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MULTIPLE POLYACRYLAMIDE APPLICATIONS FOR CONTROLLING SPRINKLER IRRIGATION RUNOFF AND EROSION

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ABSTRACT. *Runoff under sprinkler irrigation systems causes soil erosion and reduces water infiltration uniformity. Previous studies have shown that applying polyacrylamide (PAM) with irrigation water can reduce runoff and soil loss. We hypothesized that applying PAM with three consecutive irrigations would more effectively control runoff and erosion than applying the same total amount of PAM with a single irrigation. This study was conducted in the laboratory with a Rad silt loam (coarse silty, mixed, superactive mesic Durinodic Xeric Haplocambid) at 6.5% slope. Water was applied at 80 mm h^{-1} (3.2 in. h^{-1}) for 10 min [13 mm (0.5 in.) application depth] for four irrigations. PAM was applied at 3 kg ha^{-1} (2.7 lb a^{-1}) with irrigation water during the initial irrigation (single) or at 1 kg ha^{-1} (0.9 lb a^{-1}) during the first three irrigations (multiple). Both multiple and single PAM treatments caused significantly less runoff than the control for all four irrigations. However, the multiple PAM treatment reduced runoff approximately 30% more than the single application during the last two irrigations. Applying PAM at 3 kg ha^{-1} (2.7 lb a^{-1}) with one irrigation reduced cumulative soil loss by 60% compared to the control. Applying PAM at the same rate in three consecutive irrigations reduced cumulative soil loss by 80%. Both single and multiple PAM applications reduced runoff and soil loss, but multiple applications more effectively controlled runoff longer than a single application.*
Keywords. *Runoff, Soil erosion, Polyacrylamide, Sprinkler irrigation.*

Center pivots irrigate about one-third of the irrigated land in the United States (USDA, 1998). These systems are popular because they uniformly apply water with little labor and can be used on land unsuitable for surface irrigation. However, runoff can be a problem because the water application rate often exceeds the soil infiltration rate (Gilley and Mielke, 1980; Kincaid et al., 1969). Runoff on a center pivot-irrigated field generally does not flow from the field, but ponds and infiltrates in low areas within the field, resulting in reduced irrigation uniformity.

Several laboratory studies have shown that spraying concentrated PAM solutions [500 mg L^{-1} (0.05%)] on the soil surface at rates equal to or greater than 20 kg ha^{-1} (18 lb a^{-1}) increased final infiltration rate and decreased soil erosion during simulated rainfall (Ben-Hur and Keren, 1997; Levy and Agassi, 1995; Levin et al., 1991; Smith et al., 1990). Spraying PAM directly on the soil, however, requires a large volume of solution (i.e., > 5000 L ha^{-1} or 530 gal a^{-1}) or a high viscosity solution. Conversely, applying PAM with irrigation water generally requires less PAM and is more effective than applying PAM directly to the soil. Ben-Hur et al. (1989) found that applying 5 kg PAM ha^{-1} (4.5 lb a^{-1}) with water during lab simulations more effectively prevented crust formation than spraying an equivalent amount of PAM on the soil surface. Applying PAM at 10 mg L^{-1} with simulated rainfall increased final infiltration rate compared to an untreated control, while applying 20 kg PAM ha^{-1} (18 lb a^{-1}) directly to the soil did not (Flanagan et al., 1997). Levy et al. (1992) applied three PAM rates [3, 6, and 12 kg ha^{-1} (2.7, 5.4, and 11 lb a^{-1})] with irrigation water for three consecutive irrigations on small trays in the laboratory. They noted that PAM increased final infiltration rate during treated irrigations, but final infiltration rates decreased to values similar to untreated soil after irrigating twice with only water. Similarly, Aase et al. (1998) showed that applying 2 kg PAM ha^{-1} (1.8 lb a^{-1}) with irrigation water in a laboratory study reduced runoff 70% compared to the control. Reducing runoff also reduced soil loss by 75% compared to the control. However, the single PAM application, even at 6 kg PAM ha^{-1} (5.4 lb a^{-1}), had little effect on runoff after two subsequent irrigations with only water. We hypothesized that applying PAM with three consecutive irrigations would more effectively control runoff and erosion than applying the same total amount of PAM with a single irrigation. Therefore, the objective of this study was to compare single and multiple PAM application effects on runoff and soil loss using laboratory sprinkler irrigation simulations.

