

Evaluation of Polyacrylamide (PAM) for Reducing Sediment and Nutrient Concentration in Tail Water from Central Coast Vegetable Fields

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Introduction

Current state and federal water quality regulations, such as the conditional waiver for agricultural discharge and proposed total maximum daily loads (TMDL) for nutrients and sediments, will require that growers implement best management practices that minimize impairments to surface and ground water quality. While most growers are currently using recommended practices such as drip irrigation, cover crops, and integrated pest management to reduce the impacts of agriculture on water quality, additional management tools could help growers achieve more dramatic improvements to water quality.

Growers who produce vegetables and row crops on highly erodible soils, such as the east side of the Salinas valley or sloped fields in the Elkhorn watershed, have a difficult challenge in reducing sediment and nutrient levels in run-off. Though many growers are using sediment basins and drip irrigation to minimize run-off and capture sediments, these practices are costly and may not fully achieve water quality targets. Our initial trials evaluating polyacrylamide (PAM), a chemical polymer, for use in sprinkler and furrow systems, demonstrated significant reductions in sediment and nutrient concentration in irrigation run-off.

A brief primer on PAM

Polyacrylamide (PAM) is a polymer used to stabilize soil and prevent erosion. Various forms of PAM exist, but the type used for erosion control is a large, negatively charged molecule (12-15 megagrams per mole) that is water soluble. PAM is commercially available in dry granular, emulsified liquid, and dry tablet forms, and costs as low as \$2 to \$4 per pound depending on the formulation, supplier, and cost of the raw materials used for manufacturing PAM (*ie.* natural gas). Non agricultural uses of PAM include waste and potable water treatment, processing and washing of fruits and vegetables, clarification of juices, manufacturing of cosmetics, and paper production.

Use of PAM for irrigation and erosion control

Beginning in the early 1990's numerous studies demonstrated that low application rates of PAM (1 to 2 lb/acre) reduced run-off and improved water quality in furrow systems by stabilizing the aggregate structure of soil, by improving infiltration, and by flocculating out suspended sediments from irrigation tail-water. Most of the research and demonstrations of PAM for irrigation were conducted in Idaho and Washington states where soils are very erodible. By 1999, almost 1 million acres of land were annually treated with PAM in the northwest of the United States. Additionally, growers in the San Joaquin Valley and the Bakersfield areas of California have been using PAM to reduce soil erosion during irrigation events.

Application methods

Most applications of PAM have been conducted in furrow systems by adding dry or liquid product to water flowing in the head ditch or the main line (if gated pipe is used) at a rate to achieve a 2.5 to 10 ppm concentration in the furrow water. The application can be made continuously during the irrigation or until the water advances almost to the end of the furrows. An alternate application method, called the “patch method” involves applying granular PAM to the first 3 to 5 feet of the head of each furrow. The granular PAM slowly dissolves during the irrigation, releasing product into the water. Applications of PAM into sprinkler systems require equipment for injecting concentrated liquid PAM into a pressurized main line at flow rates between 0.25 to 2 gallons per minute to treat a 30 to 100-acre field irrigated with solid-set impact sprinklers.

Human and environmental safety

PAM has a very low toxicity to mammals and is safe to handle, but precautions should be taken to minimize skin and eye exposure, and to avoid breathing dust from dry material. PAM can cause skin irritation in sensitive individuals. PAM becomes very slippery when wet so spills should be cleaned with a dry absorbent before attempting to wash it. PAM is sometimes confused with acrylamide monomer, a precursor in the manufacturing of PAM. Acrylamide monomer, a potential neurotoxin, has a high, acute toxicity in mammals. The Federal EPA requires that PAM sold for agricultural uses contain less than 0.05% acrylamide monomer. In soil, PAM degrades by physical, chemical, biological, and photochemical processes, but it does not decompose into the acrylamide monomer.

Environmental studies of PAM have not shown any negative effects to the aquatic organisms. Anionic (negatively charged) PAM has a very low toxicity to fish, daphnia and algae. A previous study of the movement of PAM from agricultural fields showed that less than 3% of the applied product remained in the run-off leaving the field. The remaining PAM in the tail water was almost completely removed through adsorption to suspended sediments as the water flowed a distance of 300 to 1000 ft in the tail water ditch.

Evaluation of PAM in Central Coast vegetable fields

Although research in other parts of the United States has demonstrated that PAM can reduce soil erosion during irrigations, few if any evaluations of this practice have been conducted in vegetable and row crop fields on the Central Coast. Considering the important need to identify effective conservation practices that can improve farm water quality, we conducted a series of field trials to evaluate the effect of PAM¹ on infiltration, run-off, and the concentration of sediment and nutrients in tail-water from furrow and sprinkler systems.

