Vegetated treatment ditches: ineffective in reducing nutrient, sediment, and E. coli bacteria concentrations in irrigation run-off on the central coast.

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Irrigation run-off from cool season vegetable fields on the central coast of California can carry significant loads of sediment, nutrients, and bacteria. Planting vegetation in permanent ditches on farms can stabilize banks thereby preventing erosion, and potentially provide a biological treatment that could improve water quality. Due to food safety concerns, many vegetable growers have been reluctant to increase plantings of vegetated ditches because the plant cover may harbor small animals that could transport microbial contaminants to an adjacent crop of leafy greens. Research reports from other regions of the United States suggest that vegetation in these ditches could reduce bacterial loads in run-off, thereby reducing the risk of microbial contamination to downstream fields as well as reducing loads of nutrients and sediments. Another obstacle to vegetating ditches, especially for maximizing water treatment benefits, is cost. The ditches may need to be graded, hand planted, and frequently watered to establish vegetation, and then maintained to prevent infestation of weedy species.

Polymers are another management tool that can improve farm water quality. Our past studies have shown that adding polyacrylamide (PAM) to irrigation water at concentrations of 5 ppm significantly reduced concentrations of sediment and associated nutrients in tail water run-off. However, we have not examined the effect of PAM on bacterial loads in irrigation run-off. If the bacteria are associated with sediment in the run-off, PAM could greatly reduce the migration of E. coli and other bacteria that pose food safety risks to leafy green crops. Furthermore the combination of polyacrylamide and vegetation treatment may improve water quality more than either practice alone.

Because of lack of information on the efficacy of vegetation and polymers to reduce bacterial loads in run-off under central coast conditions, we undertook a 2 year field study that simulated E. coli contamination in a lettuce field. The field trials evaluated the effectiveness of vegetated treatment ditches, polyacrylamide polymer, and the combination of these two practices to reduce bacteria, sediment, and nutrient concentrations in irrigation run-off.

Procedures

Field trial design Field trials were conducted at the USDA-ARS Spence Research Farm, near Salinas CA. The soil type was a Chualar sandy loam. The water source was ground water. Run-off treatments included: 1. untreated irrigation water and run-off water treated through a bare (non-vegetated) ditch (control treatment), 2. untreated irrigation water and run-off water treated through a vegetated ditch (vegetated treatment); 3. irrigation water treated with 5 ppm of polyacrylamide polymer and run-off water treated through a bare ditch (PAM treatment). 4. irrigation water treated with polyacrylamide polymer (2.5 ppm in 2007 and 5 ppm in 2008) and run-off water treated through a vegetated ditch (vegetated PAM treatment). Treatments were randomly assigned to the field plots so that each treatment was evaluated on each plot during 4 consecutive irrigation events. The soil was cultivated between irrigation events to remove residual effects of the polymer in the soil. Run-off collected at the lower end of the plots was diverted through either a vegetated or bare ditch.

Treatment ditches. A tractor implement was used to scrape V-shaped ditches for treating irrigation run-off at the lower end of each of the 4 plots beginning in August of 2007. The ditches measured 170 ft long, 10 ft wide, and 3 ft deep. Creeping wild rye *(Leymus triticoides)* seedlings were transplanted on the bottom and lower sides of the ditch at a density of 1 plant/ft^2. Red fescue *(Festuca rubra)* seedlings were planted on the upper sides of the ditch. The ditches were irrigated twice per week to establish the vegetation (Fig. 1). Volunteer grain rye and barley from a previous cover crop also germinated and contributed to the vegetation during the 2007 season (Fig. 1). However, creeping wild rye and red fescue dominated the vegetation during 2008 season (Fig. 1). Non-vegetated ditches were established next to the vegetated ditches before the start of each field trial. The bare ditches had the same dimensions as the vegetated ditches.