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MATERIALS AND METHODS

Laboratory equipment and procedures used during this study were similar to those used by Aase et al. (1998) to compare runoff and soil loss from soil treated with 0, 1, 2, 4 or 6 kg PAM ha^{-1} (0, 0.9, 1.8, 3.6 or 5.4 lb a^{-1}) during a single irrigation. Soil was irrigated with an oscillating nozzle simulator similar to one described by Meyer and Harmon (1979). An 8070 Veejet nozzle, 3 m (10 ft) above the soil surface, applied water at 80 mm h^{-1} (3.2 in. h^{-1}) with a nozzle pressure of 76 kPa (11 psi). Irrigations lasted 10 min and applied 13 mm (0.5 in.) of water. This application rate and depth were similar to those on the outer spans of center pivots in southern Idaho. The resulting droplet energy from this type of nozzle spraying downward was about 25 J kg^{-1}, calculated according to Kincaid (1996).

We used well water for all tests. The water had an electrical conductivity (EC) of 0.73 dS m^{-1}, sodium adsorption ratio (SAR) of 1.7, and pH of 7.2. PAM-treated irrigation water was mixed by adding a concentrated PAM solution [1920 mg L^{-1} active ingredient (0.19%)] to well water in 210-L (55-gal) containers to achieve the desired PAM concentration. The concentrated PAM solution was prepared from a dry granular material with molecular weight of 12 to 15 Mg $mole^{-1}$ and an 18% negative charge density (Superfloc A836, marketed by American Cyanamid Co., Roanoke, Texas). All PAM rates and concentrations reported in this article are active ingredient, not bulk material.

We used a Rad silt loam (coarse silty, mixed, superactive mesic *Durinodic Xeric Haplocambid*) for this study. Soil texture, determined by hydrometer method, was 30% clay, 55% silt, and 15% sand (silty clay loam). The soil had 18 g kg^{-1} (1.8%) organic matter, saturated paste pH of 7.6, saturated paste extract EC of 1.0 dS m^{-1}, and SAR of 1.1. Soil was passed through a 6.4-mm (0.25-in.) screen prior to filling the steel boxes. The boxes were 1.2 m (4 ft) wide, 1.5 m (5 ft) long, and 0.2 m (8 in.) deep, except on the downslope end which was 0.15 m (6 in.) deep so the runoff trough could be attached. To avoid layering and segregation, the soil surface was stirred and mixed prior to leveling. This resulted in a uniform 0.15 m (6 in.) soil depth in the entire box with lightly packed surface. The resultant bulk density was about 1.0 Mg m^{-3} (62 lb ft^{-3}), similar to freshly tilled surface soil. Soil surface slope was set at 6.5% to represent a steep portion of a field where runoff would be a problem.

Three treatments, control, single PAM application, and multiple PAM applications, were compared. Each treatment was irrigated four times. The elapsed time between irrigations was 7 to 10 days, enough time for the soil surface to dry. PAM application rate was chosen based on the previous study by Aase et al. (1998). The single application treatment received 3 kg PAM ha^{-1} (2.7 lb a^{-1}) at 22.5 mg PAM L^{-1} with the first irrigation, followed by three water-only irrigations. The multiple application treatment received 1 kg PAM ha^{-1} (0.9 lb a^{-1}) at 7.5 mg PAM L^{-1} during the first three irrigations, followed by a fourth irrigation with only water. The control treatment was irrigated with only water for all four irrigations. All runoff from a soil box during an irrigation was collected in a container via the runoff trough affixed to the down-slope end of the box. Collected runoff was weighed and later filtered to determine sediment mass.

