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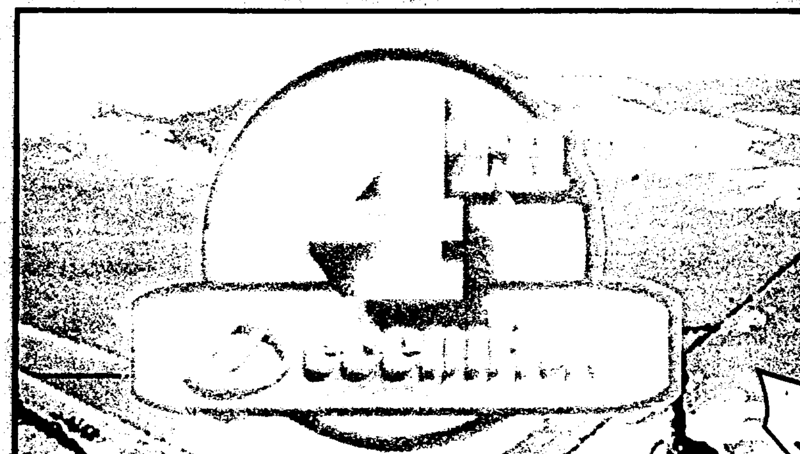

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SPRINKLER IRRIGATION RUNOFF AND EROSION CONTROL WITH POLYACRYLAMIDE

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ABSTRACT

Applying polyacrylamide (PAM) with furrow irrigation water dramatically reduces soil erosion and frequently increases infiltration. We conducted three studies to determine if PAM controlled runoff and soil erosion under sprinkler irrigation. These studies were conducted in the laboratory on 1.5 m long, 1.2 m wide and 0.15 m deep soil boxes. Water was applied at 80 mm h^{-1} with an oscillating nozzle irrigation simulator. Applying 2 to 4 kg PAM ha^{-1} significantly reduced runoff and soil erosion during the irrigation when PAM was applied. These beneficial effects decreased with each subsequent irrigation. Multiple PAM applications maintained runoff and erosion control longer than a single application, even though both treatments received the same total amount of PAM. Seventy percent residue cover more effectively controlled runoff and erosion than PAM, while 30% cover was about as effective as PAM. A single PAM application of 2 to 4 kg ha^{-1} may be adequate for a critical irrigation (i.e. seedling emergence), but multiple PAM applications are necessary for season-long benefits. Tillage and residue management practices should be considered before PAM is applied to control runoff under sprinkler irrigation. These results, however, could vary with irrigation water quality and soil chemistry.

Keywords: sprinkler erosion, PAM, irrigation runoff, crop residue.

INTRODUCTION

Approximately 45% of the irrigated land in the United States is sprinkler irrigated (USDA, 1998). Ideally, runoff should not occur from properly designed and managed sprinkler irrigation systems. However, nonuniform field slopes and soils potentially cause runoff from irrigation systems designed for average or representative conditions. This is especially true for center pivots and linear move irrigation systems, which are used on more than 75% of the sprinkler irrigated land (USDA, 1998). Center pivots often apply water faster than it can infiltrate, resulting in runoff and nonuniform irrigation (Kincaid et al., 1969; Aarstad and Miller, 1973). One reason for this is center pivot cost per unit area is reduced by increasing lateral length. However, application rates increase with distance from the pivot point to compensate for the larger irrigated area. Similarly, cost per unit area of linear move systems can be reduced by increasing the application rate so field length can be maximized. Decreasing irrigation system pressure also reduces costs but increases application rates because the area wetted by nozzles is less (Gilley and Mielke, 1980).

The key to controlling erosion from sprinkler irrigation is reducing or eliminating runoff. Runoff can be controlled by reducing application rate, increasing surface storage, or increasing soil intake rate. The application rate under center pivot and linear move systems can be reduced by mounting sprinklers on booms to increase wetted area. Reservoir or basin tillage increases surface storage, greatly reducing sprinkler irrigation runoff (Aarstad and Miller, 1973; Kincaid et al., 1990; Kranz and Eisenhauer, 1990; Oliveira et al., 1987). Infiltration can be increased with tillage, crop residue and some types of polymers, such as high molecular weight, anionic polyacrylamide (PAM).

