NET INFILTRATION AND SOIL EROSION EFFECTS OF A FEW PPM POLYACRYLAMIDE IN FURROW IRRIGATION WATER

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Furrow irrigation-induced erosion, seal formation, and reduced net infiltration are severe problems in the United States of America (USA) Pacific Northwest. High molecular weight (10^7 g mol^{-1}), anionic (18% charge density) polyacrylamide (PAM) is a potent flocculent. Economical PAM application strategies can reduce seal formation, runoff and erosion in furrow irrigation. Three years of studies verified this for 3 soils. Field slopes were 0.5-7.0%. Furrow lengths were 150-250 m and inflow rates were 12.8-37.8 L min^{-1}. PAM reduced erosion by 43 to 99% for various application strategies using as little as 5 ppm PAM in furrow advance water with renewal of 5 ppm PAM for 5 minutes of each subsequent hour of irrigation. PAM stabilized net infiltration at higher rates by reducing seal formation. PAM increased the lateral wetting extent by 25% and net infiltration by 15% compared to controls. PAM efficacy varied with concentration, duration of furrow exposure, and flow rate. Furrow-bottom crusts of similar soil strength formed in PAM-treated and control furrows, but their associated seals produced different net infiltration.

INTRODUCTION

The energy of water applied at the soil surface disrupts and rearranges soil aggregates and primary particles. Infiltration reducing seals form on furrow bottoms while soils remain wet, and harden into crusts upon drying (Segeren and Trout, 1991). Seals contribute to erosion, low irrigation efficiency, crop yield and quality loss, and nutrient leaching from field heads. The energy of applied water sequentially detaches, disrupts, suspends, and transports aggregates and particles in runoff. Disrupted, transported, and redeposited fines promote surface sealing and crusting, and impair infiltration. In furrow irrigation, where downslope infiltration results in increasingly smaller downstream flows, (the opposite of rain induced rill erosion where streams increase as runoff accumulates) furrow bottom crust and seal formation increases at the lower field reaches as stream carrying capacity decreases. This exacerbates the tendency for upper furrow reaches to be over irrigated while lower reaches, with less net water applied, less infiltration opportunity time, smaller wetted perimeter, and formation of conductivity-reducing seals, tend to be under irrigated (Trout *et al.*, 1990).

Sojka and Carter (1994) identified irrigation induced erosion as a serious threat to sustainability of irrigated agriculture. On erodible soils, or where furrow slope and/or length are high, furrow irrigation is inherently erosive and soil loss can greatly exceed soil loss tolerance (T) (Carter, 1990). In the United States Pacific Northwest, as much as 50.9 Mg ha^{-1} of soil loss has been documented for a single furrow irrigation. Loss of 5-50 Mg ha^{-1} yr^{-1} is common, and can be triple that in upper furrow reaches (Berg and Carter, 1980; Fornstrom and Borelli, 1984; Kemper *et al.*, 1985). Furthermore, much of the fluvial and riparian pollution in Northwestern river basins originates as chemicals adsorbed on sediment from irrigation return flows (Berg and Carter, 1980; Brown *et al.*, 1981).

Soil physical properties have been improved since the 1950's by treating with polyacrylamide (PAM) or related polymers (Azzam, 1980). PAM, however, merely stabilizes existing structure. It does not generate structure (Cook and Nelson, 1986; Shaviv *et al.*, 1987). Compared to controls, PAM-treated soils had lower bulk density (Terry and Nelson, 1986), lower cone indices (Cook and Nelson, 1986; Helalia and Letey, 1989), and higher hydraulic conductivity (El Morsy *et al.*, 1991; Malik *et al.*, 1991; Bryan 1992). This was attributed to PAM's ability to maintain structure (El Morsy *et al.*, 1991), reduce dispersion (Helalia and Letey, 1988), and lessen surface seal formation (Shainberg *et al.*, 1990; Lentz *et al.*, 1992).

When PAM-treating the entire surface 10-30 cm, application rates of 250-500 kg ha^{-1} or more were required for measurable effects. This is cost prohibitive for all but a few uses. In a 3 year study we applied small economical amounts of PAM to furrows via irrigation water. The objective was to prevent soil detachment and transport in irrigated furrows, thereby mitigating erosion and its negative consequences, including seal formation. Much smaller amounts of PAM were expected to be effective since only a few millimeters of soil depth in the wetted perimeter would adsorb PAM from the advancing irrigation stream, and detached solids would flocculate and resist suspension or transport.

