PRACTICAL FIELD APPLICATION AND PAM TRANSPORT IN SURFACE IRRIGATION

by Tim D. Stieber and Heidi Chapman-Supkis

Polyacrylamide (PAM) products for erosion and infiltration management are being marketed in all western states. Field trials and demonstrations initiated by USDA's Agricultural Research Laboratory in Kimberly, Idaho, and by industry touched off a wildfire of producer interest in PAM technology. An estimated 50,000 acs were treated during 1995 —the first growing season receiving full industry promotion. Producers are quick to try this new technology because it is flexible, easy to implement, and the risk is low (i.e. rates are economic and there is little chance of crop damage). Producer satisfaction with PAM is high because it produces fast, dramatic, and visual results and multiple crop production benefits are apparent to most producers.

Although various PAM materials have been researched for erosion and infiltration management since the 1950s, the ultra high molecular weight, water soluble polymers developed in the 1980's allowed economic application rates. As early as 1986, Wallace and Wallace (1986) described at least five erosion problems which could be solved with PAM. Lentz et al (1992) outlined field application methods for treating irrigation water with PAM for controlling erosion and increasing water infiltration. This allowed 95% erosion control and infiltration benefits with very low PAM application rates. Further research tested PAM over a range of soil types and slopes *(Lentz and Sojka, 1994)*. By the 1994 growing season, anyone current in the literature knew what PAM could do. What was needed was to transfer PAM technology to producers and overcome field scale application difficulties.

Problems anticipated or observed during initial adoption included: variable erosion control across irrigation sets, selection or adjustment of application rates based on field erosion potential, difficulty getting dry PAM dissolved into irrigation water, problems with dry PAM metering equipment and PAM caused blockage of siphon tubes.

Objectives:

1. Demonstrate and test PAM technology on a farm field scale.
2. Measure application uniformity for dry and liquid methods.
3. Measure losses of PAM to conveyance systems and in field runoff.
4. Identify barriers to widespread adoption of PAM technology.

Methods and Materials

All tests were conducted on furrow irrigated fields in southwest Idaho. Soils on the study fields were variations of Owyhee and Greenleaf silt loam. The number of field sites used to study various objectives is listed in Table 1. A commercially available PAM material, Superfloc A-836, CYTEC Industries Inc., was utilized for all field tests reported here. Superfloc A-836 is similar to other commercially available materials; moderately anionic, about 18% charge density, a molecular weight of 12 to 18 million g/mole.

Polyacrylamide concentration in water samples was determined using a flocculation test adapted from Lentz et al. (1996). This test relies on a light spectrophotometer to detect the rate of settling for a kaolin clay dispersant. Accuracy of 0.3 to 0.5 ppm can be obtained if rigorous calibration is performed and procedures are carefully followed. Lab standards (0, 1, 5, 10 and 20 ppm PAM) were prepared using irrigation water from each site. Generally a low and high range calibration equation were needed as illustrated in Figure 1. Correlation coefficients were generally greater than 0.97. The tests were conducted within 30 hours at a water temperature of 65o to 75oF. Kaolin clay dispersant (0.1 g +/- 0.005 g) was placed into 5 ml test tubes that had been calibrated for a Hach 2000 spectrophotometer. The Hach 2000 was set to continuously read percent light transmittance (%T). Pre-testing indicated that a %T of 0.35% was the clarity shift inflection point for the equipment and dispersant utilized. After placing 5 ml of sample into a tube it was Vortex mixed for 1 min. then quickly transferred into the Hach 2000. The time to reach 0.35 %T was recorded and used to calculate PAM concentration.

Total water flow to each field was measured using cipoletti weirs or a current velocity meter and ditch cross sectional measurements. This enabled PAM injection based on total flow to the field. Delivery to furrows was via 0.75 to 1.25-in. siphon tubes flowing at 2 to 8 gal./min.. Furrow inflows and runoff were measured hourly using a catch can and stop watch for the first 12 hrs., and at the termination of each 24-hr. irrigation. Sediment delivery off furrows was measured using Imhoff cones *(Sojka et al 1992)* with calibration relationships developed for each soil type with and without PAM treated water. A computer spreadsheet *(Sojka et al, 1994)* integrated all water flow and sediment measurements and calculated a water budget and sediment delivery for each furrow.

