A Guide to Using Polyacrylamide (PAM) Polymers for Control of Irrigation Run-off on the Central Coast

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Introduction

Federal and state water quality regulations require that growers implement management practices to minimize impairments to surface and ground water quality. Although many farmers 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 achieve more dramatic improvements to water quality.

Irrigation run-off can often be difficult to control on soils with low infiltration capacity such as poorly aggregated sandy soils, or soils susceptible to crusting. Sediments suspended in irrigation tail water carry adsorbed nutrients and some classes of pesticides such as pyrethroids. Nitrogen, phosphorus, and several classes of pesticides have been determined to impair the quality of surface water on the Central Coast. The use of practices such as retention ponds and drip irrigation can significantly control irrigation tail water, but these practices can be expensive and may not be suited for all crops and farms. Baby greens, for example, are typically irrigated with overhead sprinklers, and although many cool season vegetables can be grown with drip, almost all of these crops are established with overhead sprinklers during the first 2 to 4 weeks of stand establishment.

Research studies conducted since 2003 on the Central Coast have repeatedly demonstrated that polyacrylamide (PAM), a chemical polymer can significantly reduce sediment, nutrient, and pesticide concentrations in irrigation run-off from sprinkler and furrow systems. PAM may be a cost-effective practice to minimize soil erosion and reduce the load of nutrients, sediments, and pesticides in tail water from fields that tend to have significant volumes of irrigation run-off. The following guide summarizes research findings for the Central Coast and how to effectively use PAM for achieving improved water quality.

What is PAM?

Polyacrylamide (PAM) is a chemical polymer used for a variety of purposes. 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. The main agricultural use of PAM is for stabilizing soil and preventing erosion. PAM is also used for dust control on unpaved roads.

Various forms of PAM exist, but the type used for erosion control is a large, negatively (anionic) charged molecule (12-15 megagrams per mole) that is water soluble. Both cross-linked chained PAM and positively (cationic) charged PAM are not suitable for erosion control. Cross-linked chained PAM products are sometimes used in agriculture

for improving water holding capacity of soil or potting mixes. PAM suitable for erosion control is commercially available in dry granular, liquid, and dry tablet forms, and costs as low as $4 to $6 per pound depending on the formulation, supplier, and cost of the raw materials used for manufacturing PAM (*ie.* natural gas). Liquid formulations of PAM generally contain between 25% to 50% active ingredient. Liquid formulations are often emulsified with mineral oil. A liquid PAM product suspended with humectants, which does not contain mineral oil, is also commercially available. PAM is also available as an effervescent dry tablet that is 5% active ingredient and dissolves rapidly when added to water.

PAM use for 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 in furrow irrigated fields.

Water quality efficacy of PAM in furrow systems

PAM has been most successfully used in furrow irrigation to improve infiltration, reduce erosion, and improve water quality. Most applications of PAM are done 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. The application is 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. Granular PAM slowly dissolves during the irrigation, releasing product into the water. Tablet forms of PAM can also be applied to the beginning of each furrow. Since the PAM tablet dissolves slowly, this application method releases less product into the irrigation water than by other methods described, and can be less effective in controlling sediment and associated nutrients and pesticides. However, because the tablet formulation of PAM dissolves slowly it may last for several irrigations, thereby saving labor.

Research on the Central Coast demonstrated that PAM applied initially to furrows at a concentration of 10 ppm followed by water without PAM, significantly reduced the concentration of sediment, phosphorus, and nitrogen in the run-off water across a range of soil types. On average, suspended sediments were reduced by 86% (Table 1), total phosphorus was reduced by 80%, and soluble phosphorus was reduced by 42% (Table 2). Total nitrogen was also reduced in the run-off by 65%, but PAM had no significant effect on the concentration of nitrate, which is the soluble form of nitrogen in water (Table 3). The PAM treatment had inconsistent effects on infiltration. On some soils, PAM

significantly improved infiltration and on other soils there was no effect on infiltration. On a few soils, infiltration was decreased with the addition of PAM.