MATERIALS AND METHODS

Studies were conducted near Kimberly, Idaho from 1991-93 on fields with slopes ranging from 0.5-7.0% and typical furrow lengths of 150-250 m. Detailed methods were described elsewhere (Lentz *et al.*, 1992; Lentz and Sojka, 1994). Briefly: PAM concentrations in irrigation water ranged from 0.25-20 g m^{-3} (0 g m^{-3} for controls), comparing per irrigation applications ranging from 0 kg ha^{-1} (controls) to 3 kg ha^{-1} for the highest PAM application. Three basic application strategies were used. The first and most common was an initial high load (IH), which involved treating irrigation inflows with 10 g m^{-3} PAM only during furrow advance (the period when water traverses the dry furrow). A second strategy was an initial high-load plus episodic (intermittent) application (IE). This was similar to the IH, but also applied PAM for brief (5-10 min.) episodes (every one to four hours) throughout the irrigation. A third strategy (CL) was the continuous application of low concentrations (0.5 g m^{-3}) of PAM throughout the irrigation period.

Inflows ranged from 12.8-37.8 L min^{-1} and irrigation durations ranged from 8-12 h. Outflows were measured using calibrated flumes and sediment concentrations were estimated using Imhoff cones. Net infiltration was taken to be the difference between total inflow and total outflow. Sediment concentration was determined from 1-litre runoff samples collected at times of outflow readings. Together they provided a weighted sum of sediment loss for the irrigation period. Calculations were made using FUROFIGR, a Pascal program (Lentz and Sojka, 1993). A conservative factor, to relate tailwater sediment loss to seasonal field erosion, was applied to the data (Lentz and Sojka, 1994). Comparisons were made of net infiltration and sediment loss for 43 control and PAM-treated pairs. Data are from irrigations on trafficked, freshly cultivated and shaped furrows. Parameters such as inflow rate, irrigation period, and furrow slope are identical for each control/PAM-treatment pair, but may differ between pairs. Data were grouped by application strategies for comparison.

Water electrical conductivity (EC) ranged from 0.1-0.5 dS m^{-1} and Na adsorption ratio (SAR) ranged from 0.4-0.7. Studies were in randomized blocks using untreated irrigation water (controls) or PAM-treated water in a given furrow in each block with 3-6 replications of each block. Water application times and amounts were the same for controls and PAM-treated furrows for a given irrigation. Studies were conducted on three semi-arid silt loam soils with similar epipedons: Portneuf (Durixerollic Calciorthids), Power (Xerollic Haplargids), and Purdam (Haploxerollic Durargids). The PAM was anionic (18% hydrolysis, 15 Mg mol^{-1}), marketed by Cytec (Wayne, NJ, USA) as "Magnifloc 836A" and "836A Superfloc". In 1991 the effect of PAM and a starch copolymer on lateral extent of surface wetting (24 h post irrigation) was measured (see Lentz *et al.*, 1992). In 1993 surface crust strength in control and PAM-treated furrow bottoms were measured approximately weekly in one study using a "Geotester" penetrometer (Italy) with a 0.64 cm diameter flat tip inserted to 0.64 cm depth. Crust strengths were measured for 7 irrigation cycles prior to irrigation, at 2 mid-field positions (3 probes/position), in 4 furrows/treatment.

RESULTS AND DISCUSSION

Net infiltration

Mean net infiltration across all comparisons for the 3 years was 30.3 mm per irrigation for controls and 35.0 mm per irrigation for PAM-treated furrows (Figure1). Net infiltration varied from year to year depending on the duration of irrigations required in each year's irrigation management regimen. Average net infiltration increased for PAM-treated furrows in 35 of 43 replicated PAM-treatment comparisons. Trout and Mackey (1988) demonstrated high

