Polyacrylamide Decreases Furrow Erosion

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Abstract

Erosion from furrow irrigated land is a serious problem in southern Idaho and several other areas. Polyacrylamide, a very long chain polymer, increases aggregate stability and flocculates suspended sediments. It thus can potentially reduce furrow sediment detachment and transport. Recirculating infiltrometer studies showed that 0.5 kg/ha/irrigation of polyacrylamide applied with the irrigation water can dramatically reduce furrow erosion.

Introduction

Soil erosion from furrow irrigated land is a serious problem in several areas of the Western U.S. A USDA-Soil Conservation Service survey indicated 3.2 million ha, 21% of the irrigated cropland, are affected by erosion to some degree (Koluvek et al. 1993). Annual soil loss of 5 to 50 t/ha (0.6 to 6 mm soil depth) from furrow-irrigated fields threatens the sustainability of profitable agricultural production (Koluvek et al. 1993, Carter 1993). Eroded sediments also fill drains, river channels and reservoirs. Sediment in irrigation return flows causes serious degradation of water quality in several western rivers such as the Yakima in Washington and the Snake in southern Idaho. Regulation of irrigation return flow water quality is likely in the near future.

Polyacrylamide (PAM) is a high molecular weight, long chain polymer. Characteristics such as chain length (molecular weight) and degree of cross-linkage and type and density of associated charges are varied to produce polymers with varying performance qualities. PAM is used as a flocculating agent in several industrial processes, including food processing and wastewater treatment, and thus is widely available and relatively economical (about $2.50/kg). PAM

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was first researched and marketed as a soil conditioner about 30 years ago as a product called Krilium. That product proved uneconomical because of the large quantities required. Recent laboratory studies using new products and application techniques have shown PAM used in economical quantities can increase soil infiltration rates and reduce erosion (Helalia and Letey 1988, Shainberg et al. 1990, Wallace and Wallace 1986, Wallace et al. 1986, Mitchell 1986).

Furrow erosion occurs when the shear exerted by flowing water detaches and transports soil particles (Trout and Neibling 1993). The stability of soil aggregates determines their erodibility. Because furrow erosion occurs at the furrow surface, only the wetted perimeter need be treated, greatly reducing the PAM requirement compared to broadcast application and incorporation. Small concentrations of PAM can be applied in the irrigation water, reducing application costs. Water-applied PAM provides the additional benefit of flocculating sediments in the flowing water which effectively reduces their transportability and increases their tendency to deposit in the furrow.

The USDA-ARS in Kimberly, Idaho began polyacrylamide research for furrow erosion reduction in 1991. Two years of field studies have been carried out to determine the best application strategies and materials. Lentz et al. (1992) found that injection of 5 to 10 mg/L of a high molecular weight, moderately anionic PAM into the irrigation water during furrow stream advance reduced sediment yield by 70 to 99%. In the following irrigation, with no additional PAM application, sediment yields were still reduced 40 to 60%. By the fourth irrigation, residual treatment effects were small. PAM-starch copolymers at the same concentrations produced small effects (20% erosion reductions) the first irrigation, but moderate effects (30% reductions) the second irrigation. PAM treatments also resulted in an average 30 to 40% increase in infiltration.

The objective of this research was to study the effects of water-applied PAM on erosion and sediment transport under the controlled field conditions provided by a recirculating blocked-furrow infiltrometer. The studies were carried out on a Portneuf silt loam soil which has very low aggregate stability and is highly erodible.

Methodology

Three series of tests were carried out in 1992 on Portneuf silt loam soils. Series 1 was conducted on an established corn field following cultivation. Series 2 and 3 were conducted on previously unirrigated furrows on a fallow field in which grain stubble had been recently disked and plowed under. Both fields had 1.1% slopes in the furrow direction.

Irrigation was applied to 6-m long test furrow sections with a recirculating blocked-furrow infiltrometer (Blair and Trout 1989). This device uses a small centrifugal pump in a sump to continually recycle the runoff from the furrow section back to the upper end of the section. A downstream weir maintains near normal flow depth in the furrow section and a mariotte syphon supply tank maintains a constant water volume in the recycling system. The decreasing tank water level, recorded with a pressure transducer and data logger, is directly related to the infiltration rate in the furrow section. The system continually recycles all sediment in the runoff through the furrow section such that, if erosion is sufficient, the sediment concentration eventually reaches the transport capacity of the flow. Initial inflow rate to the furrow sections was low (about 6 L/min) so that the water advanced through the sections in about 2 minutes (3 m/min). Inflow rates were then increased to 18 L/min for series 1 and 2 and 23 L/min for series 3.

