POLYACRYLAMIDE EFFECT ON FURROW EROSION AND INFILTRATION

T. J. Trout, R. E. Sojka, R. D. Lentz

ABSTRACT. *Erosion from furrow irrigated land is a serious problem in southern Idaho and elsewhere in the western United States. High molecular weight anionic Polyacrylamide (a water soluble polymer), increases soil aggregate stability and flocculates suspended sediments, thereby reducing sediment detachment and transport in irrigation furrows. Application of 0.7 kg/ha/irrigation of polyacrylamide in irrigation water has reduced furrow erosion by 85 to 99%. In the present work, sediment movement and infiltration were measured in a recirculating furrow infiltrometer with two polyacrylamide treatments. Mean erosion reduction was 70%. Polyacrylamide increased mean infiltration by 30%, probably the result of reduced sediment movement and furrow surface seal formation. Infiltration was inversely related to maximum sediment concentration in the flowing water for both treated and untreated furrows. Farmers who use polyacrylamide must adapt their irrigation management to the higher infiltration to maintain desired irrigation efficiencies.* ***Keywords.*** *Polyacrylamide, PAM, Polymer, Surface seal, Irrigation.*

Polyacrylamide (PAM) is a high molecular weight, long chain, water soluble polymer. Characteristics such as chain length (molecular weight), degree of cross-linkage, and type and density of associated charges are varied to produce polymers with varying performance characteristics. 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.

Polymers were first researched and marketed as soil conditioners about 30 years ago. One of the first commercial products was called Krilium. Early products were uneconomical for most situations because of the large quantities required to treat the tilled soil layer. Recent laboratory studies utilizing new products and application techniques have shown that PAM used in relatively small 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) increased initial infiltration into furrows in a silty clay by 30% with 32 kg/ha of PAM applied in the irrigation-water. Levy et al. (1991) decreased runoff from sprinkler irrigation with 20 kg/ha PAM applied prior to the irrigation season. The reduced runoff resulted in reduced erosion.

The USDA-ARS in Kimberly, Idaho, began investigating the use of polyacrylamide to reduce furrow erosion in 1991. Lentz et al. (1992) proposed that, because furrow erosion occurs at the furrow surface, only the wetted perimeter need be treated, and the small concentration of PAM required can be applied in the irrigation water. This greatly reduced the amount of PAM required compared to broadcast application and incorporation. Water-applied PAM provided the additional benefit of flocculating sediments in the flowing water which reduces their transportability and increases their tendency to deposit in the furrow.

Lentz et al. (1993) reported that anionic PAM was more effective than cationic forms for reducing furrow erosion of Portneuf silt loam. Lentz et al. (1992) reported that 5 to 10 mg/L of a high molecular weight, moderately anionic PAM in the irrigation water during furrow stream advance reduced sediment yield at the end of the furrow 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 only 20% erosion reductions the first irrigation, but slightly greater effects (30% reductions) the second irrigation. Lentz and Sojka (1994), summarizing three years of field studies, concluded that the most cost-effective PAM application is during furrow stream advance with possible short doses later in the irrigation. They reported that application rates of 0.7 kg/ha or greater reduced erosion an average of 94% and resulted in a 15% average increase in infiltration. Lower application rates also gave dramatic, but more variable results.

The probable reason for increased infiltration with PAM application is the reduced depositional seal formation resulting from reduced erosion and sediment movement. Segeren and Trout (1991) and Trout (1990) showed that, on the Portneuf silt loam soil, depositional seal formation reduced furrow infiltration by 50%. In those tests, seal formation was prevented on control furrows with cheesecloth placed on the furrow wetted perimeter. Trout (1992), in recirculating infiltrometer tests with varying flow velocity rates, measured an inverse relationship

Article was submitted for publication in October 1994; reviewed and approved for publication by the Soil and Water Div. of ASAE in January 1995. Presented as ASAE Paper No. 93-2036.

