Project Title:	Water treatment technology using polyacrylamide (PAM) to control sediment in agricultural run-off and to improve chlorine treatment of tailwater.
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Abstract:

Leafy green growers will need to implement mitigation practices to comply with ever-stricter water quality regulations on the central coast. Sediment and pesticides in run-off from irrigated fields impairs water quality in creeks, rivers, and estuaries in most coastal valleys where vegetables are intensively produced. In addition, the leafy green marketing agreement (LGMA) now requires that farming operations that store water in open reservoirs or reuse tailwater for irrigation to maintain generic *E. coli* levels below 10 MPN/100 ml. In most cases open water reservoirs will need to be treated with chlorine to assure a low concentration of generic *E. coli*. This project developed and tested a simple and inexpensive method to minimize sediment losses from sprinkler irrigated leafy greens fields by treating the irrigation water with polyacrylamide (PAM) using an applicator designed for pressurized irrigation systems. Additionally, this project developed and tested equipment to apply PAM to irrigation runoff draining into tailwater ponds to reduce the concentration of suspended sediments and potentially improve the efficacy of chlorine to treat *E. coli* and coliform bacteria.

Objectives

The main objective of this project is to develop and test equipment for adding dry polyacrylamide (PAM) to pressurized irrigation systems and tailwater ponds. Specific objectives include:

Objective 1. Scale up applicator for injecting dry PAM product into pressurized water for use at the well. **Deliverable:** Application system for dry PAM designed to operate at flow rates as high as 1000 gallons per minute.

Objective 2. Evaluate the effectiveness of the dry PAM applicator to reduce sediment concentration in run-off from an additional 1 to 2 commercial leafy green fields. **Deliverable:** Summary of the reduction in suspended sediments in sprinkler runoff using the PAM applicator.

Objective 3. Evaluate equipment for automatically dosing dry PAM into farm ditches for removal of suspended sediments in runoff. **Deliverable:** Equipment design for dosing PAM into open ditches and data on the efficacy of this practice to mitigate suspended sediment in runoff.

Objective 4. Extend results to the leafy green industry. **Deliverables:** 2 to 3 oral presentations at grower meetings, 1 newsletter/blog article, one-on-one consultation with 3 or more growers

Procedures (Objectives 1 -3):

Objective 1. *Scale up applicator for injecting dry PAM product into pressurized water for use at the well.* The design of the PAM applicator tested in 2019 and 2020 was modified and scaled up for installation at the well. The prototype applicator that was used in field testing consists of cartridges filled with PAM that insert into a series of six stainless steel cylindrical chambers (Fig. 1), built by Ray Fab Inc. in Salinas, CA. The chambers are paired together using Victaulic fittings so that the irrigation water enters into one chamber and exits out through the paired chamber (Fig 1). Dissolved PAM releases into the water as it streams through the gap between the cartridge and the wall of the chamber. Modifications were made to the static mixers (Fig. 2) that insert between the PAM cartridges and chamber walls to increase turbulent flow of water around the cartridges thereby maximizing the dissolution of PAM. Pressure loss through the PAM applicator is approximately 6 to 8 psi at a flowrate of 66 gpm through the each pair of chambers. The scaled-up applicator will consist of 7 pairs of chambers and will be located at the well. During irrigation events a portion of the irrigation water on the mainline will be diverted into the inlet of the applicator using a small centripetal pump. (Fig. 3). The applicator should be able to treat irrigation water at flow rates between 1200 to 1500 gpm.