Several laboratory studies have shown that concentrated PAM solutions (500 mg L^{-1}) sprayed on the soil surface at rates equal to or greater than 20 kg ha^{-1} increased final infiltration rate and decreased soil erosion during simulated rainfall (Ben-Hur and Keren, 1997; Levy and Agassi,

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1995; Levin et al., 1991; Smith et al., 1990). Shainberg et al. (1990) found no benefit from applying PAM at rates greater than 20 kg ha^{-1}. On steep field slopes (30-60%) under simulated rainfall, Agassi and Ben-Hur (1992) showed that applying a concentrated PAM solution (2500 mg L^{-1}) at 20 kg ha^{-1} reduced erosion 6 to 11 fold compared to a control. Applying 15 and 30 kg PAM ha^{-1} to soil in the field before rainfall simulation increased final infiltration rate and decreased soil erosion for three consecutive rains (Zhang and Miller, 1996). Under natural rain, spraying 5 or 20 kg PAM ha^{-1} on the soil reduced annual runoff compared to the control (Stern et al., 1991). Other field studies have shown reduced erosion or runoff under moving sprinkler systems when 20 kg PAM ha^{-1} was applied to the soil before irrigation (Levy et al., 1991; Stern et al., 1992).

One problem with spraying concentrated PAM solutions on the soil is the large volumes of material that must be applied. Viscosity of PAM solutions limit concentrations to 2000 to 3000 mg L^{-1}. To apply 10 kg PAM ha^{-1} for example, 5000 L ha^{-1} of a 2000 mg L^{-1} PAM solution must be sprayed on the soil. These application rates are not feasible for field situations unless PAM is applied with irrigation water since 10000 L ha^{-1} equals 1 mm application depth. Ben-Hur et al. (1989) found that applying 5 kg PAM ha^{-1} with water during lab simulations more effectively prevented crust formation than spraying an equivalent amount of PAM on the soil surface. Levy et al. (1992) applied three PAM rates (3, 6 and 12 kg ha^{-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.

Based on the success of PAM with furrow irrigation, many irrigators are interested in using PAM with sprinkler irrigation. Applying low rates of PAM with furrow irrigation water effectively controls soil erosion from furrow irrigated fields. Using just 10 mg PAM L^{-1} during the advance phase of furrow irrigation (typically 1-2 kg PAM ha^{-1}) can reduce soil erosion over 90% (Lentz et al., 1992; Trout et al., 1995; Sojka and Lentz, 1997; Sojka et al., 1998). Thus, we conducted three laboratory research projects to determine the effectiveness of applying low rates of PAM (<6 kg ha^{-1}) with irrigation water for controlling runoff and soil erosion. In the first study, we compared several PAM rates to identify an optimum application rate (Aase et al., 1998). The effectiveness of PAM and surface residue used separately and in combination was investigated during the second study (Bjorneberg et al., 2000). The third study compared the effectiveness of PAM applied with one irrigation or during three consecutive irrigations (Bjorneberg and Aase, 2000). This paper summarizes these three studies to give a collective view of the effectiveness of PAM for controlling runoff and soil erosion from sprinkler irrigation.

MATERIALS AND METHODS

All three studies were conducted in the laboratory using an irrigation simulator. Six steel boxes were constructed to hold the soil for these studies. The boxes were 1.5 m long, 1.2 m wide and 0.2 m deep, except the downslope side was 0.15 m deep so a trough could be attached to funnel runoff into containers. The boxes were hinged so surface slope could be varied from 1 to 15%.

Surface soil (0-0.2 m deep) collected from two southern Idaho fields was stored in covered containers until needed in the laboratory. Soil was passed through a 6.4-mm screen to remove or crush large clods when filling soil boxes. To avoid layering and segregation, the soil was stirred and mixed prior to leveling to a uniform depth of 0.15 m. The soil surface represented a newly prepared dry field seedbed with bulk density of about 1 Mg m^{-3} and surface soil (0-75 mm) water content of 10 to 15 g g^{-1}. Between replications of each study, we removed the surface 30 mm of soil from all boxes to ensure that no residual PAM remained (Malik et al., 1991). New soil was added and mixed with the remaining soil and leveled to a uniform depth of 0.15 m.

The irrigation simulator, similar to one described by Meyer and Harmon (1979), used an oscillating nozzle mounted 3 m above the soil surface. We used an 8070 Veejet nozzle and 76 kPa to apply water at 80 mm h^{-1}, representing a typical application rate for the outer end of center pivots used in southern Idaho. The median drop size was 1.2 mm diameter and droplet energy was about 25 J kg^{-1}, calculated as described by Kincaid (1996).