Uniformity of PAM delivery across the field headland was monitored by collecting water samples from siphon tube discharge at a minimum of five points at increasing distance from PAM injection. This enabled calculation of a lower quarter average application uniformity. PAM concentration in irrigation runoff and water flow were combined to give total PAM loss for each furrow for that 24-hr. irrigation. Losses to suspended sediment and ditches was calculated by difference; PAM applied minus PAM accounted for in irrigation flow from siphon tubes. Sites selected for PAM uniformity work had negligible sediment in the inflow water.

Three trials were conducted to study PAM influence on siphon tube blockage. For each trial, dry

Table 1. Polyacrylamide field trial objectives and number of fields involved.

Measurable Field Objectives Number of Fields	No. of Fields
Measure benefits of PAM usage on a farm field scale.	12
Measure application uniformity for dry and liquid methods.	9
Measure losses of PAM to conveyance systems and in field runoff.	6
Determine PAM influence on siphon tube flow rate.	3

Figure 1. Typical high and low range calibration equations for determing PAM concentration using kaolin clay dispersant method.

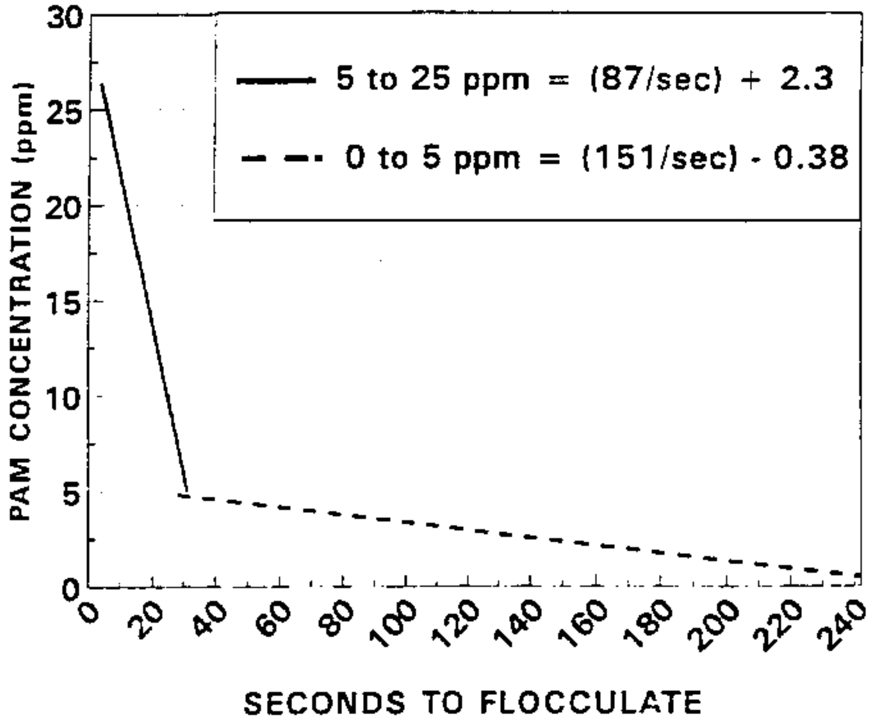


Table 2. Treatments evaluated for influence on siphon tube flow during PAM application.

Treatment	Description
No PAM	Tube flow was measured for irrigation water not treated with PAM.
PAM	Irrigation water treated to be at 8 ppm PAM for 3 to 7 hours.
Wax	Molten paraffin wax. Excess removed by heating tube with a torch.
Paint	Exterior, latex paint poured through tubes after aluminum primer
Plastic	3/4-in. polyurethane plastic siphon tubes
New tubes	New siphon tubes that had no appreciable aluminum oxide weathering.
New + wax	New siphon tubes treated with paraffin wax.
New + Teflon	New siphon tubes with inside coated with Teflon (Slick 50).
1-in. tubes	1-in. weathered tubes set at a low flow rate.
1-in. + inserts	1-in. weathered tubes with 3/4-in. plastic inserts to restrict flow

Table 3. Equations for calculating PAM addition rate to irrigation flow for various PAM materials and methods of application.

- Liquid Solution Injection (gpm) = (gpm irrigation flow x desired PAM ppm) / *PAM* stock solution ppm
- Oil Emulsion Injection (mls/min) = (desired ppm) x (cfs irrigation flow) x (1.7) / (Percent PAM in Emulsion)
- Metering Dry - Water Treatment: (oz/min) = (desired ppm) x (cfs irrigation flow) x 0.06
- Metering Dry - Rate Per Acre: (oz/min) = [(desired lbs/ acre) x (acres served) x (16 oz/ lb)] / Water Advance (min)
- Furrow Placement Method: Dry (oz/furrow) = (acres served x lbs. per acre desired) / 16 oz per lb.
- General rate for PAM Blocks = 1 lb. of block per acre irrigated

Table 4. Lower quarter average application uniformity for PAM applications made to farm fields. Target PAM concentration, based on water flow, was generally 6 to 10 ppm.