Names are necessary to report factually on available data. However, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

The authors are **Thomas J. Trout**, ***ASAE Member Engineer***, Agricultural Engineer, **Robert E. Sojka**, Soil Scientist, and **Rodrick D. Lentz**, Soil Scientist, USDA-Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho.

between sediment concentration in the recirculating flow, which increased with flow velocity, and furrow infiltration.

The objectives of this research, under the controlled field conditions provided by a recirculating blocked-furrow infiltrometer, were to:

- Determine the effectiveness of irrigation water-applied PAM in reducing furrow erosion.
- Determine the effect of PAM on furrow infiltration.
- Determine the mechanism whereby PAM affects infiltration.

METHODS

Three experiments were carried out at the Northwest Irrigation and Soils Research Laboratory near Kimberly, Idaho, in 1992 on fields of Portneuf silt loam (table 1). Portneuf silt loam (a coarse-silty, mixed, mesic Durixerollic Calciorthid) has low aggregate stability (Lehrsch et al., 1991) and is highly erodible (Koluvek et al., 1993). Experiment 1 was conducted in July on an established corn field following cultivation. Experiments 2 and 3 were conducted in August on previously unirrigated furrows in a fallow field in which grain stubble had been recently disked and plowed under. Furrows in both fields had 1.1% slopes and had not been driven on by implement wheels.

Irrigation water was applied to 6-m-long test furrow sections with a recirculating blocked-furrow infiltrometer (Blair and Trout, 1989). This device uses a small battery-powered centrifugal pump in a sump to continually recycle the runoff from the furrow section back to the upper end of the section. A weir at the downstream end maintains near normal flow depth in the furrow section and a 500-L supply tank configured as a mariotte siphon maintains a constant water volume in the recycling system. The decreasing tank water level, recorded with a pressure transducer and datalogger, is directly related to the infiltration rate in the furrow section. The system continually recycles all sediment that runs off the section back through the furrow section such that the sediment concentration should eventually reach an equilibrium level equivalent to what would occur at steady state at the end of a long furrow. Initial inflow rate to the furrow sections was 6 L/min so that the water advanced through the sections in about 2 min. Inflow rates were then increased to 18 L/min for experiments 1 and 2, and 23 L/min for experiment 3, and irrigation continued for 8 h. Two infiltrometers were operated simultaneously, one with PAM-treated water and one without.

In experiments 1 and 2, 20 L of a 10 mg/L solution of Superfloc A-836 (CyTec Industries, Wayne, N.J.), a high molecular weight (15 Mg/mole), medium-charge density (18% hydrolysis) anionic PAM, was added to one of the infiltrometers at the beginning of the tests. This volume of water, containing 200 mg of PAM, was sufficient to complete advance through the 6-m-long furrow section. The PAM concentration in the recirculating water rapidly decreased as the PAM solution infiltrated and was diluted by water from the supply tank. After 1 h of irrigation, an additional 200 mg of PAM was added to the recycling water, which again brought the concentration in the flow up to about 10 mg/L for a short time.

In experiment 3, 250 mg of Superfloc A-836 was dissolved in one of the 500-L supply tanks before the beginning of each irrigation, so that the PAM concentration in the irrigation water remained at 0.5 mg/L throughout the irrigation. Infiltrated volumes varied from 600 to 1200 L so total PAM applications varied from 300 to 600 mg.

One-liter samples of the recycling water were collected from the recycling systems 0.25, 0.5, 1, 2, 4, and 8 h after the beginning of each test. For experiments 1 and 2, 1.25-h samples (0.25 h after the second PAM application) were also collected. The water samples were filtered and the sediment dried to determine the mass of sediment in each 1-L sample. The average sediment concentration during the first hour of each test (average of 0.25, 0.5 and 1 h samples) was used as a parameter to describe sediment movement.

Treated furrows were alternated with adjacent untreated furrows. Each infiltrometer system was used alternately with treated and untreated furrows. Tests were replicated at least five times. For each experiment, a student t statistic was used to test if mean differences in sediment concentrations and infiltration between the treated and untreated furrows were equal to zero.