Irrigation water was pumped from 210-L containers to the simulator. We used well water for all tests. The water had 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) to well water in the containers to achieve the desired PAM concentration for that treatment. The concentrated PAM solution was prepared from a dry granular material with molecular weight of 12-15 Mg $mole^{-1}$ and an 18% negative charge density (Superfloc A836, marketed by American Cyanamid Co., Roanoke, TX[1]). All PAM rates and concentrations given are active ingredient, not bulk material.

Runoff from each soil box during an irrigation was collected and weighed. The sediment mass in runoff was determined by filtering all of the collected runoff. Runoff mass was converted to equivalent depth (mm) and sediment mass was converted to mass per unit area (kg ha^{-1}).

Study 1 – PAM Application Rates

We used a Rad silt loam (coarse silty, mixed, superactive mesic Durinodic Xeric Haplocambid) and a Roza loam (fine, smectitic, mesic xerertic Haplocambid) for this study. Soil texture, determined by hydrometer method, was 30% clay, 55% silt and 15% sand (silty clay loam) for the Rad soil and 36% clay, 43% silt and 21% sand (clay loam) for the Roza soil. The Rad soil had 18 g kg^{-1} organic matter, saturated paste pH of 7.6, saturated paste extract electrical conductivity (EC) of 1.0 dS m^{-1}, and sodium adsorption ratio (SAR) of 1.1. For the Roza soil, organic matter was 14 g kg^{-1}, pH was 6.4, EC was 0.5 dS m^{-1}, and SAR was 0.7.

Since we had only six boxes in the laboratory, we divided this study into three tests. The soil slope was 2.4% for each test. PAM was only applied during the first 20-mm irrigation. Two subsequent water-only irrigations for each test applied 20 mm of water after the soil surface had dried for 7 to 10 days. For the first test, we applied 0, 1 and 2 kg PAM ha^{-1} (0, 5 and 10 mg L^{-1} PAM concentrations) during the first irrigation to the Rad soil. For the second test, we applied 0, 4 and 6 kg PAM ha^{-1} (0, 20 and 30 mg L^{-1} PAM concentrations) during the first irrigation to the Rad soil. We used the Roza loam for the third test with 0, 2 and 4 kg PAM ha^{-1}. Each treatment was replicated four times during a test. Treatment differences were determined by 95% confidence intervals because mean separation techniques should not be used for progressive rate treatments.

Study 2 – PAM and Surface Residue

We used the Roza loam for this study with a 2.4% surface slope. This study was split into two tests for two different surface residue rates. For the first test, we applied 2500 kg ha^{-1} of wheat straw, resulting in about 70% surface cover based on visual estimate. Fifteen percent of the straw was cut into 0.15-0.20 m lengths and manually inserted about 0.05 m into the soil in 0.2 m rows. The remaining straw was broadcast on the soil surface to simulate an untilled, harvested wheat field. For the second test, we broadcast all of the straw at 670 kg ha^{-1}, resulting in about 30% surface cover based on visual estimate. PAM was applied to bare or straw-covered soil at 0, 2 or 4 kg PAM ha^{-1} during the first 20 mm irrigation, followed by two water-only 20 mm irrigations for both tests. Each treatment was replicated three times. Data for the two tests were analyzed separately. We used a randomized complete block analysis of variance and Duncan's multiple range for mean separation ($P<0.05$).

Study 3 – Multiple PAM Applications

We used a Rad silt loam for this study and increased the soil slope to 6.5%. The irrigation depth was reduced to 13 mm (80 mm hr^{-1} for 10 min) to decrease the total runoff from the steeper

[1] Mention of trade names does not constitute an endorsement by the USDA over other products not mentioned.

slope. Three treatments were applied: control, single PAM application and multiple PAM application. Each treatment was irrigated four times. The single application treatment received 3 kg PAM ha^{-1} (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} (7.5 mg PAM L^{-1}) during the first three irrigations and no PAM during the fourth irrigation. The control treatment was irrigated with only water for the four irrigations. Each treatment was replicated six times. Data were analyzed as a randomized complete block. Significant differences were identified using Duncan's multiple range test ($P<0.05$).