PAM FORM APPLIED[1]	DITCH TYPE & LENGTH[2]	AVG. INFLOW CONC. (ppm)	LOWER QUARTER[3] Applica. Uniformity (%)
DRY, 7/3/94	Dirt, 1000'	14.4	55.6
DRY, 6/1/95	Concrete, 1200'	5.9	71.5
DRY, 6/12/95	Concrete, 1200'	11.0	81.8
DRY, 7/3/95	Concrete, 1100'	7.8	77.8
DRY, 8/02/95	Dirt, 600'	6.9	47.0
DRY, 8/02/95	Concrete, 1250'	16.6	56.0
LIQUID 6/10/94	Dirt, 800'	6.2	83.0
LIQUID 6/15/94	Dirt, 1200'	5.3	97.0
LIQUID 8/24/95	Concrete	4.2	87.0
DRY AVG.	na	10.4	65.0
LIQUID AVG.	na	5.2	89.0

[1] Both dry and predissolved liquid were Superfloc A-836.
[2] Length refers to distance between first and last sample points.

Superfloc A-836 was metered into ditch flow using a commercial applicator for three to seven hours. Three-quarter-in. aluminum siphon tubes were selected that were in good condition. The older tubes had an aluminum oxide coating which occurs naturally after several years of use. Various coatings and variations in tube diameter were evaluated as potential remedies (Table 2). There were five replicates of each treatment although each treatment was not evaluated for each trial.

Initial siphon tube output was set to be similar for the various treatments using a catchcan and stopwatch. Discharge from each tube was measured from six to thirteen times during irrigation.

Results and Discussion

Polyacrylamide application produced highly visual results on all field sites with treated runoff being clear and untreated furrows appearing muddy. The influence of Superfloc A-836 on sediment, nutrient, and pesticide concentration in runoff water is reported by Bahr and Stieber elsewhere in these proceedings. Large reductions in tailwater constituents (>75%) was obtained with close to 1 lb/ac PAM applied in irrigation water.

The various methods for treating irrigation water with PAM vary significantly with regard to practicality. No one method fits each situation. Adding dry PAM to irrigation flow (injection) has been the most widely adopted application method. This approach combines ease of application, low economic cost and spectacular results. PAM emulsions, dissolving blocks and placing dry PAM in the furrow are newer technologies and will likely gain in popularity since they were developed to solve problems encountered with dry PAM metering. Rate calculation equations for various methods can be found in Table 3.

▼ METHOD 1 — Liquid solutions prepared from dry PAM. Vigorous mixing and recirculation for 30 to 45 min. is required to prepare a true solution from dry PAM. A 0.3 to 0.5% solution is most common (0.3 % = 3000 ppm = 2.5 lbs PAM/100 gal water).

Advantages: Minimal in-the-ditch mixing required for uniform product delivery. Solutions can be injected into sprinklers.

Disadvantages: PAM solutions take time to prepare. Due to viscosity at high concentrations, a large tank is needed to treat large fields. Volume of 0.5% solution to treat 900 gpm flow (10 ppm dosage) is 108 gph.

Practical Tips: A Pemberthy dry powder eductor simplifies adding powder to recirculating water. A float box is useful to keep PAM solution flow to a ditch constant as tank volume decreases. A transfer pump or air lance is needed to keep hydrated PAM granules suspended until complete dissolution occurs.

▼ METHOD 2 — Liquid Emulsions. Oil emulsions with 25 to 40% PAM solids (2 to 3.3 lbs. PAM/gal.) are commercially available and can be metered into ditch flow or pressurized systems.

Advantages: Smallest volume of liquid, easy to get PAM into solution.