Table 1. Field conditions and polyacrylamide treatments for the three experiments

	Experiment 1	Experiment 2	Experiment 3
Field	1	2	2
Crop	Corn	Fallow	Fallow
Slope (%)	1.1	1.1	1.1
Flow rate (L/min)	18	18	23
PAM treatment	10 mg/L initial +200 mg @ 1 h	10 mg/L initial +200 mg @ 1 h	0.5 mg/L Continuous
PAM applied (mg)	400 mg	400 mg	300-600 mg
PAM applied (kg/ha)	0.7	0.7	0.5-1.0

RESULTS

EROSION AND SEDIMENT MOVEMENT

The PAM treatments reduced the average sediment concentration in the recirculating furrow flows in all three experiments (table 2). For all tests combined, sediment concentration during the initial hour of the test averaged 2.1 g/L for the PAM treatments and 7.0 g/L for the untreated furrows, a reduction of 70%. In four cases in which treated furrows had high sediment loads (experiment 1, tests 1 and 3; and experiment 3, tests 3 and 4), a head-cut was observed in the furrow. A furrow head-cut is a 10 to 20 mm vertical bed elevation drop and

Table 2. Average sediment concentration (g/L) during the initial hour for individual tests

	Experiment 1		Experiment 2		Experiment 3	
Test No.	Untreated	Treated	Untreated	Treated	Untreated	Treated
1	3.9	3.2	0.3	0.5	4.4	0.6
2	6.1	0.2	7.6	2.1	15.1	0.7
3	13.0	3.8	9.5	0.1	5.9	8.5
4	2.6	1.0	0.7	1.0	0.8	12.0
5	9.5	0.9	0.2	0.1	8.1	0.3
6			9.1	0.3	1.1	4.6
7					30.6	0.7
Average	7.0	1.8	4.6	0.7	9.4	3.9
S.D.	4.2	1.6	4.6	0.8	10.5	4.7
t Statistic	3.0		2.1		1.1	
Prob > t	0.04		0.09		0.32	

small water cascade that occasionally forms at high shear points and migrates upstream. As the head-cut migrated upstream, it eroded through the treated surface soil layer and produced a large amount of sediment.

Several of the untreated furrows in experiment 2 eroded little and had low sediment concentrations. Furrow flow rates were consequently increased to 23 L/min for experiment 3 to increase the erosion. This resulted in doubling the average untreated furrow sediment concentration. The continuous PAM application used in experiment 3 resulted in the smallest treatment effect (60% sediment reduction) even though total application was about the same as in the other experiments. This result supports field studies in which the greatest benefit is gained by concentrating the application during the advance phase of the irrigation.

The variability among tests with the same treatment is large (table 2). High variability in furrow erosion was also reported under field scale trials by Lentz et al. (1994). It indicates extreme sensitivity of the process to soil or hydraulic parameters or an inherent instability in the process. The amount of variability is difficult to explain since sediment concentration in the recirculating flow should be controlled by transport capacity rather than soil erodibility (Trout and Neibling, 1993).

Sediment concentrations in the untreated furrows initially increased very rapidly to a peak value and then decreased gradually with time (fig. 1). The furrows continuously treated with the 0.5 mg/L PAM solution (experiment 3) showed the same trend. Sediment concentration in the experiment 1 and 2 furrows treated with 10 mg/L of PAM during advance was low initially but increased gradually after 30 min. Apparently, either the stabilizing effects of the PAM decreased with time or the decrease in PAM concentration in the water allowed eroded sediment to remain dispersed and transportable. The second PAM application to these furrows after 1 h of irrigation quickly flocculated the moving sediment and maintained low concentrations for the duration of the tests. These sediment concentration trends over time are similar to those observed at the outflow end of field furrows (Lentz and Sojka, 1994).