In series 1 and 2, 20 L of a 10 mg/L solution of Magnifloc 836A[2] (Cyanamide Corp., Wayne, NJ), a medium-charge (20% hydrolysis) anionic PAM with a high molecular weight ($MW = 10^7$), was added to the infiltrometer at the beginning of the test. This volume of water, containing 200 mg of PAM, was usually sufficient to complete advance through the 6 m furrow section. PAM concentration in the recirculating water rapidly decreased as the PAM solution infiltrated and was diluted by water from the supply tank. After one hour of irrigation, an additional 200 mg of PAM was added to the recycling water, which again brought the concentration in the recirculating flow up to about 10 mg/L for a short time.

In series 3, 250 mg of PAM was dissolved in the 500 L supply tank before the beginning of the test, so that the PAM concentration in the irrigation water remained at 0.5 mg/L throughout the test. Infiltrated volumes varied from 300 to 500 liters so total PAM applications varied from 150 to 250 mg.

One liter sediment grab samples of the recycling water were collected 0.25, 0.5, 1, 2, 4 and 8 h after the beginning of each test. For series 1 and 2, 1.25 h samples (0.25 h after the second PAM application) were also collected. The sediment samples were filtered and dried to determine the weight of sediment in each one liter sample.

Each test was carried out on a previously unirrigated non-wheel (uncompacted) furrow section. Treatments were alternated among adjacent furrows and were replicated at least 5 times. The ANOVA procedure of SAS (SAS Institute Inc. 1988) was used to test for sediment concentration differences between untreated (control) and treated furrows in each series.

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[2] Use of trademarks, proprietary products, or vendors does not constitute a guarantee or warranty of the product by the USDA-ARS and does not imply its approval to the exclusion of other products or vendors.

Results

The PAM treatments greatly reduced the average sediment concentration in the recirculating furrow flows in all three series of tests (Table 1). For all series, sediment concentration during the initial hour of the tests (0.25, 0.5 and 1 h samples) averaged 2100 mg/L for the PAM treatments and 7000 mg/L for the control furrows (untreated), a reduction of 70%. In spite of the very high variability, treatment differences were statistically significant for series 1 and 2. In four cases in which treated furrows had high sediment loads (series 1, replications 1 and 3; and series 3, replications 3 and 4), a head cut was observed in the furrow. As the head cuts migrated upstream, they eroded through the treated surface soil layer and produced a large amount of sediment.

Several of the control furrows in series 2 had little erosion and low sediment concentrations. As a result, furrow flow rates were increased to 23 L/min for series 3 runs to increase the erosiveness. This resulted in doubling the average control furrow sediment concentrations. It also made it impossible to directly compare series 2 and series 3 treatment effects.

Table 1. Average Sediment concentration (mg/L) during the initial hour for individual runs.

Replic. No.	-- Series 1 --		-- Series 2 --		--Series 3 --	
	Control	Treated	Control	Treated	Control	Treated
1	3937	3165	338	459	4375	639
2	6105	169	7602	2146	15134	714
3	12955	3845	9510	133	5885	8535
4	2599	991	739	999	793	12000
5	9534	882	174	97	8116	255
6			9125	315	1081	4598
7					30611	664
Avg.	7026	1810*	4581	691**	9428	3915
St.Dev.	4226	1597	4610	784	10530	4692

* Significantly different, P = 0.03
** Significantly different, P = 0.07

Sediment concentrations in the control furrows generally began high and decreased with time (Fig. 1). The furrows continuously treated with the 0.5 mg/L PAM solution (series 3) showed the same tendency. However, sediment concentration in the series 1 and 2 furrows treated with 10 mg/L of PAM during advance was low initially but increased after 30 minutes. Apparently, either the stabilizing effects of the PAM decreased with time or the rapid decrease in PAM concentration in the water allowed eroded sediment to remain dispersed and transportable. The second PAM application in these treatments quickly flocculated the moving sediment and maintained low concentrations for the duration of the tests.