Polymer treatment Emulsified liquid PAM (Hydrosorb Soilfloc 300E, 37% ai wt/wt) was prediluted into 100 gal tanks of water for the 2007 trial. A high pressure centrifugal pump was used to inject tank mixed PAM into the main line to achieve a 5 ppm concentration in the irrigation water during the 2007 trial. A second tank containing 1500 ppm PAM was used to achieve a 2.5 ppm concentration of PAM in the irrigation water during the 2007 field trial. A chemical metering pump (Seepex MD) was used to directly inject the concentrated liquid PAM into the irrigation system to achieve 5 ppm concentration in the irrigation water during the 2008 trial. Separate mainlines were used for different water treatments.

E. coli field inoculation The experimental field was inoculated with a mixture of 3 marked strains of generic *E. coli* isolated from water samples that had been previously collected in Salinas. These *E. coli* isolates could be quickly identified due to their natural resistance to the antibiotic, rifampicin. A suspension of the strains was mixed with sand and placed in small porous bags. The satchels of sand-E. coli mixture were positioned 100 ft from the upper end of the field in 20 furrows within each plot, immediately before the first irrigation event. The bags were removed after the first irrigation and the field was not inoculated again during subsequent irrigation events.

Water sampling Flumes were positioned at the lower end of the ditches to measure run-off volumes and collect composite samples during the irrigation events. Composite water samples were collected at the upper and lower ends of the treatment ditches. Water samples were analyzed for pH, EC, and temperature immediately after irrigation events and then frozen until they could be analyzed for nutrients, salts, and sediment concentrations at the UC DANR analytical laboratory. Sub-samples of the composite run-off samples were also analyzed for coliform, generic E. coli, and inoculated E. coli.

Results

<u>Sediment in run-off</u>

Run-off water treated with PAM had a significantly lower concentration of suspended sediments and lower turbidity compared to untreated water sampled above the ditches in 2007 and 2008 (Fig. 2). Suspended sediments concentration measured at the outlet of the ditches was less than the concentration at the inlet for all treatments during the 2007 and 2008 trials but not statistically significant (Fig. 2). Although the average concentration of suspended sediments (total suspended solids) and turbidity in the untreated run-off (no addition of PAM) entering the vegetated ditch treatment was lower than the concentration entering the control bare ditch treatment in 2007, the differences between treatments were also not statistically significant, and was probably an artifact of the sampling method used during this year. After adjusting the sampling method in 2008, the average suspended sediment concentration and turbidity of the untreated run-off entering the vegetated and bare ditches were similar (not statistically different).

In contrast to the suspended solids, turbidity levels generally remained the same or increased slightly between the inlet and outlet of the ditches in 2007 and 2008 (data not presented). The difference in turbidity levels of the run-off measured at the inlet and outlet of the ditches were also not statistically different among treatments.

Suspended sediment concentration and turbidity levels in the outflow from the ditches was lowest from PAM treated plots (Table 1). Sediment concentrations were reduced by 89% and 90% for the PAM and PAM+veg treatments, respectively in 2007 and by 93% and 92%, for the PAM and PAM+veg treatments, respectively in 2008. Average load of sediment loss was 167 and 76 lb/acre/irrigation from the control treatment in 2007 and 2008, respectively. Treatments with PAM also reduced sediment loads by an average of 88% in 2007 and 92% in 2008.

The vegetation treatment did not consistently reduce sediment concentration and turbidity in the run-off from plots that did not receive PAM treated water. The concentration of suspended sediments in the outflow from the vegetated ditch was 35% less than the control treatment (bare ditch) in 2007. Although the difference between these treatments was statistically significant, the inflow concentration of sediments was lowest for the vegetated treatment (Fig. 2) and probably an artifact of the sampling method used during this trial. This result was not repeated in the 2008 trial. Both suspended sediment concentration and turbidity measured at the outlet of the control bare and vegetated ditch treatment were statistically similar in 2008 and actual averages were highest for the vegetated treatment (Fig. 2). Also the combined treatment of PAM and the vegetated ditch did not reduce suspended sediment, turbidity, and sediment load significantly more than the PAM and bare ditch treatment for either year (Table 1).