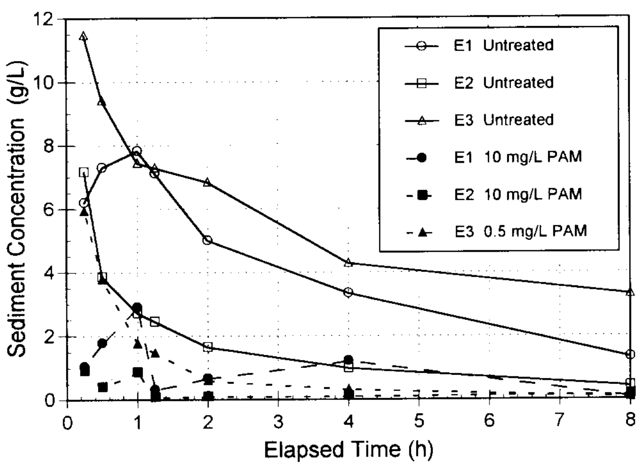

Figure 1–Sediment concentration variation over time in the recirculating furrow infiltrometer. Points represent the average for all tests for each experiment (E1-E3).

Table 3. Eight-hour cumulative infiltration (L/m) for individual tests

	Experiment 1		Experiment 2		Experiment 3	
Test No.	Untreated	Treated	Untreated	Treated	Untreated	Treated
1	50	45	116	106	66	155
2	45	44	50	74	33	160
3	40	62	33	184	52	100
4	67	96	123	126	155	140
5	38	59	175	200	48	175
6			62	200	120	146
7					26	195
Avg.	48	61	93	148	71	153
S.D.	12	21	54	54	48	30
t statistic	1.9		1.9		3.3	
Prob > t	0.12		0.11		0.02	

Infiltration

The polymer solutions resulted in increased infiltration for all three experiments (table 3). Average 8-h cumulative infiltration was 30% higher for treated compared to untreated furrows in experiment 1, 60% higher in experiment 2, and 110% higher in experiment 3. As with the sediment concentration data, there was inconsistency in the polymer effect on infiltration. These infiltration increases are larger than those measured in field furrows by Lentz and Sojka (1994). A possible reason is that although a portion of the sediment (especially the finer particles) eroded from field furrows is discharged with the furrow outflow, all sediment in the recirculating infiltrometer is recycled until it eventually deposits. This may result in a less permeable depositional layer in the infiltrometer with no treatment and a larger treatment effect. The higher flow rate in experiment 3 compared to experiment 2 appeared to reduce infiltration of the untreated furrows as it had increased sediment movement.

An inverse relationship between sediment concentration in the flow and cumulative infiltration is evident in figures 2 and 3. Similar relationships were observed between final infiltration rate and sediment concentration (data not shown). Regression analysis (linear regression of logarithmically transformed data) of the data sets shown in the two figures gave r^2 values of 0.49 and 0.67, respectively.

These logarithmic plots show that, regardless of the treatment, as sediment concentration in the flow increased over two log cycles, infiltration decreased about two-thirds. This treatment-independent relationship indicates that the PAM effect on infiltration resulted primarily from its effect on sediment movement and deposition, rather than some other effect on the soil or water.

Discussion

Figure 1 shows that the large amount of sediment initially carried in the recirculating water eventually settled out and deposited on the bed (no sediment accumulated in the recycling system). The deposition resulted in a depositional seal on the furrow perimeter. With approximately 23 L of water contained in the furrow and recycling system under steady state flow conditions, 5 g/L of sediment would result in approximately 115 g of sediment in suspension, sufficient to form a 0.2-mm-thick depositional seal on the furrow perimeter. Segeren and