RESULTS

Study 1 – PAM Application Rates

Study 1 results for the Rad silt loam were previously reported by Aase et al. (1998). Applying PAM with the first irrigation reduced runoff during that irrigation, but had little impact during subsequent irrigations (Fig. 1). Runoff from the control during the first irrigation, which was almost 30% of the applied water, was three times greater than runoff from PAM treatments. Soil loss was reduced during the first and second irrigations with rates $\geq$2 kg PAM ha^{-1} and during the third irrigation with 4 and 6 kg PAM ha^{-1} compared to the control (Fig. 1). The 1 kg ha^{-1} PAM rate was not effective for reducing soil loss. There were no differences in runoff or soil loss between the 4 and 6 kg ha^{-1} PAM rates. Based on these results, only the 2 and 4 kg PAM ha^{-1} rates were used on the Roza loam.

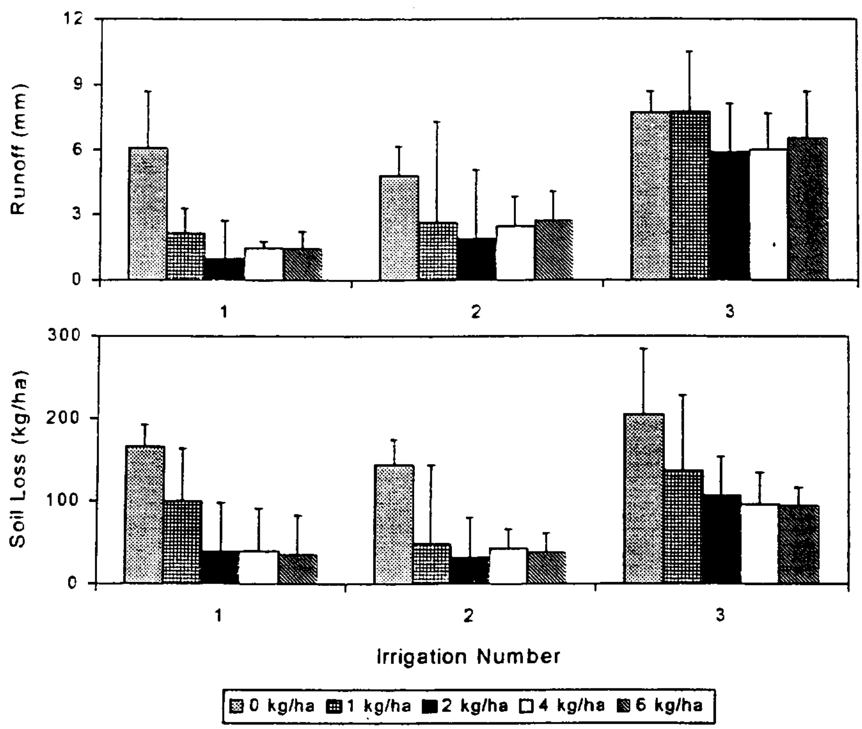


Figure 1. Runoff and soil loss from three, 20-mm irrigations on Rad silt loam during study 1. Applied four PAM rates with irrigation 1. Bars represent 95% confidence intervals (data from Aase et al., 1998).

Similar to the Rad soil, PAM treatments reduced runoff from the Roza soil for only the first irrigation. However, the 2 and 4 kg ha^{-1} PAM rates only reduced soil loss for the first irrigation (Fig. 2). The lack of residual erosion control may have partially resulted from the excessive runoff from this soil, which contained more clay and less organic matter than the Rad soil. About 30% of the applied water ran off both PAM treatments during the first irrigation on the Roza soil (Fig. 2) compared to only 5 to 10% for the Rad soil (Fig. 1). This resulted in less PAM remaining on the Roza soil compared to the Rad soil. Soil loss was also much greater for the Roza soil (Fig. 2) compared to the Rad soil (Fig. 1), resulting in greater amounts of PAM being removed with the soil.