Prior to each irrigation, we collected two, 19-mm (0.75-in.) diameter soil cores from each soil box to determine antecedent water content. One core was taken from the down-slope end of the box and the other from the up-slope end. Soil cores were divided into 0 to 75 mm (0 to 3 in.) and 75 to 150 mm (3 to 6 in.) depths. After the fourth irrigation, we collected surface soil about 5 mm (0.2 in.) deep for wet aggregate stability analysis. Samples were lifted from the soil surface with spatulas, sealed in plastic bags, and refrigerated until analysis according to the procedure described by Kemper and Rosenau (1986) as modified by Lehrsch et al. (1991).

Each treatment was replicated six times. Data were analyzed as a randomized complete block. Significant treatment differences were identified using Duncan's multiple range test ($P < 0.05$).

Results and Discussion

Runoff from these laboratory boxes represents runoff from steep areas near the outer portion of a center pivot-irrigated field and not runoff from an entire field. A single 3 kg PAM ha^{-1} (2.7 lb a^{-1}) application eliminated runoff for the first irrigation and significantly reduced runoff compared to the control for the three remaining irrigations (fig. 1). Multiple PAM applications also significantly reduced runoff for all four irrigations. Runoff was not significantly different between the single and multiple PAM treatments for the first two irrigations. However, the multiple application treatment reduced runoff an additional 30% for irrigations 3 and 4 compared to the single application. Multiple PAM applications reduced cumulative runoff 50% compared to the control. Thirty-four percent [18 mm (0.7 in.)] of the total water applied during the four irrigations ran off the control treatment compared to just 23% [12 mm (0.5 in.)] for the single application and 17% [9 mm (0.35 in.)] for the multiple application.

Both PAM application techniques significantly reduced soil loss for all irrigations (fig. 2). Although the multiple PAM treatment had less runoff than the single application for irrigations 3 and 4, soil loss was not significantly different between the two PAM treatments for any of the

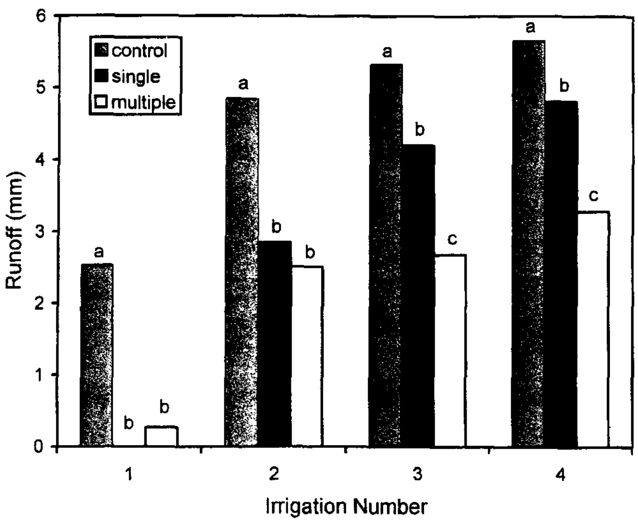

Figure 1–Mean runoff from each of the four irrigations by treatment. PAM was applied with irrigation 1 for the single treatment and irrigations 1-3 for the multiple treatment. Columns with the same letter within an irrigation are not significantly different at P < 0.05.