Disadvantages: Contain surfactants and hydrocarbons which are not desirable in irrigation runoff. Will coagulate with residual water in injection equipment. Become very viscous in cold temperatures and must be kept from freezing. More expensive than dry per unit PAM

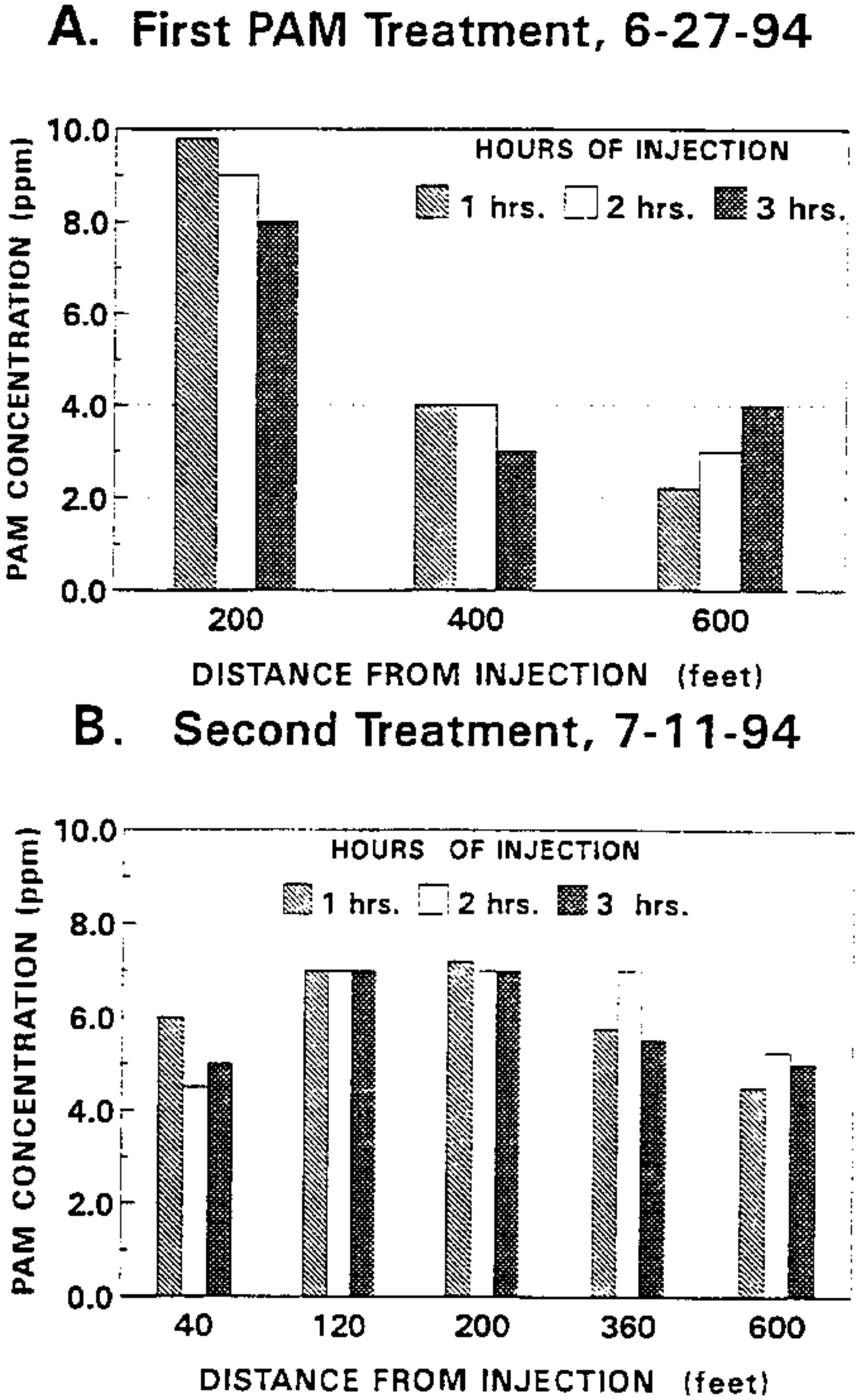
Practical Tips: Use a low pressure pump instead of a gravity feed system.

METHOD 3 — Metering Dry PAM. A dry PAM dispenser is positioned to drop dry product direcly into irrigation flow upstream from siphon tubes or gated pipe.

Advantages: Relatively straight forward procedure, especially if a high quality dispenser is used. Equipment is easily moved between fields and cost for dry products are lower than for emulsions.

Disadvantages: Some water mixing is needed for optimum performance. Tendency to over-apply due to low addition rates. Wind can blow dry PAM unless applicator area is sheltered.

Figure 2. Concentration at distrance from liquid PAM injection during the first (A) and second (B) PAM treatment of a field.



Practical Tips: Apply dry PAM near a break in the water surface to get PAM granules below the water surface. PAM dissolves quicker if ground fine but this makes it more difficult to meter. Inject 50 to 100 ft. upstream from the first siphon tube to optimize mixing.

▼ METHOD 4 — Furrow Placement of Dry. A small quantity (0.5 to 2 oz) of dry PAM is placed into the furrow so that it dissolves into the advancing water.