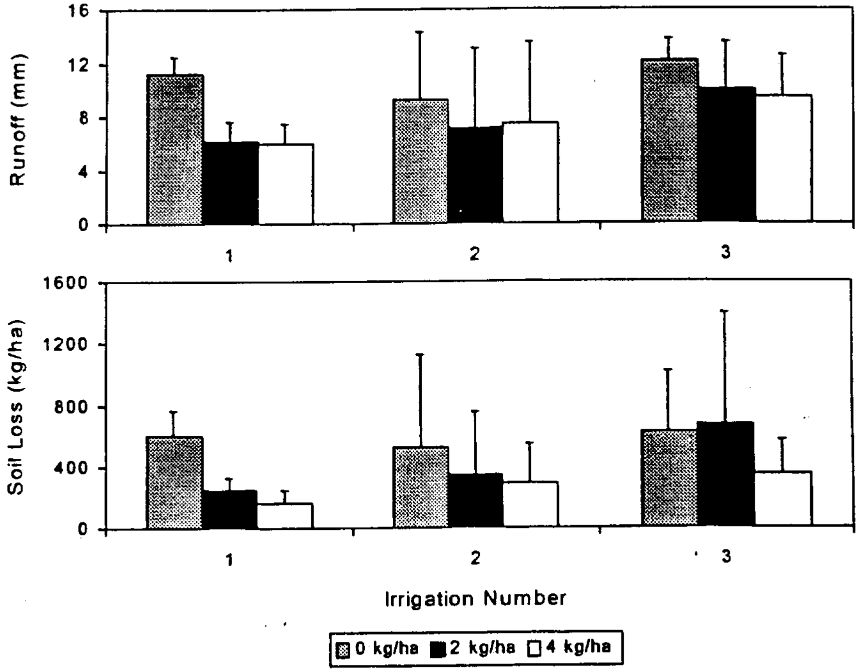
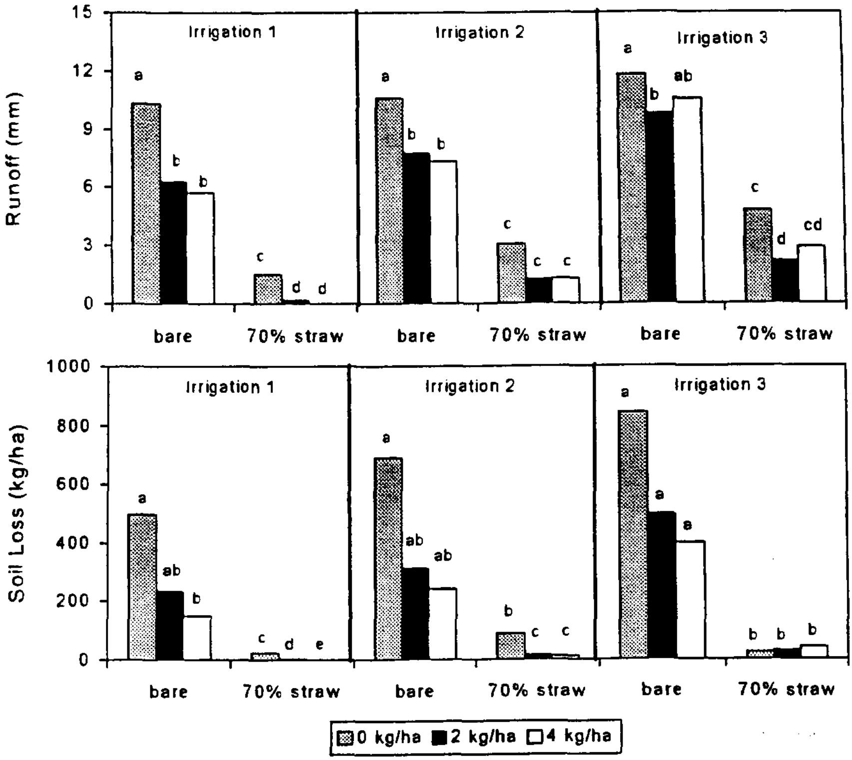


Figure 2. Runoff and soil loss from three, 20-mm irrigations on Roza loam during study 1. Applied two PAM rates with irrigation 1. Bars represent 95% confidence intervals.

Study 2 – PAM and Surface Residue

Since study 1 showed that PAM only reduced runoff for one irrigation, we conducted a second study to determine if the residual effects of PAM increased when used in combination with straw surface residue (Bjorneberg et al., 2000). Only the Roza soil was used for study 2 because the runoff potential was greater with the Roza soil than the Rad soil. The 70% straw cover more effectively controlled runoff and soil loss (Fig. 3) than either 2 or 4 kg PAM ha^{-1}.