Table 1. Effect of PAM treated water (10 ppm) on sediment concentration and turbidity of furrow tail water for 6 soils from the Salinas Valley. Treatment means represent the average of 4 replications.

	Total Suspended Solids		Turbidity	
Soil Type	**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 [1]	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 2. Effect of PAM treated water (10 ppm) on soluble and total phosphorus concentration of furrow tail water for 6 soils from the Salinas Valley. Treatment means represent the average of 4 replications.

	Soluble Phosphorus		Total Phosphorus	
Soil Type	**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 3. Effect of PAM treated water (10 ppm) on nitrate and total nitrogen concentration of furrow tail water for 6 soils from the Salinas Valley. Treatment means represent the average of 4 replications.

	Nitrate-Nitrogen		Total Nitrogen[2]	
Soil Type	**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

Water quality efficacy of PAM with overhead sprinklers

Although many research studies have evaluated the efficacy of PAM in furrow systems, fewer studies have evaluated the use of PAM with sprinklers. Several of the sprinkler studies have investigated the most efficacious method of applying PAM. Applications made before irrigating, such as by spraying PAM solution or broadcasting dry product on the surface of the soil were less effective than continuously injecting a low rate of PAM into the irrigation water. Injecting PAM at a high rate for a short period at the beginning of an irrigation was also less effective in controlling sediment and nutrients in run-off than a continuous application at a low concentration during the entire irrigation. Applications of PAM at rates of 3 to 10 lb/acre made before or at the beginning of an irrigation were less effective than 0.5 to 1 lb/acre applications made continuously during the irrigation. In most cases, injecting PAM to achieve a 5 ppm concentration in the irrigation water provided the highest reduction in sediment, nutrients, and pesticides in the tail water using the least amount of product. In some fields 2.5 ppm of PAM provided equal efficacy for control of suspended sediments as 5 ppm of PAM. In fields where very little run-off occurs during the first few hours of an irrigation, product can be saved by making an initial application for the first half hour and then applying product again when run-off becomes significant.

Water quality benefits of using PAM with sprinkler irrigation have been documented in various trials conducted on the Central Coast. Replicated studies conducted in lettuce fields showed as much as 95% reduction in concentration of suspended sediments, turbidity, and erosion of sediment (Table 4). Total Nitrogen and total phosphorus concentration in run-off were usually reduced by 60% to 70% (Tables 4). Unreplicated trials where run-off from half of a field, treated with PAM was compared with run-off from the untreated half, often showed dramatic reductions in suspended sediment concentration (Figure 1). At a field site in Santa Maria, the addition of PAM to the

irrigation water reduced suspended sediments in the run-off by 99%. Pesticides which bind strongly to sediments can also be minimized in tail water through the use of PAM. A study conducted in lettuce showed that PAM injected at 5 ppm concentration in sprinkler water reduced pyrethroid concentrations in run-off by approximately 90%.

Figure 1. Run-off from overhead sprinkler water treated with 5 ppm PAM (right) and untreated (left).

Table 4. Polyacrylamide effects on nutrient and sediment concentration, turbidity and soil erosion in a sandy loam soil cropped with lettuce and irrigated with overhead sprinklers.

Treatment	Total Kjeldahl N	Nitrate-N	Total P	Soluble P	Total Suspended Solids	Turbidity	Soil Erosion
	ppm					NTU	lb/acre/irrigation
untreated control	8.4	5.6	3.3	0.9	1082	950	87
PAM (5 ppm)	2.8	4.3	1.0	0.6	90	104	7
Statistical signficance	**[1]	NS[2]	**	**	***[1]	***	***
Reduction relative to control (%)	67	23	71	32	92	89	92

[1.] *,**,*** signify that differences between treatment means are statistically significant at the 90%, 95%, and 99% confidence levels, respectively

[2] means are not statistically different

Table 5. Summary of unreplicated field trials comparing PAM treated water with untreated water for overhead sprinklers.