Advantages: Easiest method for beginners. No application equipment required, only a calibrated scoop. Rate can easily be adjusted for wheel and non-traffic furrows to avoid excessive infiltration and slow water advance. Avoids problems of siphon tube blockage and also the potential to fill in irrigation ditches and pipes.

Disadvantages: Inconsistent erosion control, especially in the furrow headlands area of the field. Is considered more time consuming by some. Can not adjust application rate during irrigation.

Practical Tips: Spread out dry PAM over several feet of furrow prior to turning on water.

▼ METHOD 5 — Dissolving PAM Block: Pre-formed blocks can be formulated to specific weights (i.e. 1 lbs., 2 lbs., etc.). Allied Colloids has a Patent Pending on this technology. Blocks are placed in irrigation flow so that each furrow receives treated water.

Advantages: No application equipment is needed except a mesh bag or screen to hold the blocks in irrigation flow.

Disadvantages: Significant turbulence is required to dissolve a PAM block and it is difficult to have enough PAM released to control erosion on some fields.

Practical Tips: Based on observed level of erosion control, leave blocks whole or break them into smaller pieces to expose more surface area, thus releasing more PAM.

▼ PAM Application Uniformity

Collecting water samples from siphon tubes during PAM injection allowed evaluation of chemical distribution to fields (Table 4). Lower quarter application uniformity was greater for liquid (89%) than for dry application (65%). Low uniformity was associated with field situations that had little turbulent water mixing.

Although injection of liquid PAM solutions had greater application uniformity, there was little visual benefit of using dry predissolved liquids over dry. Collecting water samples from irrigation flow treated with dry PAM can be misleading since dry granules do not dissolve quickly. In fact, complete dissolution likely occurs in the furrow or after hydrated granule adheres to the side of an irrigation ditch.

▼ PAM Losses to Conveyance Systems and Field Runoff

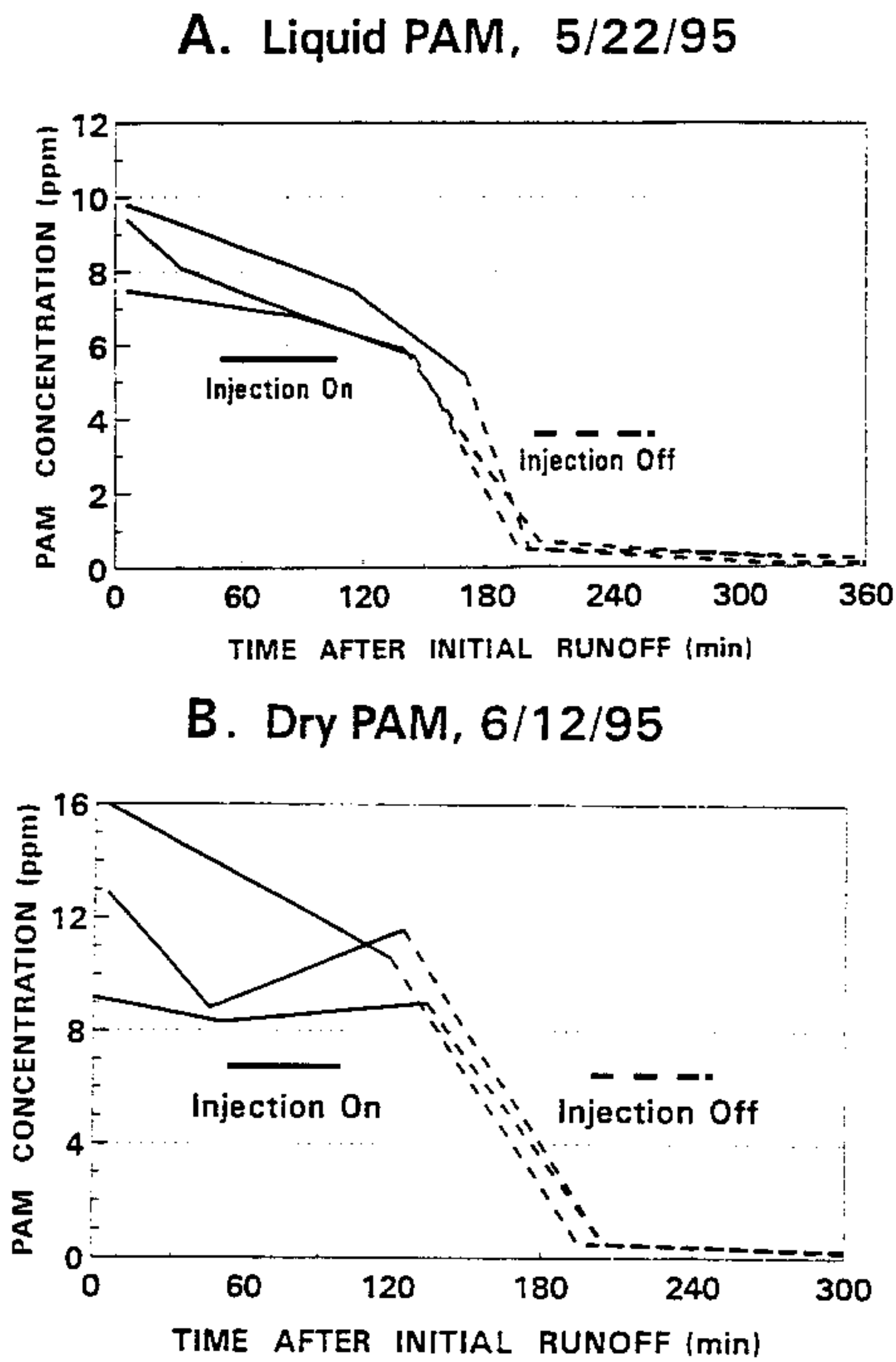
Dirt conveyance systems can complicated PAM injection by reducing PAM concentration delivered to furrows (Figure 2A). This effect declined as repeat PAM applications were made to the same system (Figure 2B).