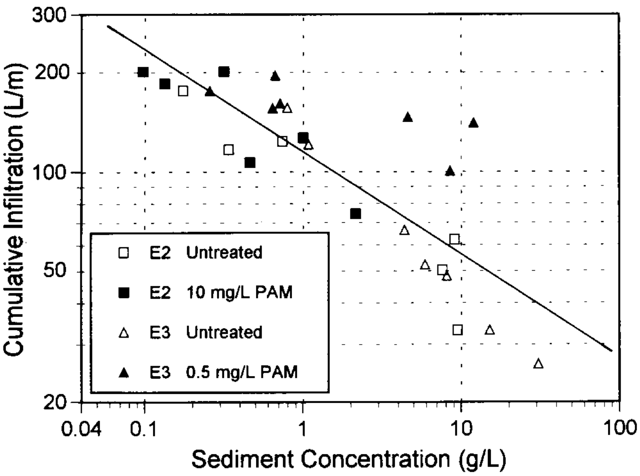

Figure 2–Cumulative infiltration (8 h) vs. average sediment concentration (initial hour) for experiments 2 (18 L/min flow rate) and 3 (23 L/min), differentiated by treatment. The best fit regression line is for the combined data.

Trout (1991) showed that such a seal on this soil had a hydraulic conductivity value about two orders of magnitude lower than that of the parent soil and resulted in an approximately 50% decrease in furrow infiltration. As the water in untreated furrows cleared late in the tests, the furrow perimeters often appeared smooth and glossy, a visual evidence of a surface seal (fig. 4a). PAM-treated furrows with little sediment movement often maintained rough, irregular perimeters (fig. 4b).

Three data points obviously lie above the trend in figure 2. All three are from experiment 3 (0.5 mg/L continuously treated furrows). Observations of these furrows showed that the relatively high concentrations of sediment particles were initially produced by a migrating head-cut. Once in suspension, the sediment particles flocculated into fairly large particles. Shainberg and Singer (1985) found that, when large flocculated particles deposit on the bed, they form a more permeable surface than unflocculated primary particles and microaggregates. This can explain the higher-than-expected infiltration. Sojka and Lentz (1994) also observed in field-scale experiments that, even though surface seals were visibly evident in PAM-treated furrows, the treatment apparently resulted in a more permeable seal because final infiltration rates were higher with treatment.

The influence of PAM on infiltration depends on the effect of depositional seals on infiltration. Soils with low inherent permeability (fine-textured or with a low permeability subsurface layer), or soils that lack fine particles to create seals may not be affected as much by PAM applications. Eisenhauer et al. (1992), using laboratory measurements of seal permeability and a furrow infiltration model, showed that for some soils, transient surface seals may have little effect on cumulative infiltration. In Mitchell's (1986) field study on a silty clay

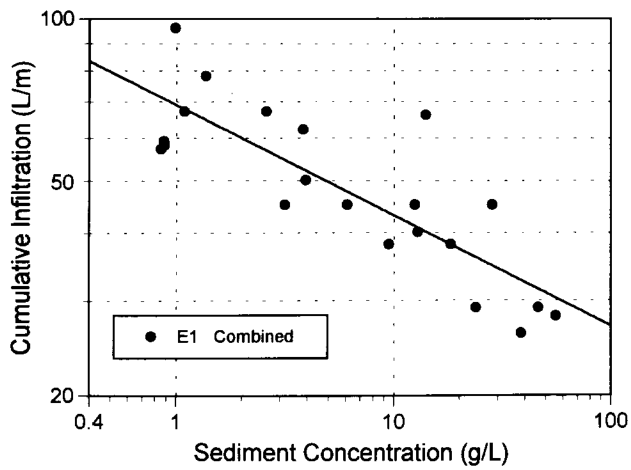

Figure 3–Cumulative infiltration (8 h) vs. average sediment concentration (initial hour) for experiment 1 and the best fit regression line. Data include combined (undifferentiated) experiment 1 data plus additional data collected from the plot during preliminary trial runs in which a range of treatments were tested.

(a)

(b)

Figure 4–Photographs of furrow perimeters taken the day following an 8-h irrigation. (a) Untreated furrow with smooth perimeter. (b) PAM-treated furrow with original aggregates remaining.

soil, although PAM increased initial infiltration, it did not affect final cumulative infiltration or final infiltration rate.