¹ Amber1200D, formerly Superfloc A-836, Amber Chem. Inc

Furrow systems

PAM has been most successfully used to improve furrow irrigation. We evaluated the effect of PAM on infiltration and the concentration of sediments and nutrients in tail water from furrows of 6 commercial vegetable fields in the Salinas Valley using a recirculating infiltrometer. Water, treated with 10 ppm of PAM was first added to a 20 ft-length of furrow. The water reaching the end of the furrow was recirculated to the head using a bilge pump. Untreated water was added from a tank to the head of the furrow to maintain a constant depth of water. Infiltration was estimated by measuring the rate that the tank emptied. Our results demonstrated that the pretreatment with PAM in the furrow water was sufficient to reduce the suspended sediments and nutrients in the tail water, but the PAM treatment did not have a consistent effect on infiltration. PAM significantly increased infiltration in a silt loam soil and significantly reduced infiltration in clay loam and sandy loam soils (Table 1). The PAM treatment reduced suspended sediments and turbidity in the run-off from all soil types. On average, the PAM treatment reduced suspended sediments by 86% (Table 2). Additionally, the PAM treatment reduced total nitrogen, soluble P, and total P in the tail water run-off (Tables 3 and 4) which corresponded to a 80% reduction in total P, 42% reduction in soluble P, and a 65% reduction in total N for all soil types tested. The concentration of total phosphorus in the tail water decreased as the concentration of suspended sediments in the tail water was reduced (Figure 1). The PAM treatment significantly reduced nitrate concentration in the furrow tail water of only one of the soil types tested.

Sprinkler systems

For PAM to be a useful conservation practice on the Central Coast, it needs to be effective with sprinkler irrigation. However, much less information has been published about the use of PAM in sprinklers than in furrow systems. We conducted several field trials evaluating the effect of PAM on run-off from solid-set sprinklers in commercial vegetable fields. A concentrated solution of PAM was injected into the main line of the sprinkler system at a rate to achieve a 5 ppm concentration in the irrigation water. The applications were done during the irrigations between germination and thinning. Each PAM application was made during the first 30 minutes of the irrigation and again when significant ponding occurred in the furrows and continued until the end of the irrigation set. Application rates of PAM varied from 0.5 to 0.75 lb/acre per irrigation.

The results from these trials demonstrated that PAM significantly reduced sediment and turbidity in run-off from sprinklers. Results of 3 irrigations from a sprinkler trial conducted near Chualar are shown in Table 5. The application of PAM reduced sediment and turbidity levels in the run-off for all irrigations, which corresponded to a 95% reduction in sediment loss. Additionally, PAM significantly reduced run-off during the 3rd irrigation. The effects of PAM on phosphorus and nitrogen concentration in sprinkler run-off were more variable than in the furrow trials. Total nitrogen and phosphorus concentration was significantly lower in tail water from the PAM treatment than the untreated control. However, at another field site, the PAM treatment did not significantly reduce nitrogen and phosphorus in tail water from the sprinklers, but it did significantly reduce sediment concentration (data not shown).

Lettuce yield

The application of PAM may potentially improve lettuce yields by increasing water penetration and by reducing soil crusting. We found that the application of PAM did not affect box yield of romaine and head lettuce at the 4 field trials where we were able to conduct yield measurements (Table 6). The PAM treatment significantly increased box weight of romaine heads at one of the field trials. Since PAM was not applied in more than 3 irrigations for any one trial, we cannot conclude if more applications of PAM would affect yield.

Conclusions

Our preliminary trials demonstrated that applying polyacrylamide at low rates through sprinkler and furrow systems can dramatically reduce sediment levels in irrigation run-off and potentially reduce total phosphorus and nitrogen concentrations. The effect of PAM on infiltration and run-off was dependent on soil type, but on most of the Central Coast soils that we tested the low rates of PAM had no significant effect on infiltration. Although our initial results are encouraging, further trials will be needed to determine if PAM can consistently reduce nutrient concentration in run-off from sprinklers, and to determine the optimal dose and application strategy for improving water quality.

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Table 1. Effect of PAM pretreatment (10 ppm) on final infiltration rate and total infiltration in furrows of 6 soil types from the Salinas Valley. Treatment means represent the average of 4 replications.

| Soil Type | Final Infiltration Rate | | Total Infiltration ² | |
|--------------------|-------------------------|---------|---------------------------------|---------|
| | PAM | Control | PAM | Control |
| | --- mm/hr --- | | ----- mm ----- | |
| Mocho silt loam | 7.5 | 3.5 | 18.4 | 16.9 |
| Metz complex | 7.9 | 7.3 | 19.8 | 18.9 |
| Rincon clay loam | 2.6 | 4.0 | 13.7 | 13.9 |
| Salinas clay loam | 5.2 | 5.0 | 18.0 | 26.6 |
| Chualar loam | 5.8 | 4.2 | 18.7 | 18.6 |
| Chualar sandy loam | 159.0 | 197.3 | 247.5 | 349.5 |
| Average | 32.4 | 38.4 | 57.6 | 76.5 |

¹ ■ = treatment means are statistically different at the 95% confidence level.

