for the close-seeded wheat crop compared to a dry bean row crop. Flow-weighted sediment and total P concentrations were about an order of magnitude less for the wheat than the dry bean (table 2). DRP loads and concentrations, however, were similar between wheat and bean (tables 2 and 3). Thus, a greater percentage of the total P in pond inflow (i.e. field runoff) from the wheat field was dissolved (DRP), and there was less particulate P to settle in the ponds. While PAM treatment did not affect DRP

Table 2. Average flow-weighted sediment, total P, and DRP concentrations flowing into and out of sediment ponds.

Treatment	Sediment Inflow (mg L^{-1})	Sediment Outflow (mg L^{-1})	Total P Inflow (mg L^{-1})	Total P Outflow (mg L^{-1})	DRP Inflow (mg L^{-1})	DRP Outflow (mg L^{-1})	DRP/Total P[a] Inflow (%)	DRP/Total P[a] Outflow (%)
2001 Spring Wheat, Field 1								
Control	431	128 *[b]	0.34	0.25 ns	0.05	0.06 *	25%	33% *
PAM	90	25 ns	0.08	0.09 ns	0.06	0.07 *	81%	89% ns
	*[c]	*	*	*	ns	ns	*	*
2001 Dry Bean, Field 2								
Control	3800	590 *	4.6	1.20 *	0.07	0.07 ns	2%	8% *
PAM	1300	150 *	1.6	0.47 *	0.08	0.07 ns	13%	33% *
	*	*	*	*	ns	ns	*	*
2002 Dry Bean, Field 1								
Control	2900	490 *	3.3	0.69 *	0.08	0.08 ns	3%	13% *
PAM	1400	320 *	1.5	0.43 *	0.08	0.09 ns	20%	35% ns
	*	ns	*	ns	ns	ns	*	ns

[a] DRP/Total P ratio is the average of the ratios for each pond during each irrigation.
[b] Paired T-test comparison between inflow and outflow with * and ns indicating significantly different and not significant, respectively, at P < 0.05.
[c] Paired T-test comparison between control and PAM with * and ns indicating significantly different and not significant, respectively, at P < 0.05.

Table 3. Average sediment, total P, and DRP mass flowing into and out of sediment ponds.

	Sediment		Total P		DRP	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Treatment	(Mg ha^{-1})	(Mg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
2001 Spring Wheat, Field 1						
Control	0.75	0.19*[a]	0.73	0.37 *	0.12	0.10 ns
PAM	0.10	0.02 *	0.15	0.11 ns	0.11	0.07*
	*[b]	*	*	*	ns	ns
2001 Dry Bean, Field 2						
Control	6.82	0.92 *	7.64	1.57*	0.14	0.12*
PAM	1.20	0.05 *	1.36	0.14*	0.09	0.04*
	*	*	*	*	*	*
2002 Dry Bean, Field 1						
Control	11.41	1.35 *	11.63	1.17*	0.33	0.14*
PAM	5.38	0.54 ns	5.93	0.64*	0.26	0.11*
	*	ns	*	ns	*	ns

[a] Paired T–test comparison between inflow and outflow with * and ns indicating significantly different and not significant, respectively, at P < 0.05.
[b] Paired T–test comparison between control and PAM with * and ns indicating significantly different and not significant, respectively, at P < 0.05.

concentrations in pond inflow, it did reduce erosion and the associated particulate P flowing into the ponds. Thus, PAM increased the proportion of DRP relative to total P in pond inflow for all three field-years (table 2). DRP was almost 80% of the total P flowing into the sediment ponds from PAM-treated furrows on the wheat field compared to 2% to 3% DRP for control furrows on the dry bean fields (table 2).

Sediment ponds significantly reduced sediment and total P losses from control furrows for all three field-years and from PAM furrows for all field-years except 2002 dry bean on field 1 (P = 0.07) (table 3). Ponds also reduced flow-weighted sediment and total P concentrations for the two dry bean fields (table 2). DRP concentrations, however, were not changed by sediment ponds except for a slight (0.01 mg L^{-1}) but statistically significant concentration increase in ponds on the wheat field (table 2).