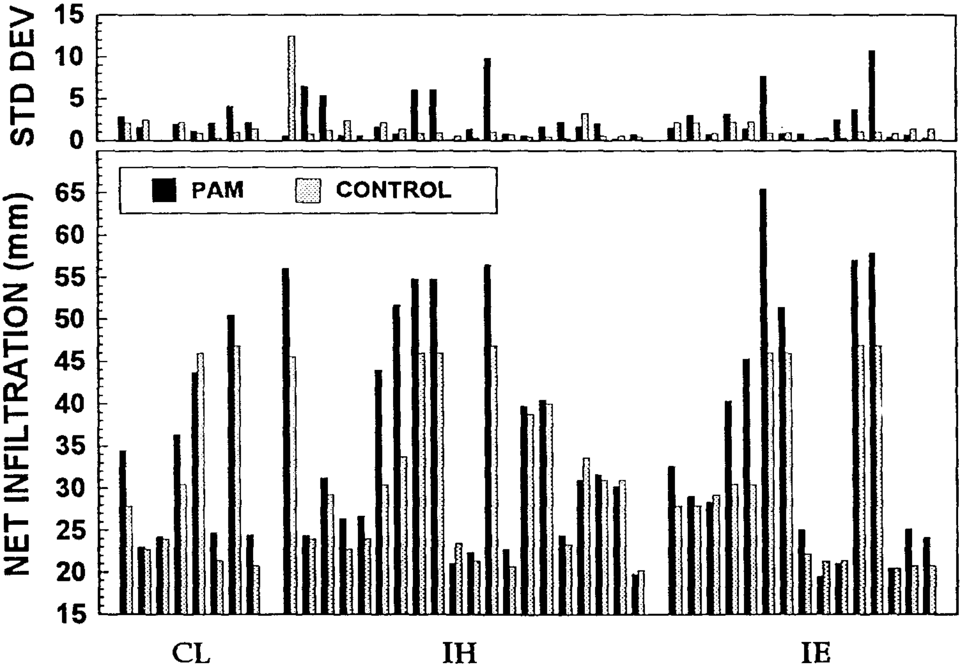

Fig. 1 Net infiltration per irrigation for control and PAM-treated pairs. Data are from trafficked, newly cultivated and shaped furrows. Inflow rate, irrigation period, and furrow slope are identical for each control/PAM-treatment pair, but differ among pairs. Treatments (CL, IH, & IE) are as in materials and methods.

variability for net infiltration measurement due both to high variability in the technique and intrinsic variability of soil properties governing infiltration. Furthermore in evaluating PAM/Control comparisons of both net infiltration and sediment-loss effects, it should be emphasized that several PAM application strategies compared and summarized were sub-optimal. In some instances this was by design, to help discriminate performance differences. There was also an evolution of application tactics as our knowledge base improved.

The extent of lateral wetting on the soil surface between furrows increased ($P \leq 0.05$) 37% with the 10 ppm PAM treatment. A similar result was seen with the starch copolymer (27%). The copolymer had less effect than PAM on reducing sediment loss (20 vs 45%, respectively). Improved net infiltration and lateral wetting have practical significance for irrigation management by reducing the duration and volume of water needed to wet the seed zone, while reducing runoff and leaching potential in upper field reaches.

Both increased net infiltration and wetting extent were partly attributed to PAM's alteration of surface seal formation in furrow-bottoms and along the wetted perimeter (Lentz *et al.*, 1992). In addition to accelerating runoff, which exacerbates erosion (Le Bissonnais and Singer, 1993), seal formation can severely limit infiltration. On some soils net infiltration drops to <1% of initial rates (Shainberg and Singer, 1985). Trout *et al.* (1993) recently demonstrated that net infiltration declines exponentially in relation to the sediment concentration of the irrigation stream. Segeren and Trout (1991) demonstrated that sediment eroded from and redeposited on furrow bottoms created the surface seals which lowered furrow hydraulic conductivity up to 90% in 1-2 h. This occurred by blockage of continuous pores with transported and reoriented sediment. The same process promotes hardsetting crusts as furrow-bottoms dry between irrigations. PAM probably enhances lateral wetting by also inhibiting down-cutting of the furrow, which lowers the water level relative to the inter-furrow soil surface. Net infiltration differences among strategies were not significant.