² total infiltration during 1.5 hours

Table 2. Effect of PAM pretreatment (10 ppm) on sediment concentration and turbidity of furrow tail water for 6 soil types from the Salinas Valley. Treatment means represent the average of 4 replications.

| Soil Type | Total Suspended Solids | | Turbidity | |
|--------------------|------------------------|---------|-----------------------|---------|
| | PAM | Control | PAM | Control |
| | --- TSS mg/L --- | | --- Turbidity NTU --- | |
| Mocho silt loam | 244 | 2024 | 55 | 1977 |
| Metz complex | 156 | 669 | 18 | 473 |
| Rincon clay loam | 412 | 1715 | 51 | 1013 |
| Salinas clay loam | 240 | 2759 | 59 | 2437 |
| Chualar loam | 306 | 2580 | 129 | 2992 |
| Chualar sandy loam | 36 | 165 | 24 | 183 |
| average | 224 | 1592 | 54 | 1459 |

¹ ■ = treatment means are statistically different at the 95% confidence level.

Table 3. Effect of PAM pretreatment (10 ppm) on nitrate and total nitrogen concentration of furrow tail water for 6 soil types from the Salinas Valley. Treatment means represent the average of 4 replications.

| Soil Type | Nitrate-Nitrogen | | Total Nitrogen ² | |
|--------------------|---------------------------------|-------------------|-----------------------------|---------|
| | PAM | Control | PAM | Control |
| | --- NO ₃ -N mg/L --- | | --- TKN mg/L --- | |
| Mocho silt loam | 1.30 | 1.95 | 2.38 | 6.38 |
| Metz complex | 23.13 | 23.33 | 1.43 | 2.25 |
| Rincon clay loam | 22.38 | 22.58 | 1.75 | 3.08 |
| Salinas clay loam | 0.71 | 1.23 ¹ | 1.38 | 6.95 |
| Chualar loam | 2.03 | 2.09 | 2.20 | 8.45 |
| Chualar sandy loam | 1.52 | 1.46 | 0.43 | 0.73 |
| Average | 8.24 | 8.48 | 1.57 | 4.48 |

¹ ■ = treatment means are statistically different at the 95% confidence level.

² Total Kjeldahl Nitrogen

Table 4. Effect of PAM pretreatment (10 ppm) on soluble and total phosphorus concentration of furrow tail water for 6 soil types from the Salinas Valley. Treatment means represent the average of 4 replications.

| Soil Type | Soluble Phosphorus | | Total Phosphorus | |
|--------------------|------------------------|-------------------|-------------------------|---------|
| | PAM | Control | PAM | Control |
| | --- Soluble P mg/L --- | | ----- Total P mg/L ---- | |
| Mocho silt loam | 0.35 | 0.78 ¹ | 0.85 | 5.30 |
| Metz complex | 0.09 | 0.16 | 0.35 | 1.33 |
| Rincon clay loam | 0.31 | 0.44 | 0.68 | 1.88 |
| Salinas clay loam | 0.36 | 0.64 | 0.80 | 5.40 |
| Chualar loam | 0.28 | 0.46 | 0.58 | 3.23 |
| Chualar sandy loam | 0.09 | 0.12 | 0.14 | 0.30 |
| Average | 0.24 | 0.42 | 0.55 | 2.80 |

¹ ■ = treatment means are statistically different at the 95% confidence level.

Table 5. Effect of PAM on nutrient and sediment concentration in run-off from solid set sprinklers. Treatment means represent the average of 4 replications.