Objective 2. Evaluate the effectiveness of the dry PAM applicator to reduce sediment concentration in run-off from an additional 1 to 2 commercial leafy green fields. Field testing of a prototype PAM applicator was continued during the 2021 season in 2 commercial lettuce fields. Trials were conducted during the sprinkler germination phase of the starting on May 1 (Trial 3), and June 21 (Trial 4) over 5 to 6 irrigation events. Lettuce was seeded on 80-inch-wide beds. The soil types were Chualar loam and Elder sandy loam at Trials 3 and 4 respectively (Table 1). The PAM applicator was positioned in the field next to the mainline (Fig. 1). The applicator cartridges were filled with Soilfloc 100D, an anionic linear PAM developed for soil erosion control manufactured by Hydrosorb Inc. Flowmeters were used to measure the flow rate in the mainline and the inlet of the applicator. Another flowmeter monitored the volume of water applied in an adjacent untreated plot. The PAM treated plots measured 3 acres in Trial 3 and 4.2 acres in Trial 4. The maximum flow rate of water applied to the PAM treated plot ranged was 480 gpm in Trial 3 to 525 gpm for Trial 4. Flow diverted through the PAM applicator was approximately 160 to 180 gpm. Flumes were installed 30 ft from the far end of the field to measure run-off volume during the irrigations in the PAM treated and the untreated

plots (Fig. 4). A stilling well and float mechanism was used to measure the height of the water in the flume. The float mechanism was interfaced with a datalogger record the height and convert the height to flow rate using a calibration curve. The datalogger also automated sampling of run-off at 5-minute intervals into containers using a peristaltic pump when the flow was greater than 1.5 gpm Composite samples of run-off were collected from the plots during 6 irrigation events and analyzed for turbidity, pH, electrical conductivity, concentration of suspended sediments, total N, nitrate-N, and orthophosphate at the UC Davis analytical laboratory.

Objective 3. Evaluate equipment for automatically dosing dry PAM into farm ditches for removal of suspended sediments in runoff. Three prototype PAM applicators were developed and tested for dosing PAM into ditches that drain irrigation runoff into tail water ponds on a vegetable farm during the 2021 season. The applicators were mounted onto wood frames that spanned across the drainage ditches and consisted of a hopper filled with granular PAM (Soilfloc 100D, Hydrosorb Inc.) that emptied into an electric powered auger, which slowly pushed granular PAM into a vertical "drop" tube suspended over the flowing runoff. The electric motor was controlled by a datalogger programmed to dose the flowing runoff with an approximate 7 ppm concentration of PAM. The flow rate in the drainage ditch was monitored using a "v" notch weir positioned upstream of the PAM applicator equipped with a float mechanism to monitor the height of runoff on the upstream side of the weir. The float was interfaced to a datalogger and a calibration curve was used to convert height of the runoff water to flow rate.

Samples of the upstream and downstream runoff water were collected from April through August during the 2021 season. During runoff events water samples upstream and downstream of the PAM applicators were automatically collected using peristaltic pumps that operated at 15-minute intervals. Grab samples of runoff were collected when the pumps occasionally malfunctioned. The downstream sampling points were located 400 to 500 ft from the PAM applicator. . Samples were analyzed for turbidity and total suspended solids to determine the efficacy of the PAM treatment to settle out suspended sediment carried in the runoff.

Results and Discussion

PAM application effects on field runoff

Field testing in lettuce irrigated with sprinklers demonstrated a significant reduction in sediment and turbidity with the addition of PAM compared to the untreated control plot. Turbidity in the runoff was reduced by 97% and 98%, respectively for Trials 3 and 4 (Tables 2 and 3, Fig. 6). Suspended sediment carried in the runoff in the PAM treated area of the field was reduced by 92% and 94%, respectively for Trials 3 and 4, compared to the untreated areas of the fields. Runoff volume also was reduced by the addition of PAM (8% and 12% reductions in runoff volume for Trials 3 and 4 respectively), indicating an improvement in infiltration (Tables 2 and 3). The combination of reduced runoff and a lower concentration of suspended sediment resulted in a significant reduction in sediment lost from the fields. Cumulative loss of sediment was reduced in the PAM treated plots by 93% in Trial 3 (Table 2) and 95% in Trial 4 (Table 3).

In Trial 4, for example, the untreated area cumulatively lost 127 lbs of sediment per acre during 6 irrigations compared to a loss of only 6 lbs of sediment per acre in the PAM treated area.