Sediment Loss

Mean sediment loss for the 3 years was 0.924 Mg ha^{-1} for controls and 0.257 Mg ha^{-1} for PAM-treated furrows (Fig. 2). Sediment loss was less ($P \leq 0.05$) for PAM-treated furrows in all 43 comparisons. Sediment loss reduction ranged from 43-99%. Soil loss tolerance (T-value) for these soils is 11.2 Mg ha^{-1} yr^{-1}. Soil displaced from upper field reaches and redeposited in lower reaches is unaccounted for in furrow sediment-loss measurements. Also, individual comparisons of freshly tilled furrows must be adjusted to reflect season-long soil loss. Therefore a correction factor was used to relate furrow sediment loss to erosion. For these data, 0.467 Mg ha^{-1} sediment loss at the furrow outlet (dashed line Fig. 2) approximates the T value. Control furrow sediment loss exceeded T in 75% of the comparisons. Although CL used less PAM, sediment loss was reduced most effectively by IH and IE (Fig. 2).

Soil Strength

Mean furrow-bottom crust strength was 1.12 MPa. Daily means ranged from 0.46-2.21 MPa. Mean crust gravimetric water content at sampling was 13.8%. Daily means ranged from 2.6-24.4%. Although 0.5-1.0 cm thick crusts were present, no PAM-related strength differences were observed. This was attributed to inability under this irrigation regime for crusts to completely dry between irrigations, and due to high measurement variability. Notably, crusts formed in both PAM-treated and control furrows. Although seals formed during irrigation were sufficiently differentiated to affect infiltration and erosion, their associated crusts could not be distinguished on the basis of soil strength measurements.

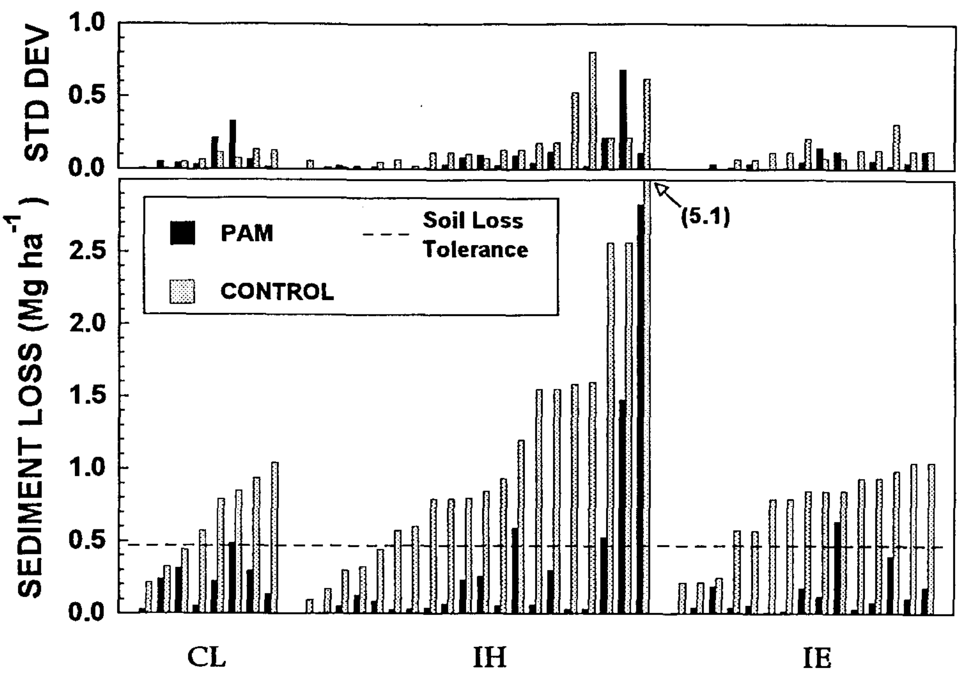

Fig. 2. Sediment loss per irrigation for control and PAM-treated pairs. Data are from trafficked, newly cultivated and shaped furrows. Inflow rate, irrigation period, and furrow slope are identical for each control/PAM-treatment pair, but differ among pairs. Treatments (CL, IH, and IE) are as in materials and methods.

PAM Application Cost

Seasonal application amounts and costs depend on extent of irrigation but approached $US 4 ha^{-1} for the 1st irrigation (less for successive irrigations). Simple technology and low cost hold promise for 3rd world use of PAM to control erosion and net infiltration in irrigation.

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