Treatment	Total N	NO3-N	P (Total)	P (Soluble)	Total Suspended Solids	Turbidity
	---------- ppm ----------					NTU
	----------Watsonville (clay loam) ----------					
PAM (5 ppm)	0.8	58.6	1.2	1.2	47	33
Control	2.9	48.4	2.0	0.9	652	1289
	----------Salinas (sandy loam) ----------					
PAM (5ppm)	1.4	1.7	0.7	0.7	72	63
Control	4.2	1.7	1.9	0.7	985	2291
	----------Salinas (sandy loam) ----------					
PAM (10 ppm)	2.7	1.3	0.4	0.2	179	108
Control	5.5	1.8	2.4	0.5	1332	3536
	----------Chualar (loamy sand) ----------					
Pam (5 ppm)	2.3	2.7	1.9	0.8	646	218
Control	11.8	6.5	8.2	2.1	3870	503
	---------- Santa Maria ----------					
Pam (5 ppm)	1.6	14.78	0.6	0.51	60	13
Control	7.0	17.02	10.1	0.95	5930	4417
	---------- Gilroy (silt loam) ----------					
Pam (4 ppm)	1.2	8.1	1.0	0.9	74	42
Control	4.0	6.5	3.5	1.2	2057	2408

Frequency of application and residual benefits of PAM

Research trials conducted on the central coast demonstrated that the greatest concentration of suspended sediments in run-off was after tillage operations, such as cultivation. No residual water quality benefit from PAM applications prior to tillage were measured in subsequent irrigations without PAM treatment. Other trials conducted in commercial vegetable fields with overhead sprinklers demonstrated that if soil was not disturbed by tillage, PAM continued to reduce sediment and nutrient concentration in run-off during subsequent irrigations without PAM treatment. However, the reduction in sediment concentration from the previous PAM application was less than measured in plots treated with PAM. The greater number of previous irrigations with PAM, increased water quality benefits in the subsequent irrigations without PAM.

Several Central Coast vegetable growers have also reported that using PAM in the first 2 to 3 germination irrigations after planting continued to control sediment in tail water during additional irrigations without PAM up to the thinning stage of the crop. These growers also switched from overhead sprinklers to surface placed drip tape after thinning the plant stand, and did not need to apply PAM for the remainder of the crop.

PAM injection methods for sprinkler systems

Although PAM can substantially improve water quality, the polymer can be difficult to inject into pressurized irrigation systems. Options are to premix a tank of dilute PAM solution (0.1% to 0.15%) or to directly inject concentrated solutions (25% to 50%) into the irrigation water.

Injection using dilute solutions of PAM

Because PAM is a large molecule, it is difficult to mix into water. Though it is water soluble, PAM tends to stick to itself, rather than dissolving into water. Mixing up a batch of PAM solution in a tank can be time consuming and therefore costly. Either dry granular PAM, concentrated liquid PAM can be diluted to a 0.1% to 0.15% solution. Effervescent PAM tablets can also be used to mix up dilute solutions of PAM. Adding water to the bottom of the tank before adding PAM prevents it from sticking to the walls. A high pressure centrifugal pump can be used for both mixing and injecting into a pressurized water line. A recirculation hose is recommended to agitate the solution so that is as homogeneous as possible during injection and a flow meter is needed to adjust the injection rate to achieve the desired PAM concentration in the irrigation water. The tank capacity needed to complete an irrigation should be estimated. If the volume of the tank is too large, PAM solution may need to be stored for several days. Often PAM solutions stratify during storage and need to be thoroughly remixed before injecting.

Injection of concentrated solutions of PAM

Direct injection of concentrated liquid PAM can be the easiest and cheapest method of application for pressurized irrigation systems. However, only certain types of injectors can be used with PAM because of its sticky nature. PAM clogs injection pumps with valves, such as some diaphragm pumps. Centrifugal, peristaltic, and auger pumps will often work well with PAM. Venturi (mazzei) injectors also can be used for injecting PAM into pressurized irrigation systems, but the one-way check valves that are often on the intake of the venturi are susceptible to plugging.