The concentration of soluble P, total P, nitrate-N, and total N in runoff samples was also measured. Only the concentration of total P which is associated with soil particles was significantly reduced in the runoff treated with PAM. The concentration of total P in PAM treated runoff was reduced by 58% and 73% in Trials 3 and 4, respectively (data not presented).

The combined results of the four trials conducted in 2021 and 2020 demonstrated that on average the PAM applicator reduced turbidity in runoff by 95% and suspended sediments by 90% (Tables 4 and 5). Runoff volume was reduced by an average of 26% using PAM and soil erosion was reduced by an average of 93% for the 4 trials.

The applicator cartridges were examined to estimate the remaining amount of PAM after the trials were completed. Less than 5% of the starting volume of PAM was lost, which would suggest that no more than 1 lb of PAM per acre was applied to the fields during the germination phase of the crops.

Pam treatment of irrigation runoff

The prototype ditch applicators tested in this project greatly reduced the suspended sediment and turbidity of runoff flowing in the drainage ditches and retained in the tail water ponds. Turbidity of the untreated runoff averaged 2412 NTU (Fig. 7). After treatment with PAM the concentration in the downstream runoff averaged 23 NTU corresponding to a 99% reduction in turbidity (Fig. 7). Total suspended solids (suspended sediments) in the untreated runoff averaged 2778 mg per L before treatment. After treating with PAM the concentration in the downstream runoff averaged 71 mg per L, corresponding to a 97% in reduction in suspended sediments (Fig. 8). In one of the treated ditches, we estimated that the reduction in suspended sediments in runoff reduced the load of sediment by 9.3 tons during a 150-day period starting on June 9th 2021. In another ditch on the ranch which had higher flow rates, the reduction during a 200-day period starting on May 25th was almost 42 tons of sediment.

A chlorine assay conducted during the prior year of this project demonstrated that the large reduction in suspended sediment in runoff using PAM doubled the concentration of free chlorine after treatment. Hence growers may be able to reduce the amount of chlorine needed to treat runoff for reuse by half using the ditch applicator to remove suspended sediments.

Extension of results (objective 4): The results of this project were presented at the fall and meeting held by the California Leafy Green Research Board in October 2021 and at the annual meeting in March 2022. A presentation on the results of the project were also made at the annual UC Irrigation and nutrient management meeting in February 2022. In addition, articles summarizing the use of polyacrylamide for sediment control was published in the UCCE Salinas Valley Agriculture Blog (January 2021) and Vegetables West Magazine (Cahn et al. 2021).

Conclusions

The dry PAM applicator developed through this project showed potential to greatly reduce sediment and sediment-bound pesticides in tailwater run-off from sprinklers, thereby helping growers meet water quality targets required by regulatory agencies. The design of the applicator is scalable to suit irrigation systems with a range of flow rates. The applicator also minimizes labor and product required for treating irrigation water with PAM. The auger system for dosing runoff also greatly reduced suspended sediment and turbidity in runoff. Greatly reducing suspended sediments in the runoff using PAM would potentially reduce the chlorine requirement to control *E. coli* and meet LGMA food safety requirements by 50%.

Table 1. Description of PAM field trials conducted in 2020 and 2021.

Description	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**
Crop	Romaine	Green leaf	Romaine	Romaine
Soil type	Chualar loam Placentia sandy loam	Chualar loam	Chualar loam	Elder sandy loam
Wet date	4/15/2020	5/8/2020	5/1/2021	6/21/2021
Bed width	80-inch	80-inch	80-inch	80-inch
Bed length	691 ft	616 ft	930 ft	1236 ft
Treatment area	1.9 acres	3.4 acres	3 acres	4.2 acres
Max. sprinkler flow rate	260 gpm	480 gpm	480 gpm	525 gpm
Germination water depth (5 to 6 irrigations)	4.7 inches	6 inches	5.1 inches	4.5 inches

Table 2. Volume, turbidity, and sediment concentration in run-off from PAM and untreated plots within a commercial romaine lettuce field irrigated with overhead sprinklers beginning on 5/1/21.