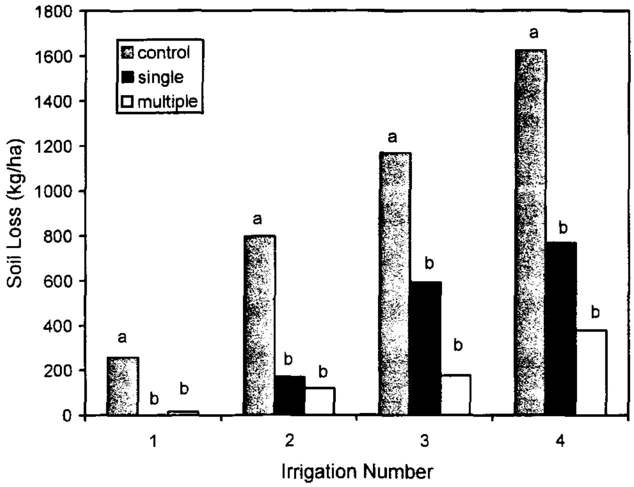

Figure 2–Mean soil loss from each of the four irrigations by treatment. PAM was applied with irrigation 1 for the single treatment and irrigations 1-3 for the multiple treatment. Columns with the same letter within an irrigation are not significantly different at P < 0.05.

four irrigations. Runoff sediment concentration was not significantly different between the two PAM treatments or between the control and the single application. However, the multiple PAM treatment had significantly lower sediment concentration than the control for all irrigations (fig. 3). Cumulative soil loss over the four irrigations was 1.5 Mg ha^{-1} (0.68 ton a^{-1}) and 0.69 Mg ha^{-1} (0.31 ton a^{-1}) for the single and multiple PAM treatments, respectively. This was 60 and 80% less than the cumulative soil loss for the control [3.8 Mg ha^{-1} (1.7 ton a^{-1})].

Surface soil water content was not different among treatments before each irrigation. Applying PAM with irrigation water significantly increased aggregate stability, measured after the fourth irrigation, compared to the untreated soil. Aggregate stability was not significantly different between the two PAM application techniques, following a similar trend as soil loss. The single and multiple PAM treatments averaged 80% and 85% stable aggregates, respectively, compared to 66% stable aggregates for the control.

Runoff increased with each irrigation for the single PAM application, but remained almost constant after the first irrigation for the multiple application (fig. 1). Soil loss, however, increased with each irrigation for all treatments (fig. 2). PAM could stabilize the soil surface during three consecutive irrigations for the multiple application treatment, but the PAM-stabilized surface was probably degraded gradually by erosion and water droplet impact with each consecutive irrigation on the single treatment. Multiple PAM applications may have enhanced infiltration by preserving pore structure (Sojka et al., 1998), but did not significantly reduce soil detachment by water droplets and therefore did not reduce soil erosion compared to the single application treatment.

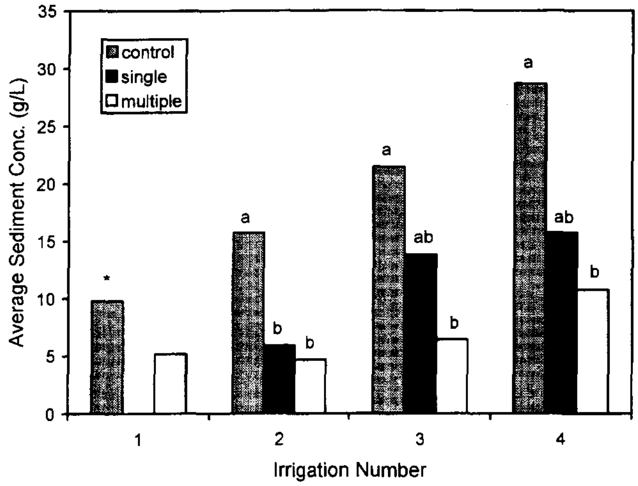

Figure 3–Average sediment concentration in runoff from each of four irrigations by treatment. * No runoff occurred from any replication of the single treatment and two replications of the multiple treatment during irrigation 1. Therefore statistical analysis was not conducted for irrigation 1. Columns with the same letter within an irrigation are not significantly different at P < 0.05.