The low injection rate, required to achieve 2.5 to 10 ppm PAM concentration in irrigation water using concentrated liquid PAM, also limits which pumps can be used. Table 6 lists injection rates needed for a range of system flow rates to achieve 2.5 and 5 ppm PAM concentration in the irrigation water. Depending on the percentage of active ingredient, injection rates of concentrated liquid PAM could be less than 30 ml per minute (1 ounce per minute). Auger metering pumps, although relatively expensive, offer the best control for injecting low rates of liquid PAM into pressurized water lines (Figure 2). These pumps have few moving parts to clog, and are suitable for injecting at water pressures as high as 100 psi with minimal effects on the injection rate. The injection rate of the pump can be adjusted down to as little as 15 ml per minute. A graduated cylinder, plumbed in line with the pump, can facilitate calibration (Figure 3). For emulsified oil based PAM products, crop oil can be used for calibration and to displace PAM from the pump after use.

Centrifugal pumps usually have too high of a flow rate to be used for direct injection of concentrated PAM products. Used in conjunction with a venturi injector, centrifugal pumps can be used to inject low rates of PAM into pressurized irrigation systems. Venturi injectors require a pressure differential between the inflow and outflow to create suction. The pressure differential can be created by a booster pump (Figure 4) or by using a centrifugal pump to raise the pressure on the upstream side of the venturi (Figure 5).

A static mixer placed down stream of the injection site is recommended to pre-mix the PAM prior to injection into the main line (Figure 5). Static mixers, which are sections of pipe with baffles to create a mixing vortex in the flowing water, cause additional losses in pressure and should not be placed directly on the main line if possible. Direct injection of concentrated liquid PAM can be uniformly mixed in the irrigation water without a static mixer if the distance traveled between the injection point and the field is more than 500 feet. Metering pumps may need to be configured with a static mixer as diagramed for the venturi in Figure 5 if the distance of mixing in the mainline is limited. As with any chemical, proper back flow prevention equipment should be used when injecting PAM into irrigation water to prevent contamination of the water source.

Figure 2. Trailer outfitted for injecting liquid PAM into the main line of an irrigation system using an auger metering pump.

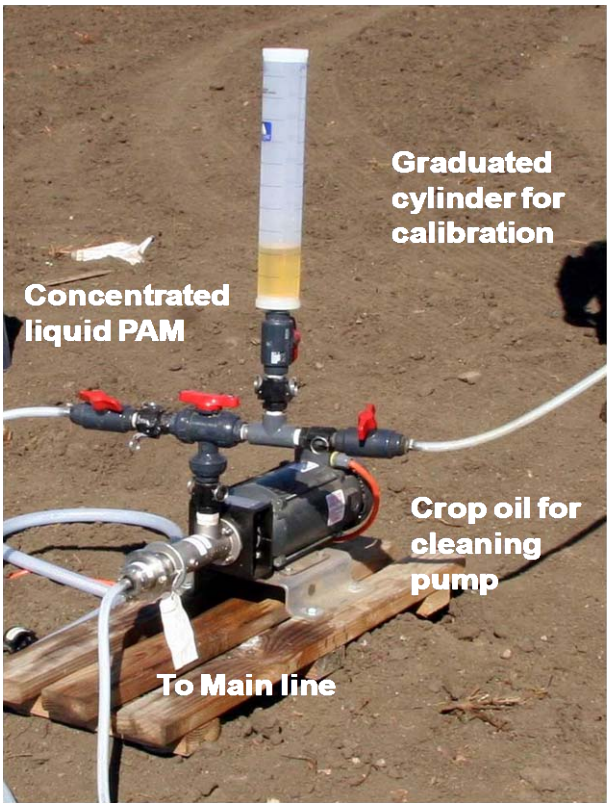

Figure 3. Auger metering pump set up with calibration cylinder and intakes lines for concentrated PAM and crop oil. Crop oil is used for calibration and cleaning pump.