	Runoff Volume		Turbidity		Total Suspended Solids		Sediment Loss	
Date	Untreated	PAM	Untreated	PAM	Untreated	PAM	Untreated	PAM
	% of Applied water		---- NTU[1] ----		---- mg/L ----		-- lbs sediment/acre --	
5/1/2021	0.0	0.0	-	-	-	-	-	-
5/3/2021	0.0	2.3	534	17	470	39	0.0	0.2
5/5/2021	10.3	9.9	326	13	408	28	9.8	0.5
5/7/2021	16.3	15.6	389	10	476	51	19.2	1.7
5/10/2021	14.9	9.1	396	10	508	25	11.0	0.3
Average per irrigation	8.3	7.4	411	12	466	36	10.0	0.7
Cumulative	7.4	6.8					40.0	2.8
Average reduction per irrigation[2] (%)		11		97		92		93
Total reduction[3] (%)		8						93

[1.] Nephelometric turbidity units

[2.] Average reduction as a percentage of untreated (control) treatment

[3.] Total reduction as a percentage of untreated (control) treatment

Table 3. Volume, turbidity, and sediment concentration in run-off from PAM and untreated plots within a commercial romaine lettuce field irrigated with overhead sprinklers beginning on 6/21/21

	Runoff Volume		Turbidity		Total Suspended Solids		Sediment Loss	
Date	Untreated	PAM	Untreated	PAM	Untreated	PAM	Untreated	PAM
	% of Applied water		---- NTU[1] ----		---- mg/L ----		-- lbs sediment/acre --	
6/21/2021	1.8	1.8	1971	71	1580	134	9.7	0.7
6/23/2021	13.6	17.9	940	35	868	83	30.0	3.1
6/25/2021	11.7	9.3	626	7	676	56	12.1	0.7
6/28/2021	8.9	7.4	1664	10	1900	31	22.9	0.3
6/30/2021	21.8	11.4	1671	16	1580	68	52.0	1.2
Average per irrigation	11.6	9.5	1374	28	1321	74	25.4	1.2
Cumulative	10.0	8.8					126.8	6.0
Average reduction per irrigation[2] (%)		17		98		94		95
Total reduction[3] (%)		12						95

[1.] Nephelometric turbidity units

[2.] Average reduction as a percentage of untreated (control) treatment

[3.] Total reduction as a percentage of untreated (control) treatment

Table 4. Average effect of PAM on volume and turbidity of sprinkler runoff for field trials conducted during 2020 and 2021.

	Runoff volume			Turbidity		
	Untreated	PAM	Reduction	Untreated	PAM	Reduction
	% of applied water		%	-------- NTU[1] ---------		%
Trial 1	6.9	5.7	17	1219	89	93
Trial 2	7.6	2.4	69	1156	95	92
Trial 3	7.4	6.8	8	411	12	97
Trial 4	10.0	8.8	12	1374	28	98
Average	8.0	5.9	26.4	1040	56	95

[1.] Nephelometric turbidity units

Table 5. Average effect of PAM on suspended sediments transported in sprinkler runoff and sediment loss for field trials conducted during 2020 and 2021.

	Total Suspended Solids			Sediment loss		
	Untreated	PAM	Reduction	Untreated	PAM	Reduction
	---------- mg/L ----------		%	lbs sediment/acre		%
Trial 1	796	106	87	66	8	89
Trial 2	577	86	85	73	3	96
Trial 3	466	36	92	40	3	93
Trial 4	1256	60	95	127	6	95
Average	774	72	90	76	5	93

Figure 1. Field trials evaluated a prototype PAM applicator in sprinkler irrigated lettuce.

Figure 2. PAM cartridge with static mixing elements.