The decreasing sediment concentrations in the recycling flows (fig. 1) did not result from a decrease in sediment transport capacity, since flow rates and thus velocities did not decrease. (Except when head-cuts formed, furrow cross-sectional shape did not change substantially after the initial several minutes of flow.) Instead, the net sediment deposition was likely the result of three phenomena: 1) irregular channel shape and perimeter roughness resulted in a wide range of flow velocities which gave particles random opportunities to enter a low velocity eddy and settle to the bed; 2) sediment particles moved to the bed with infiltrating water; and 3) once the seal began to form, the soil water tension at the perimeter tended to hold otherwise erodible particles in place (Segeren and Trout 1991; Brown et al., 1988). Even under steady-state flow and transport conditions, transported sediment eventually deposits on furrow beds which can result in net deposition.

Effect of PAM on Irrigation Management

Where PAM application increases infiltration, farmers must adapt their irrigation water management practices to the increased infiltration to maintain desired irrigation efficiencies. Irrigation times must be reduced, or water applications will increase and deep percolation loss may increase. Inflow rates must be increased during furrow stream advance or advance rate will be slower and water distribution will be less uniform. Since PAM reduces erosion, the use of high inflow rates to maintain or even improve uniformity is feasible.

Effect of Sediment Movement on Furrow Water Distribution

The relationship between sediment movement and infiltration may affect water distribution along furrows. At the head (inflow) end of furrows, flow velocity is high and the water often contains little sediment, so erosion rates are usually high but little sediment is deposited. Further along the furrow, flow rate and shear decreases (because of upstream infiltration) and transported sediment concentration increases (because of upstream erosion), so erosion decreases and deposition of upstream eroded sediments increases. At the tail (outflow) end of the furrow, flow rates and shear are low and transported sediment continues to deposit but at a decreasing rate. Trout and Neibling (1993) describe these furrow erosion and deposition processes in detail. In typical furrows in southern Idaho with moderate, uniform slopes, the head-end 25% of furrows are eroded and most sediments deposit in the middle half. The tail 25% of most furrows experience little erosion and less deposition than the middle half.

This nonuniform erosion and deposition process would result in the greatest seal formation in the middle portion of furrows, and thus higher infiltration rates and water applications would occur in the head and tail sections. The impact of these erosion, deposition, and seal formation processes may be greater than the predicted effect of infiltration opportunity time and wetted perimeter on infiltration and water distribution along furrows. Trout (1992) measured higher than expected infiltration into the tail portions of furrows. The importance of erosion and deposition processes on water distribution depends on the erosiveness of the flow, the erodibility of the soil, and the permeability of the depositional seal relative to the permeability of the underlying layers. PAM use to decrease erosion should also reduce the effects of nonuniform erosion, deposition, and seal formation on infiltration uniformity.

Prospects for PAM Use for Furrow Erosion Control

Koluvek et al. (1993) estimated that over 2 million ha of irrigated land in the western United States is affected by erosion and annual sediment yields often exceed 20 Mg/ha. Polyacrylamide, at economical application levels [0.7 kg/ha @ $10.00/kg (estimated retail price) = $7.00/ha per application], can dramatically reduce furrow erosion and sediment loss. Field studies have shown that PAM should be applied following each cultivation and one or two additional times during the season to gain adequate control (Lentz et al., 1992). At four applications per year and a 90% reduction of a 20 Mg/ha soil loss, the cost of the application is about $1.50/Mg of soil saved.

Both farmers and commercial firms are very interested in PAM use. The USDA-Natural Resources Conservation Service is conducting field trials or demonstrations in several states. Manufacturers have registered materials for soil application in several states including Idaho, California, and Texas (as of April 1995), and PAM is being used in Oregon and Washington where registration is not required. Practical methods to apply PAM in surface irrigation water are still being refined.

Conclusions

Small concentrations of polyacrylamide in irrigation water dramatically reduces furrow erosion and sediment loss. By reducing erosion, PAM also reduces or alters depositional seal formation, which may result in increased infiltration. Irrigation management changes may be required to maintain desired irrigation efficiencies.