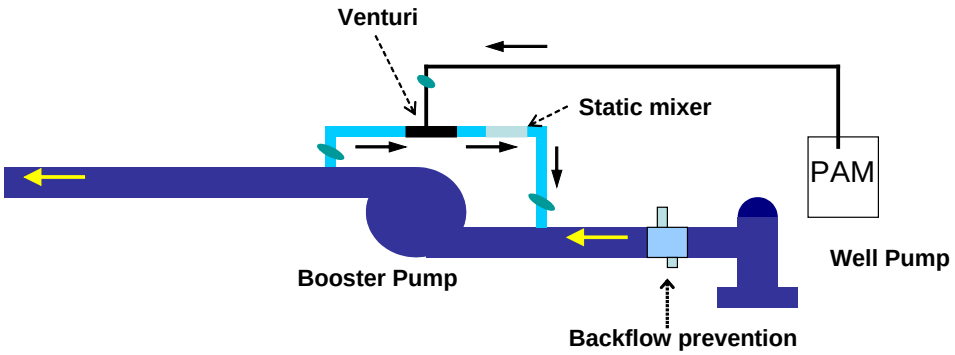

Figure 4. PAM injection using venturi injector between booster and well pump.

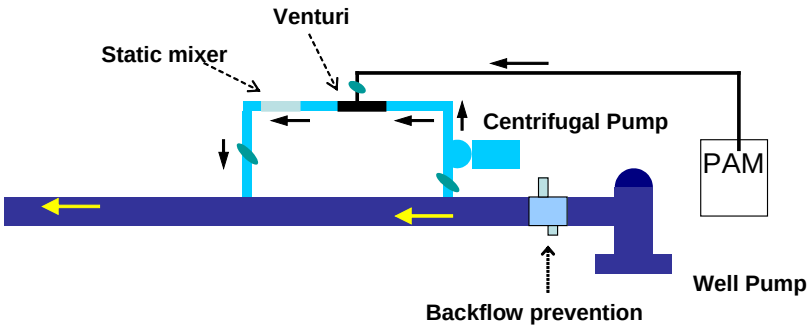

Figure 5. PAM injection using venturi injector and centrifugal pump.

Table 6. Injection rates of liquid PAM required to achieve 5 ppm or 2.5 ppm concentration for products with different contents of active ingredient.

Pump	50% PAM		37% PAM		25% PAM	
flow rate	5 ppm	2.5 ppm	5 ppm	2.5 ppm	5 ppm	2.5 ppm
gal/min	---------- injection rate ml/min ----------					
400	15	8	20	10	30	15
500	19	9	26	13	38	19
600	23	11	31	15	45	23
700	26	13	36	18	53	26
800	30	15	41	20	60	30
900	34	17	46	23	68	34
1000	38	19	51	26	76	38
1100	42	21	56	28	83	42
1200	45	23	61	31	91	45
1300	49	25	66	33	98	49
1400	53	26	72	36	106	53
1500	57	28	77	38	113	57
1600	60	30	82	41	121	60
1700	64	32	87	43	129	64
1800	68	34	92	46	136	68
1900	72	36	97	49	144	72
2000	76	38	102	51	151	76
2100	79	40	107	54	159	79
2200	83	42	112	56	166	83
2300	87	43	117	59	174	87
2400	91	45	123	61	181	91
2500	95	47	128	64	189	95

Safety considerations with PAM

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. Rubber gloves suitable for handing chemicals, eye protection, long sleeve shirts, and a respirator (for dry materials) should be used depending on the recommendations of the material safety data sheet. Always review the material safety data sheets before handling PAM products. PAM becomes very slippery when wet so spills should be cleaned with a dry absorbent before attempting to wash it. Closed systems of transferring product between tanks or injecting into the irrigation system minimize spillage.

Polyacrylamide 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.

PAM use on food crops

PAM is safe to apply to food crops. However, the PAM product needs to be registered with the California Department of Food and Agriculture (CDFA) as "food safe" before applying it to crops. Also, the buyer/processor of the produce should be informed that PAM is being applied to the crop, especially if the application is made near harvest.