Initial water runoff from furrows can contain relatively high PAM concentration (Figure 3A, 3B). A furrow will consume PAM and outflow concentration will reflect on soil conditions. Generally PAM concentration in runoff water is 25 to 35 percent of furrow inflow levels. Concentration in runoff water drops quickly once injection ceases (Figure 3A, 3B) for both liquid and dry methods. PAM application was intentionally allowed to continue for 2.5 hours after runoff to collect the data illustrated in Figure 3A and 3B. These two trials resulting in the highest PAM losses in runoff (Table 5). Losses averaged 6.2% of applied PAM when application was halted within one hour of water runoff. Shutting off PAM at the appropriate time and adjusting irrigation flows will require increased management by producers.

▼ PAM Losses from Furrows and Fields

A set of paired samples were collected from furrows and from exit drains leading to common return flow canals. Dirt tail ditches consumed PAM much like an irrigation furrow (Fig. 4A). Reductions in PAM concentration from water transport via tail ditches was variable (14 to 86%) due to variation in ditch construction and length. PAM losses from furrows

Figure 3. PAM concentration in furrow during and after injection using liquid (A) and and dry (B) methods.



and from fields dropped quickly once PAM injection ceased (Figure 4B).

Total seasonal losses from five one pound per acre PAM treatments may range from 0.25 to 0.75 lbs./ac. Delivery to return flow canals will be less than amounts lost off furrows with losses unlikely to exceed 0.4 lbs./ac. for the growing season.

▼ PAM Influence on Siphon Tube Flow

Small diameter siphon tubes (3/4 to 1 inch) are often used to transfer water from open ditches to furrows. Typical flow from these tubes range from 2.5 to 4.5 gpm. PAM treatment always reduced water flow rate to the furrow (Table 6-8) and this caused problems for some irrigators. For example, if 900 gallons per minute flow is delivered to a field and each siphon tube was reduced in flow by 25%, this would leave 225 gpm to overflow the ditch.

PAM reduction in siphon flow depends on siphon tube condition and silt content of irrigation water (Fig-

Figure 4. PAM concentration leaving furrows and leaving fields during (A) 1 hr. (B) PAM application.