References

Blair, A. W. and T. J. Trout. 1989. Recirculating furrow infiltrometer design guide. Technical Report CRWR 223. Center for Research in Water Resources, College of Engineering, Univ of Texas, Austin.

Brown, M. J., W. D. Kemper, T. J. Trout and A. S. Humphreys. 1988. Sediment, erosion, and intake in furrows. *Irrig. Sci.* 9(1):45-55.

Eisenhauer, D. E., D. F. Heermann and A. Klute. 1992. Surface sealing effects on infiltration with surface irrigation. *Transactions of the ASAE* 35(6):1799-1807.

Helalia, A. M. and J. Letey. 1988. Cationic polymer effects on infiltration rates with a rainfall simulator. *Soil Sci Soc. of Am. J.* 52(1):247-250.

Koluvek, P. K., K. K. Tanji and T. J. Trout. 1993. Overview of soil erosion from irrigation. *J. of Irrigation and Drainage Eng. ASCE* 119(6):929-946.

Lehrsch, G. A., R. E. Sojka, D. L. Carter and P. M. Jolley. 1991. Freezing effects on aggregate stability affected by texture, mineralogy, and organic matter. *Soil Sci. Soc. of Am. J.* 55(5):1401-1406.

Lentz, R. D., I. Shainberg, R. E. Sojka and D. L. Carter. 1992. Preventing irrigation furrow erosion with small applications of polymers. *Soil Sci. Soc. of Am. J.* 56(6):1926-1932.

Lentz, R. D., R. E. Sojka and D. L. Carter. 1993. Influence of polymer charge type and density on polyacrylamide ameliorated irrigated furrow erosion. In *Preserving Our Environment—The Race is On. Proc. of the XXIV Conf. of the Int. Erosion Control Assoc.*, Indianapolis, Ind., 23-26 February.

Lentz, R. D. and R. E. Sojka. 1994. Field results using polyacrylamide to manage furrow erosion and infiltration. *Soil Sci.* 158(4):274-282.

Levy, G. J., M. Ben-Hur and M. Agassi. 1991. The effect of polyacrylamide on runoff, erosion and cotton yield from fields irrigated with moving sprinkler systems. *Irr. Sci.* 12(2):55-60.

Mitchell, A. R. 1986. Polyacrylamide application in irrigation water to increase infiltration. *Soil Sci.* 141(5):353-358.

Segeren, A. and T. J. Trout. 1991. Hydraulic resistance of soil surface seals in irrigated furrows. *Soil Sci. Soc. of Am. J.* 55(3):640-646.

Shainberg, I., D. N. Warrington and P. Rengasamy. 1990. Water quality and PAM interaction in reducing surface sealing. *Soil Sci.* 149:301-307.

Shainberg, I. and M. J. Singer. 1985. Effect of electrolyte concentration on the hydraulic properties of depositional crusts. *Soil Sci Soc. Am. J.* 49(5):1260-1263.

Sojka, R. E. and R. D. Lentz. 1994. Net infiltration and soil erosion effects of a few ppm polyacrylamide in furrow irrigation water. In *Proc. of the 2nd Int. Symp. on Sealing, Crusting, and Hardsetting Soils: Productivity and Conservation.* Univ. of Queensland, Brisbane, Australia, 7-11 February 1994.

Trout, T. J. 1990. Surface seal influence on surge flow furrow infiltration. *Transactions of the ASAE* 33(5):1583-1589.

———. 1992. Flow velocity and wetted perimeter effects on furrow infiltration. *Transactions of the ASAE* 35(3):855-863.

Trout, T. J. and W. H. Neibling. 1993. Erosion and sedimentation processes on irrigated fields. *J. of Irrig. and Drainage Eng. ASCE* 119(6):947-963.

Wallace, A. and G. A. Wallace. 1986. Effects of very low rates of synthetic soil conditioners on soils. *Soil Sci.* 141(5):324-327.

Wallace, A., G. A. Wallace and A. M. Abouzamzam. 1986. Effects of soil conditioners on water relationships in soils. *Soil Sci.* 141(5):346-352.