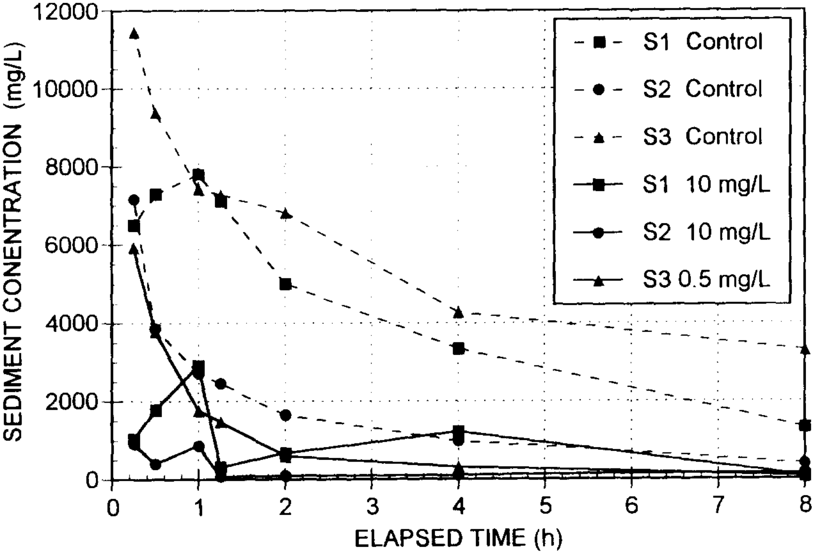

Figure 1. Sediment concentration over time in the recirculating furrow infiltrometer. Points represent the average for all replication for each series (S1-S3).

The high initial and decreasing sediment concentration in furrows has been observed in several field studies (Trout and Neibling 1993). In furrow-irrigated fields, this trend could result from an initial flushing of loose sediment lying in the furrow and that produced by wetting during stream advance. However, in the recirculating infiltrometer, this initial sediment is continually recycled through the furrow. Erosion theory predicts that it requires more energy to initially detach or displace sediment particles than to keep them moving. Consequently, the sediment concentration in the infiltrometer should increase and asymptotically approach the transport capacity of the flow. The decreasing concentration implies that, after a rapid initial increase in sediment transport, there is a net deposition (ie: deposition rate exceeds the erosion rate) and that sediment continues to deposit even though the sediment load is less than the transport capacity. This phenomena can be explained by two processes: 1) the highly variable flow velocity and shear distributions in irregular furrows allows all particles, given enough opportunities, to enter a low velocity eddy and fall to the bed; and 2) the soil water tension that develops at the furrow wetted perimeter (Segeren and Trout, 1991) holds deposited particles in place. These same processes occur under field conditions but their effects are difficult to isolate.

The ARS is continuing PAM research to determine the most economical and effective materials (primarily charge and charge density) and concentrations, and application timing and methods (Lentz et al. 1992, Lentz et al. 1993). We are also exploring the effects of dissolved ions (salts) on PAM effectiveness and the effect of PAM on furrow infiltration (Trout and Lentz 1993). A related application which is being explored, is the use of PAM to increase the efficiency of sediment collection ponds.

One commercial firm in southern Idaho is marketing a PAM product and paddle-wheel powered applicator. The applicator, rotated by the flowing water, meters out a concentrated PAM solution into the field water supply ditch. One problem observed when the water supply contains much suspended sediment, is that the sediment flocculates and settles out in the delivery system and sometimes even plugs the entrance to siphon tubes.

Conclusions

Small concentrations of polyacrylamide in irrigation water can dramatically reduce furrow erosion and sediment loss. PAM stabilizes and reduces the erodibility of soil surface particles, and flocculates small particles which make them more difficult to transport. Tested PAM concentrations amounted to 0.25 to 0.67 kg/ha applications, which would cost less than $1.70 per ha per irrigation. The PAM application can be concentrated early during the irrigation or applied uniformly during the irrigation. This practical and economic process shows great promise to reduce furrow-induced soil erosion.

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