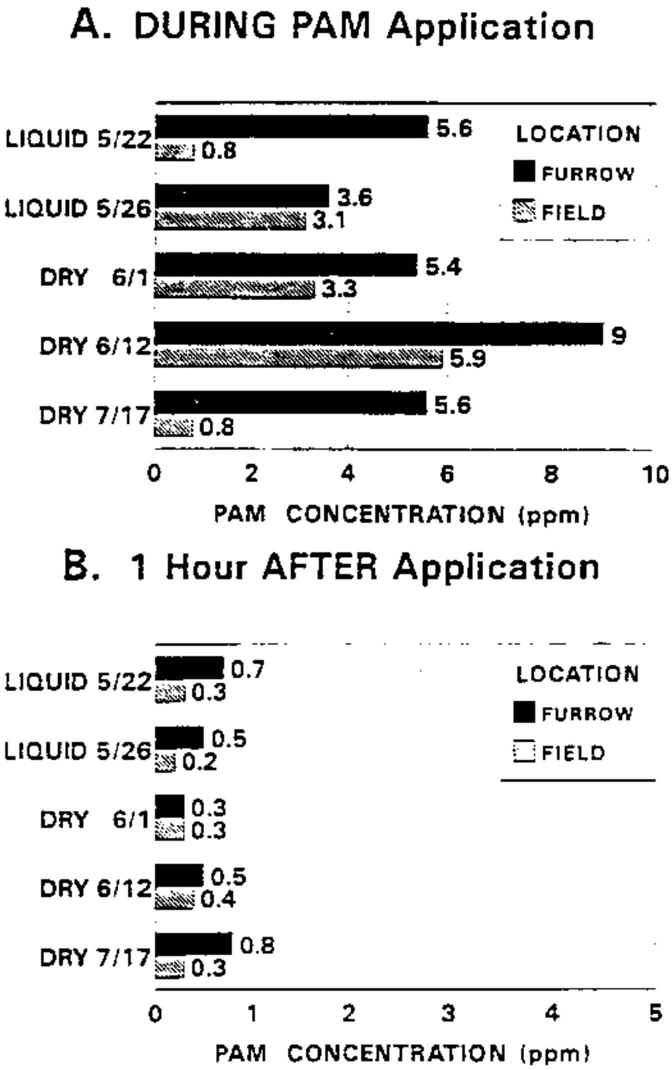


Figure 5. Influence of siphon tube age (A) and interior coating with paint (B) during water treatment with 8-10 ppm PAM.

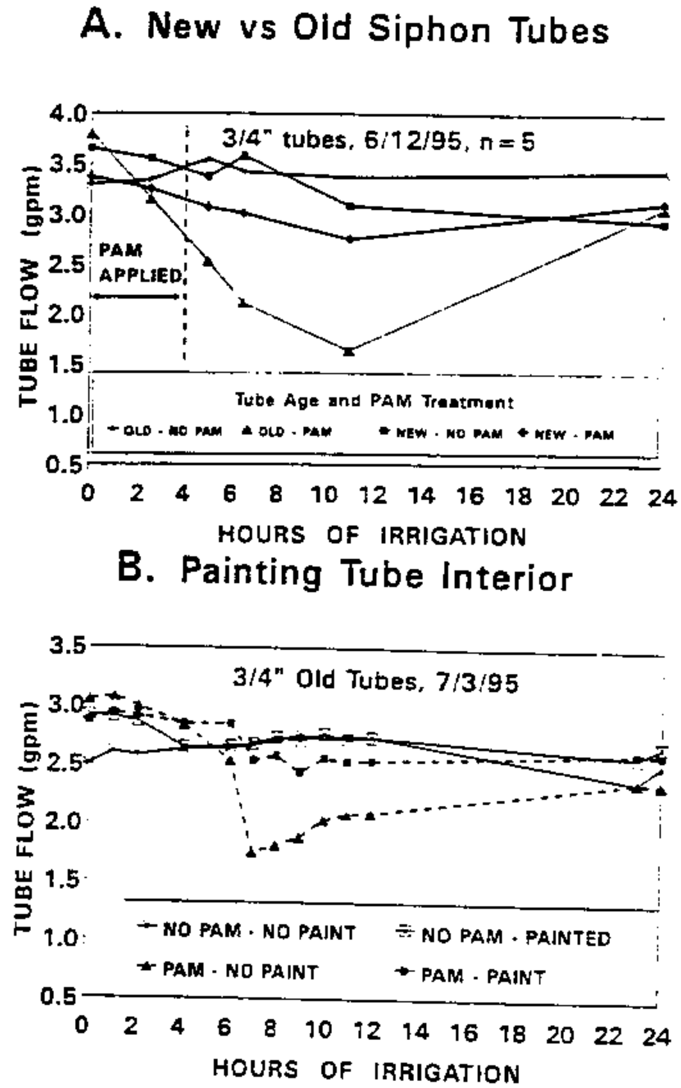


Table 5. Fate of PAM applied as an 8 to 10 ppm water treatment during the advance phase of irrigation. Dirt ditches were freshly made and not previously exposed to PAM.