Environmental toxicity studies of PAM

Environmental studies of PAM have not demonstrated any negative effects to the aquatic organisms at concentrations used for soil erosion control. Anionic (negatively charged) PAM has a very low toxicity to fish, *Ceriodaphnia* 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 agricultural fields. 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. Mineral oils used to emulsify liquid PAM have been shown to have acute and chronic toxicity to aquatic test organisms such as *Ceriodaphnia nubia* and *Hyalella azteca* at concentrations greater than 1 ppm in pure water. In field tests, mineral-oil based PAM was less toxic to the same organisms than reported in laboratory tests. Applied at a 5 ppm concentration, the toxicity of the run-off water diminished with distance along the length of the furrow within the field. Mineral oil PAM products with high PAM content (50%), and therefore low mineral oil content were found to less toxic to aquatic organisms than products with a lower PAM content (37% PAM). Using non oil based liquid, or dry products can assure that PAM applications do not cause aquatic toxicity. Choosing liquid PAM with the lowest mineral oil content may also minimize potential aquatic toxicity.

Cost of using PAM

The cost of applying PAM will vary depending factors such as the product formulation, supplier, method of application, field size, irrigation method, and number of irrigations. Applying PAM to small acreage fields is usually more costly per acre than applications made to large fields. Dry granular product is usually substantially cheaper than liquid products. Liquid PAM products emulsified with mineral oil are less costly than liquid PAM without mineral oils such as products with humectants ingredients.

An analysis of using liquid emulsified oil PAM with sprinklers on a farm with 10-acre field sizes suggested that costs can vary between $26 to $36 per acre for 4 applications of PAM depending on the method of application (Tables 7 and 8). Although a metering pump is more expensive than a centrifugal pump, the savings in labor costs was estimated to reduce the overall costs of injecting liquid PAM. Growers also can receive cost-share payments for using PAM under the USDA Natural Resources Conservation Service EQIP (Environmental quality incentive program).

Table 7. Estimated cost of 4 applications of liquid emulsified oil PAM using a metering pump and overhead sprinklers on a 10-acre vegetable field.

Source	unit	number of units	cost/unit	amortized	seasonal use	total cost/acre/year	area treated	cost/field
Equipment costs			$	years	acres/year	$	acres	$
metering pump and controller	ea	1	3000	5	100	6.00	10	60.0
20 gal tank	ea	1	100	5	100	0.20	10	2.0
fittings and calibration tube	ea	1	200	5	100	0.40	10	4.0
electrical services	ea	1	200	5	100	0.40	10	4.0
trailer	ea	1	500	5	100	1.00	10	10.0
Material/Operational Costs								
Liquid PAM for 4 irrigations[1]	lb	2	5	--	--	--	10	100.0
pump maintenance (7% of value)	ea	1	210				10	21.0
Labor Costs								
(4 irrigations) 1 hr per irrigation	hours	4	14	--	--	--	10	56.0
Total Costs ($/field)								257.0
Total Costs per Acre ($/acre)								25.7

[1.] application rate is 0.5 lb PAM per acre

Table 8. Estimated cost of 4 applications of diluted PAM solution using a centrifugal high pressure pump and overhead sprinklers on a 10-acre vegetable field.

Source	unit	number of units	cost/unit	amortized	seasonal use	total cost/acre/year	area treated	cost/field
Equipment costs			$	years	acres/year	$	acres	$
5.5 hp gas pump	ea	1	600	5	100	1.20	10	12.0
1000 gal fertilizer tank	ea	1	700	5	100	1.40	10	14.0
flow meter	ea	1	60	5	100	0.12	10	1.2
Material Costs								
Liquid PAM for 4 irrigations[1]	lb	2	5	--	--	--	10	100.0
Fuel costs	gal	4	2				10	0.8
pump maintenance (7% of value)	ea	1	42				10	4.2
Labor Costs								
(4 irrigations) 4 hrs per irrigation	hours	16	14	--	--	--	10	224.0
Total Costs ($/field)								356.2
Total Costs per Acre ($/acre)								35.6