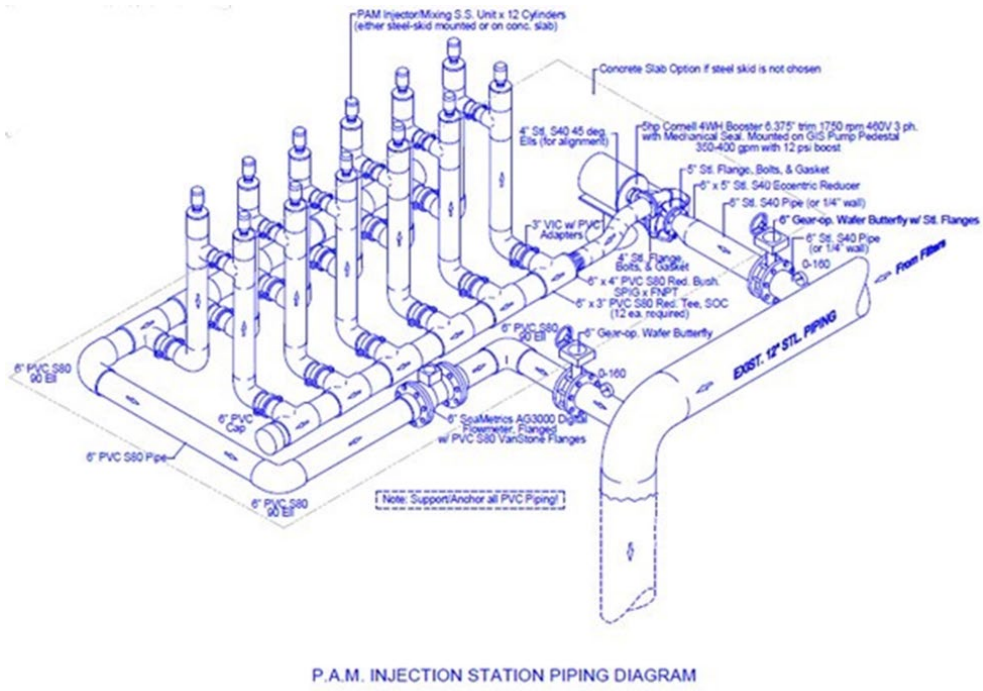

Figure 3. Design for full scale PAM applicator that can be located at a well and treat between 1200 and 1500 gpm of pressurized irrigation water.

Figure 4. Flume and peristaltic pumping system used to monitor run-off volume and automatically collect run-off samples from test plots in a commercial lettuce field.

Figure 5. Applicator for dosing granular PAM into drainage ditches.

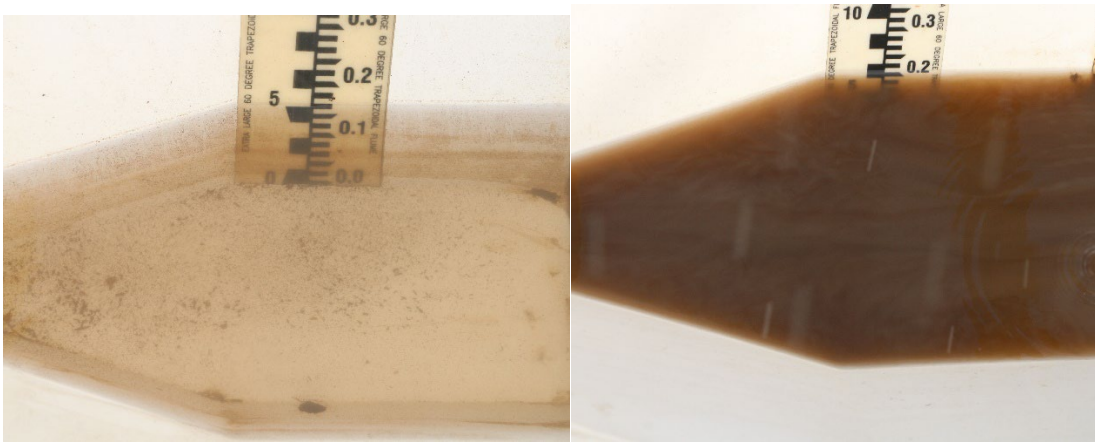

Figure 6. Sprinkler run-off from PAM treated (left) and untreated (right) plots in a commercial romaine lettuce field. Run-off is flowing through flumes positioned at the lower end of the plots.