PAM did not affect flow-weighted DRP concentrations of water flowing into or out of the sediment ponds (table 2). The mass of DRP that flowed into ponds was directly related to the volume of water that flowed into the ponds from the wheat ($R^2 = 0.96$) and dry bean ($R^2 = 0.97$) fields (data not shown). The mass of DRP retained in sediment ponds was directly related to the volume of water that infiltrated in the ponds (fig. 1). The linear relationships for dry bean on fields 1 and 2 were not significantly different. However, the linear regression for the wheat was significantly different (P < 0.001) from the combined regression for the dry bean. The greater regression slope for ponds on dry bean fields indicates a greater DRP concentration than on the wheat field. In other words, more DRP infiltrated with given volume of water in ponds on the dry bean fields. On a relative basis, the proportion of DRP retained in a sediment pond essentially equaled the proportion of pond inflow that infiltrated within the pond (fig. 2). Thus, the main mechanism for reducing dissolved P in these sediment ponds was DRP infiltrating with water. Net sorption or desorption of P was evidently minimal in sediment ponds during the retention times represented in this study. The percent of total P retained in sediment ponds was not related to pond infiltration ($R^2 = 0.03$).
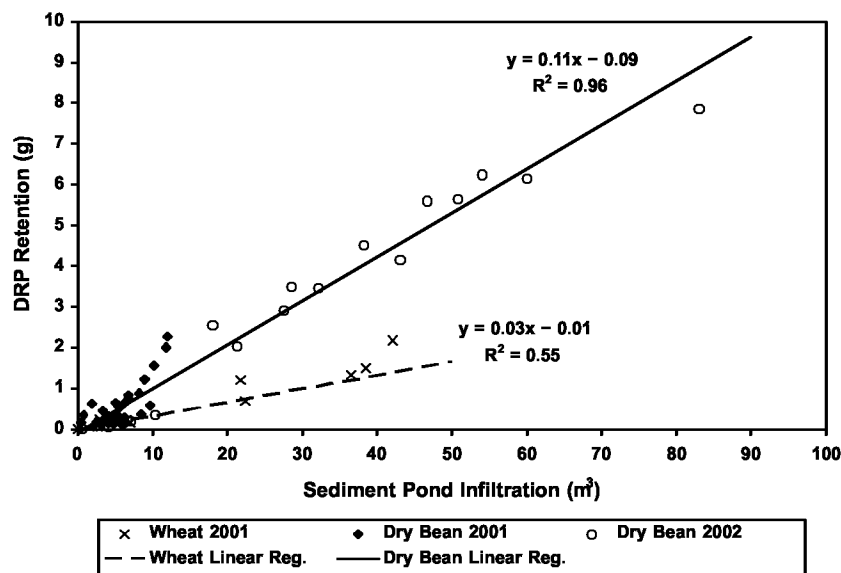

Figure 1. Relationships between infiltration within sediment ponds and DRP mass retained in sediment ponds.
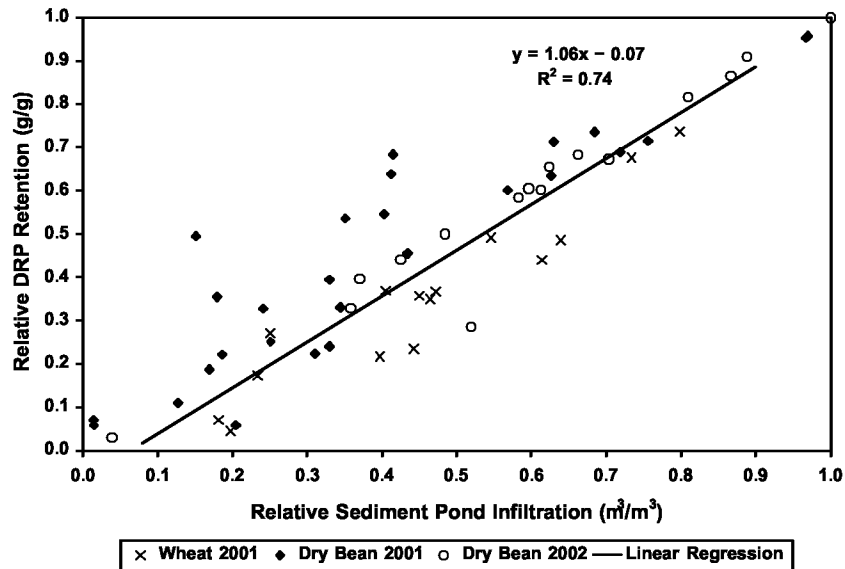
Figure 2. Relationship between the relative amount of pond inflow that infiltrated within sediment ponds and the relative DRP mass retained in sediment ponds.

The combined effect of PAM and sediment ponds was evaluated by comparing pond inflow from control furrows to pond outflow from PAM-treated furrows. Mass transport of sediment was reduced 95% to 99% and total P was reduced 86% to 98% by these two practices (table 3). The combined effect on DRP mass was only 39% to 71%. Combined reductions for DRP mass were less because DRP concentrations were not reduced by either PAM or sediment ponds. Using 2001 dry bean as an example, PAM reduced sediment inflow by 82% and the pond reduced sediment outflow by another 96% for a combined sediment load reduction of 99% (table 3). Total P reductions were similar with 82% from PAM and 90% from the pond for a combined reduction of 98%. DRP mass was only reduced 38% by PAM and 53% by the pond (due to increased infiltration) for a combined reduction of 71% (table 3).

CONCLUSION

PAM reduced sediment and total P losses from irrigation furrows by 50% to 80% by both reducing soil erosion and increasing infiltration. This reduced the loading into the sediment ponds, thereby reducing the mass of sediment and total P retained in the ponds. However, the percentages of sediment and total P retained were not different between PAM and control. The average retention percentages across both treatments were 86% for sediment and 66% for total P for the three field years. The combined effect of PAM and sediment pond treatments reduced mass transport of sediment 95% to 99% and total P 86% to 98%. PAM and sediment ponds had little or no effect on DRP concentrations. The mass of DRP retained in sediment ponds was directly related to the amount of water that infiltrated within the ponds. Applying PAM to irrigation furrows and installing sediment ponds at the end of the field were an effective combination for reducing sediment and total P losses from furrow-irrigated fields, but these practices only reduced DRP losses by decreasing the volume of water that ran off the fields.

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