| Treatments | PAM Application lb ai/acre | Applied Water inches | Total Kjeldahl N | | P (soluble) P (total) | | Total Dissolved Solids | Total Suspended Solids | Turbidity NTU | Runoff | | Sediment lb/acre |
|----------------------------------|-------------------------------|-------------------------|-------------------|------|-----------------------|------|------------------------|------------------------|------------------|--------|-----|---------------------|
| | | | mg/L | mg/L | gal/acre | (%) | | | | | | |
| -----1st Irrigation 7/9/04----- | | | | | | | | | | | | |
| PAM | 0.73 | 0.78 | 2.83 ¹ | 6.03 | 0.41 | 0.55 | 905 | 72 | 66 | 1389 | 6.6 | 0.8 |
| Untreated Control | 0.00 | 0.86 | 5.20 | 3.56 | 0.61 | 2.83 | 885 | 900 | 2647 | 1138 | 4.9 | 8.5 |
| -----2nd Irrigation 7/14/04----- | | | | | | | | | | | | |
| PAM | 0.58 | 0.81 | 2.35 | 1.97 | 0.22 | 0.38 | 1073 | 32 | 39 | 1932 | 8.8 | 0.5 |
| Untreated Control | 0.00 | 0.84 | 5.13 | 1.51 | 0.39 | 2.05 | 905 | 786 | 1691 | 1947 | 8.5 | 12.8 |
| -----3rd Irrigation 7/19/04----- | | | | | | | | | | | | |
| PAM | 0.54 | 0.82 | 1.73 | 10.5 | 0.33 | 0.33 | 1103 | 20 | 16 | 976 | 4.4 | 0.2 |
| Untreated Control | 0.00 | 0.71 | 4.00 | 10.1 | 0.47 | 2.23 | 800 | 1205 | 3031 | 1507 | 7.9 | 15.1 |
| -----Average/Total----- | | | | | | | | | | | | |
| PAM | 1.85 | 2.41 | 2.30 | 6.2 | 0.32 | 0.42 | 1027 | 42 | 40 | 1432 | 6.6 | 1.5 |
| Untreated Control | 0.00 | 2.41 | 4.78 | 5.1 | 0.49 | 2.37 | 863 | 964 | 2456 | 1531 | 7.0 | 36.4 |

¹ = treatment means are statistically different at the 95% confidence level

Table 6. Effect of PAM on box yield and head weight of romaine and head lettuce.

| Trial Location | Box Weight | | Box Yield | |
|------------------------|--------------------|---------|----------------------|---------|
| | PAM | Control | PAM | Control |
| | ----- lb/box ----- | | ----- box/acre ----- | |
| King City ² | 41.0 ¹ | 39.1 | 760 | 731 |
| Chualar-a ³ | 21.9 | 21.1 | 1145 | 1130 |
| Soledad ⁴ | 39.3 | 38.5 | 1179 | 1190 |
| Chualar-b ³ | 24.0 | 24.6 | 944 | 957 |
| Average | 31.5 | 31.0 | 1007 | 1002 |

¹ = treatment means are statistically different at the 95% confidence level

² romaine

³ romaine hearts

⁴ iceberg

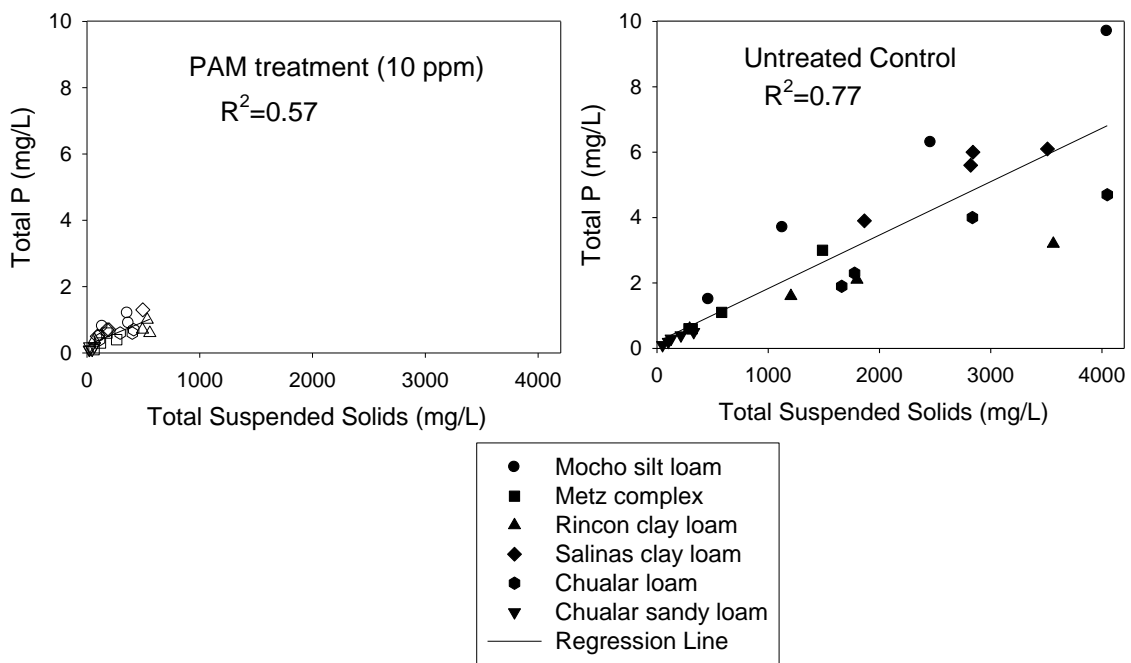


Figure 1. Relationship between suspended sediments and total phosphorus in furrow tail water, treated and untreated with PAM, for 6 soils in the Salinas Valley.