Ditch system and PAM form used	PAM applied lbs / acre	Lost during conveyance	Stayed in field	Lost in runoff
		— % of Applied —		
DIRT, LIQUID[1]	2.72	34	62	4
DIRT, LIQUID[1]	1.88	16	78	6
DIRT, DRY[2]	1.89	33	53	14
AVERAGE	2.16	27.6	64.3	8.0
CONCRETE, LIQUID[2]	1.28	7.1	78	14.8
CONCRETE, DRY[1]	1.10	4.3	89	6.6
CONCRETE, DRY[1]	1.10	3.9	88	8.2
AVERAGE	1.16	5.1	85.0	9.9

[1] PAM injection shutoff within 45 minutes of water runoff.
[2] PAM application continued for 2.5 hours after runoff.

ure 5A). New siphon tubes having a smooth interior and flow rate will likely not be reduced in flow by more than 10 %. Old tubes delivering silt laden water can be expected to be reduced in flow from 25 to 50% and may stop entirely. During PAM application, silt is prevented from reaching siphon tubes due to PAM's flocculating activity. The interior of siphon tubes become coated with PAM and collect silt once PAM injection ceases. This can cause an abrupt reduction in flow from each siphon tube (Figure 5B) which results in flooding of irrigation supply canals. This phenomena is most prevalent when flow rate from siphons is less than 5 gpm and irrigation water contains high silt levels.

Treatments were evaluated for influence on siphon tube flow during PAM application (Table 2). Wax, paint, and Teflon coating of the tube interior were evaluated since these treatments covered the oxidized metal tube interior walls. Flow from control tubes usually increased slightly during these tests due to flow reduction in all the PAM treated tubes resulting in a rise in ditch water level. Paint was the most effective coating for old siphon tubes (Table 6, 7); although this treatment was not very practical to apply.

Influence of siphon tube diameter was evaluated by setting one inch diameter siphons to flows similar to adjacent smaller tubes. An additional treatment utilized 3/4-in. plastic reducers plugged into the end of each tube. Longer than 3/4-in. siphons set to run slower were only marginally less influenced by PAM (Table 8). Restricting 1-in. tube flows with plastic reducer inserts resulted in less tube flow reduction than 3/4-in. tubes or tubes without inserts (Table 8). A preliminary recommendation to producers would be to use their newest tubes of the largest diameter practical for a given field. Several producers reported that tube blockage was greater when dry PAM was applied compared to liquid PAM solutions. No formal testing was conducted to test this observation.

Table 6. Discharge from 3/4-in. aluminum siphon tubes as influenced by tube age, tube coating and water treatment with PAM (6/12/95). Siphon tube length was 60 ins., water temperature 71° F and sample n = 5.

TUBE AGE	TUBE COATING	WATER TREATMENT	WATER FLOW (gpm) INITIAL	+ 10 HOURS	% RDXN
Old	none	none	3.3	3.4	+3%
Old	none	PAM	3.8	1.6	-58%
New	none	PAM	3.5	2.9	-17%
Old	paint	PAM	3.2	2.9	-9%
New	paint	PAM	3.6	3.1	-14%
Old	Wax	PAM	3.1	2.4	-23%
New	Wax	PAM	3.2	2.9	-9%
Old	PAM	teflon	3.6	3.0	-17%
Old	3/4-in. plastic siphon tubes		3.3	2.5	-24%
LSD 0.05 (95% confidence)			ns	0.6 gpm	-17.6%

Table 7. Discharge from 3/4-in. aluminum siphon tubes as influenced by PAM water treatment and tube coating (7/03/95). Siphon tube length was 60 ins., water temperature 74° F and sample n = 6.

WATER TREATMENT	TUBE COATING	WATER FLOW (gpm) INITIAL	+10 HOURS	PERCENT REDUCTION
none	none	2.50	2.67	+6.8%
none	paint	2.92	2.68	-8.2%
PAM	none	3.05	1.75	-42.7%
PAM	paint	2.86	2.54	-11.2%
LSD 0.05 (95% confidence)		ns	0.41 gpm	14.5%

Table 8. Discharge from aluminum siphon tubes as influenced by PAM water treatment, tube coating and tube diameter (7/18/95). Siphon tube length was 60 ins., water temperature 75° F and sample n = 4.

Water TRT., Tube Size, Coating	Water Flow (gpm) INITIAL	+10 HOURS	Percent Reduction
NO PAM, 3/4-in., none	2.32	2.15	+5%
PAM, 3/4-in., none	2.32	1.03	-56%
PAM, 3/4-in., paint	2.33	2.15	-8%
PAM, 1-in., none, set slow	2.80	1.66	-41%
PAM, 1-in., with 3/4-in. plastic inserts	2.37	1.77	-25%
LSD 0.05 (95% confidence)	ns	0.47 gpm	14.5%

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