Using PAM alone was about as effective as using 30% straw cover alone to control runoff and soil loss (Fig. 4). PAM was still effective when applied to straw-covered soil, but surface cover did not improve the residual effects of PAM. However, PAM reduced runoff from bare soil for all three irrigations during this study (Fig. 3 and 4), which was different from study 1.



gure 3. Runoff and soil loss from three, 20-mm irrigations on bare and straw-covered Roza ›il during study 2. Applied two PAM rates with irrigation 1. Columns with the same letter ithin an irrigation are not significantly different at P<0.05 (data from Bjorneberg et al., 2000).

aboratory procedures were similar between studies 1 and 2, and the same Roza soil was used r both studies. Approximately 50% of the applied water ran off the bare soil control treatments this study, similar to the Roza soil in study 2. The only identified difference was greater iriability among replicates within a treatment for the Roza soil in study 1 (coefficients of iriation from 20 to 50%) compared to study 2 (coefficients of variation from 10 to 25%).

udy 3 – Multiple PAM Applications

ngle and multiple PAM applications reduced runoff by similar amounts for the first two igations compared to the control (Fig. 5). For the last two irrigations, the three, 1 kg PAM ha^{-1} plications more effectively controlled runoff than the one, 3 kg PAM ha^{-1} application. ımulative runoff from the multiple PAM treatment (9 mm) was 25% less than from the single ۱M treatment (12 mm). Multiple PAM applications stabilized the soil surface for the first three igations. For the single PAM application, however, the stabilized soil surface was slowly graded by droplet impact, runoff and erosion during subsequent irrigations. There was also ss time for PAM to degrade between irrigations with multiple applications, which may be more portant under field conditions than in the laboratory.

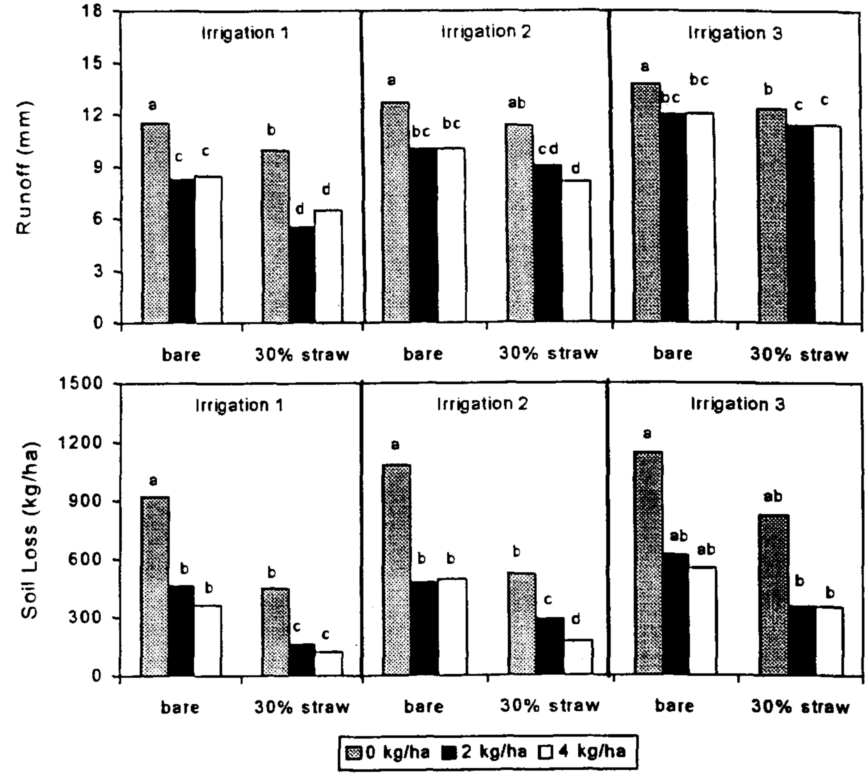


Figure 4. Runoff and soil loss from three, 20-mm irrigations on bare and straw-covered Roza soil during study 2. Applied two PAM rates with irrigation 1. Columns with the same letter within an irrigation are not significantly different at $P<0.05$ (data from Bjorneberg et al., 2000).

Both single and multiple PAM applications significantly reduced soil loss compared to the control for all four irrigations (Fig. 5). Unlike runoff, soil loss was not significantly different between single and multiple PAM treatments for the last two irrigations. Sediment concentration in runoff from the multiple PAM treatment was significantly less than from the control, but the single application sediment concentration was not different from either the control or the multiple application for irrigations 3 and 4 (data not shown).