Conclusions

Applying 1 kg PAM ha^{-1} (0.9 lb a^{-1}) with three consecutive simulated irrigations reduced runoff more than applying the same total amount of PAM with one irrigation. Soil loss, however, was similar between the two PAM application techniques, and both had less soil loss than the control. Results from this study indicate that PAM more effectively controls runoff from sprinkler irrigation when applied with multiple irrigations than when applied with a single irrigation. Keep in mind that we applied < 10% of seasonal water need for many crops. Additional PAM applications may be needed for season-long benefits. Given the cost of PAM (\$13-17 kg^{-1} or \$6-8 lb^{-1}), practices such as conservation tillage or reservoir tillage may be more cost effective than applying PAM. Innovative application techniques allowing PAM to be applied only to outer spans of a center pivot may improve the feasibility of applying PAM with sprinkler irrigation.

References

Aase, J. K., D. L. Bjorneberg, and R. E. Sojka. 1998. Sprinkler irrigation runoff and erosion control with polyacrylamide—Laboratory tests. *Soil Sci. Soc. Am. J.* 62(6): 1681-1687.

Ben-Hur, M., and R. Keren. 1997. Polymer effects on water infiltration and soil aggregation. *Soil Sci. Soc. Am. J.* 61(2): 565-570.

Ben-Hur, M., J. Faris, M. Malik, and J. Letey. 1989. Polymers as soil conditioners under consecutive irrigations and rainfall. *Soil Sci. Soc. Am. J.* 53(4): 1173-1177.

Flanagan, D. C., L. D. Norton, and I. Shainberg. 1997. Effect of water chemistry and soil amendents on a silt loam soil—Part 1: Infiltration and runoff. *Transactions of the ASAE* 40(6): 1549-1554.

Gilley, J. R., and L. N. Mielke. 1980. Conserving energy with low-pressure center pivots. *J. Irrig. Drain. Div. ASCE* 106(IR1): 49-59.

Kemper, W. D., and R. C. Rosenau. 1986. 2nd Ed. Aggregate stability and size distribution. In *Methods of Soil Analysis: Physical and Mineralogical Methods*, Part 1, ed. A. Klute, 425-442. Madison, Wis.: ASA.

Kincaid, D. C. 1996. Spraydrop kinetic energy from irrigation sprinklers. *Transactions of the ASAE* 39(3): 847-853.

Kincaid, D. C., D. F. Heermann, and E. G. Kruse. 1969. Application rates and runoff in center-pivot sprinkler irrigation. *Transactions of the ASAE* 12(6): 790-794, 797.

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. Am. J.* 55(5): 1401-1406.

Levin, J., M. Ben-Hur, M. Gal, and G. J. Levy. 1991. Rain energy and soil amendments effects on infiltration and erosion of three different soil types. *Aust. J. Soil Res.* 29(3): 455-465.

Levy, G. J., J. Levin, M. Gal, M. Ben-Hur, and I. Shainberg. 1992. Polymers' effects on infiltration and soil erosion during consecutive simulated sprinkler irrigations. *Soil Sci. Soc. Am. J.* 56(3): 902-907.

Levy, G. J., and M. Agassi. 1995. Polymer molecular weight and degree of drying effects on infiltration and erosion of three different soils. *Australian J. Soil Res.* 33(6): 1007-1018.

Meyer, L. D., and W. C. Harmon. 1979. Multiple-intensity rainfall simulator for erosion research on row sideslopes. *Transactions of the ASAE* 22(1): 100-103.

Smith, H. J. C., G. J. Levy, and I Shainberg. 1990. Water-droplet energy and soil amendments: Effect on infiltration and erosion. *Soil Sci. Soc. Am. J.* 54(4): 1084-1087.

Sojka, R. E., R. D. Lentz, and D. T. Westermann. 1998. Water and erosion management with multiple applications of polyacrylamide in furrow irrigation. *Soil Sci. Soc. Am. J.* 62(6): 1672-1680.

USDA. 1998. *1998 Farm and Ranch Irrigation Survey*. National Agricultural Statistics Service. http://www.nass.usda.gov/census/.