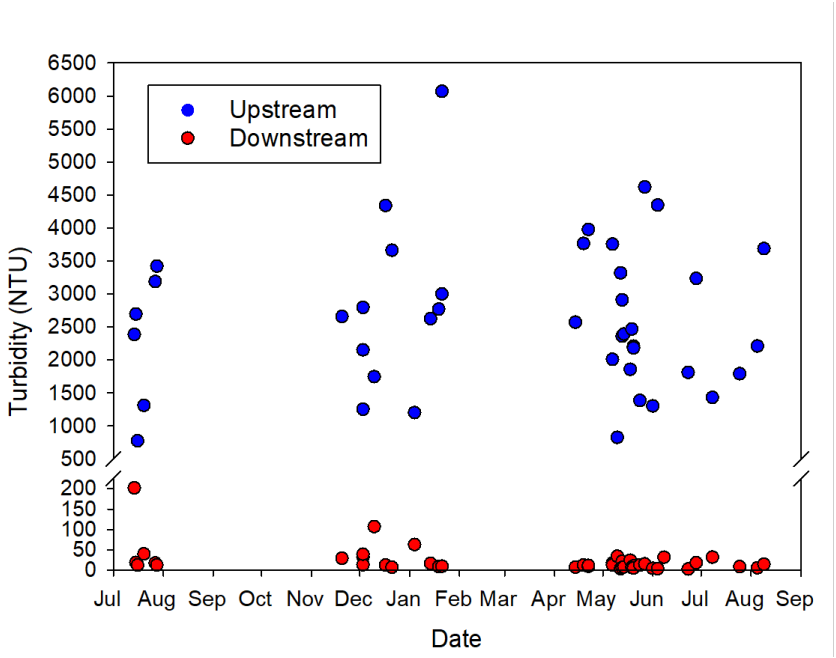

Figure 7. Turbidity of irrigation runoff upstream and downstream of the PAM ditch applicator sampled during July 2020 – August 2021.

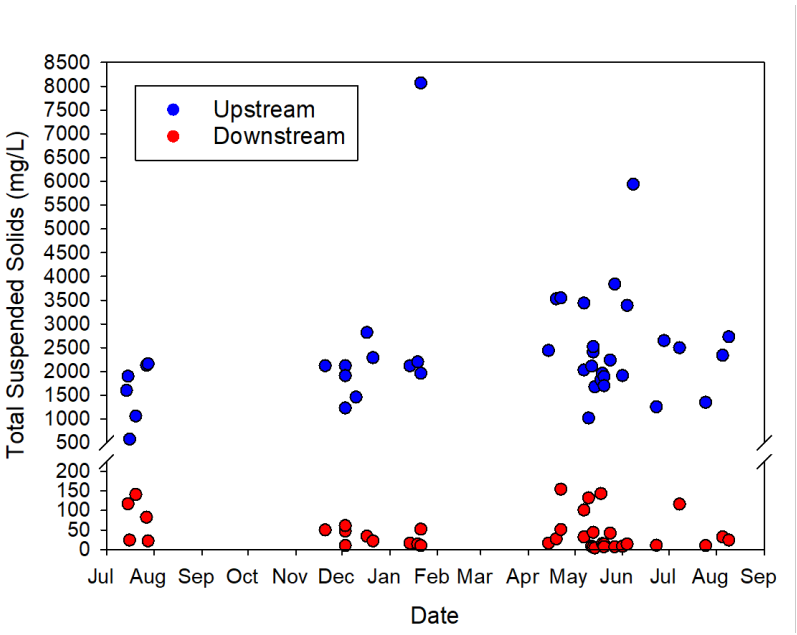

Figure 8. Total suspended solids in irrigation runoff upstream and downstream of the PAM ditch applicator sampled during July 2020 – August 2021.