Applying 1 kg PAM ha^{-1} with the first irrigation was more effective compared to the control during study 3 than study 1. In study 3, both runoff and soil loss were reduced about 90% (Fig. 5). Runoff was reduced only 66% and soil loss was not significantly reduced for the first irrigation in study 1 (Fig. 1). These differences may result from differences in irrigation depth and PAM concentration. Since the irrigation depth was less in study 3 (13 vs. 20 mm), the PAM concentration had to be greater (7.5 vs. 5 mg L^{-1}) to apply the same amount of PAM. However, Aase et al (1998) found no benefit to applying the same of amount of PAM (2 or 4 kg ha^{-1}) with less water (8 vs. 20 mm).

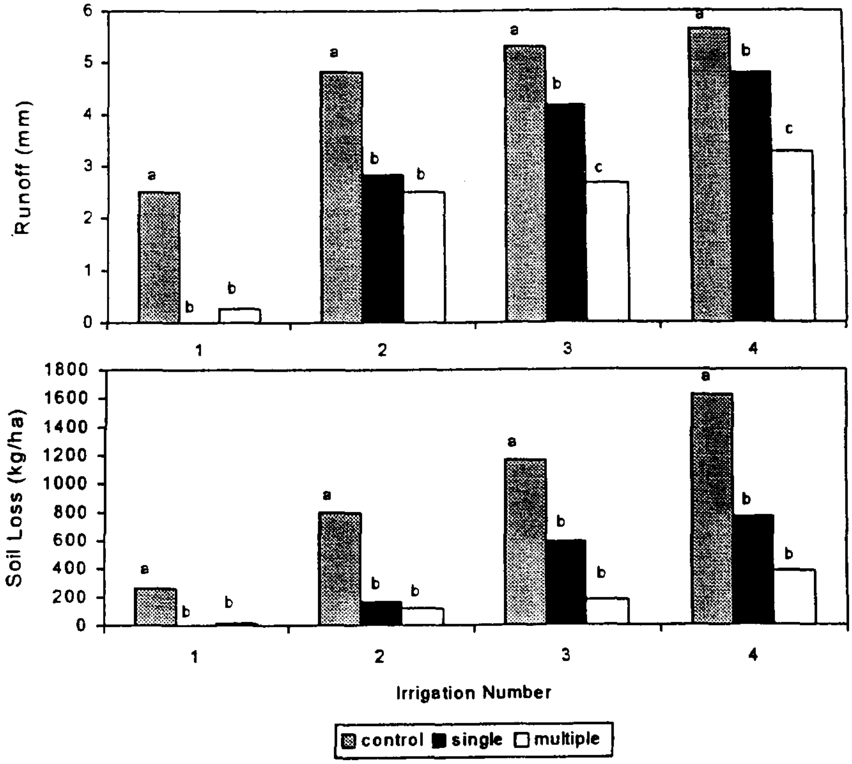


Figure 5. Runoff and soil loss from four, 13-mm irrigations for study 3. PAM was applied at 3 kg ha^{-1} with irrigation 1 (single) or at 1 kg ha^{-1} with irrigations 1-3 (multiple). Columns with the same letter within an irrigation are not significantly different at $P<0.05$ (data from Bjorneberg and Aase, 2000).

CONCLUSIONS

Based on these study results, we conclude that PAM can effectively control runoff and soil erosion when applied through a simulated sprinkler system. A single application of 2 to 4 kg PAM ha^{-1} is effective for at least one irrigation under laboratory conditions. Applying PAM to straw-covered soil controlled runoff and soil loss equally or better than using PAM or straw cover alone. Seventy percent straw cover more effectively reduced runoff and soil loss than PAM and was effective for three irrigations. Applying 2 or 4 kg PAM ha^{-1} was about as effective as 30% straw cover for controlling runoff and soil erosion. Reductions in runoff and soil erosion after four irrigations were greater with multiple PAM applications than a single PAM application, even though the same total amount of PAM was applied. Under field conditions, a single application could be used for a critical irrigation such as seedling emergence or before crop cover is established, but multiple PAM applications and crop residue should be used for season-long runoff and soil erosion control. Bear in mind, these results could vary with irrigation water quality and soil chemistry.

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