<u>Nutrients in run-off</u>

Treatments with PAM had significantly lower concentrations of total N and total P in run-off than the untreated control at the inlet of the treatment ditches in 2007 and 2008 (data not shown). The addition of PAM reduced total N in run-off at the inlet of the ditches between 38% and 64% relative to the untreated control in 2007 and by more than 67% relative to the untreated control in

2008. At the outlet of the treatment ditches, PAM treatments had more than 64% less total N in run-off compared to the untreated control (Table 2). Run-off from PAM treated plots also had 65% to 73% less total P than the untreated control at the outlet of the treatment ditches (Table 6).

Vegetation in the ditches minimally affected the total N and P concentrations in sprinkler run-off. Total N concentration at the outlet of the vegetated ditch was significantly less than the untreated non-vegetated ditch in 2007 (Table 2); however, the concentration of total N in run-off entering the inlet to the vegetated ditch was also less than the concentration at the inlet of the untreated control ditch (data not presented). Furthermore, the difference in total N concentration between the inlet and outlet of the vegetated ditch was not statically different from the other treatments. Total N concentration at the inlet and outlet of the vegetated ditch was statistically similar to the untreated control ditch in 2008. Finally, the concentration of total N at the outlet of the ditches was statistically similar for the PAM and PAM+vegetation treatments in 2007 and 2008, demonstrating that the concentration of total N in run-off from PAM treated plots was not further reduced by flowing through the vegetated ditch (Table 2).

Similar to total N results, vegetation only had minimal effects on total P concentration at the outlet of the ditches. Total P concentration in the run-off exiting the ditches was statistically similar between the bare control ditch and the vegetated ditch in the 2007 and 2008 trials (Table 3). Also, the difference in total P concentration in the run-off between the inlet and outlet of the ditches was similar among all treatments. The concentration of total P at the outlet of the ditches was statistically similar for the PAM and PAM+vegetation treatments in 2007 and 2008, also demonstrating that the vegetation did not further reduce the total P concentration in the sprinkler run-off.

Soluble P concentration was statistically similar among treatments at the inlet and outlet of the ditches in 2007. Soluble P concentration of run-off from the outlet of the vegetated ditch was higher than the concentration measured at the outlet of the control treatment in 2008. Also, soluble P concentration in the run-off significantly increased between the inlet and outlet of the vegetated ditch. In comparison the control treatment had similar concentrations of soluble P between the inlet and outlet of the ditch

The addition of PAM to the irrigation water had no significant affect on the concentration of soluble P in the run-off during the 2007 trial; however, the addition of PAM significantly reduced soluble P concentration in the run-off at the inlet and outlet of the non-vegetated ditch relative to the control treatment in 2008 (Table 3). The reduction in soluble P concentration in the run-off of the PAM treatment was 32% less than the concentration in the untreated control (Table 3).

The addition of PAM to the irrigation water also had no significant affect on the concentration of nitrate-N in the run-off during the 2007 trial relative to the control treatment. The PAM treatment had significantly lower NO_3 concentration in the run-off entering the treatment ditch than the concentration measured at the inlet of the control ditch in 2008. The average reduction in NO_3 concentration due to the addition of PAM was 31% less the concentration measured in the control treatment in 2008.

Ammonium (NH_4) concentration of run-off was not significantly different among treatments during the 2007 trial. The addition of PAM to the irrigation water significantly reduced NH_4-N concentration in the run-off relative to the control treatment during the 2008 trial. The concentration of NH_4-N at the outflow of the PAM treatment ditch was 44% to 66% lower than the concentration of NH_4-N in the out flowing runoff from the control treatment in 2008 (Table 2).

Coliform and *E.coli* bacteria in run-off

Introduced strains of rifampicin resistant *E.coli* generally composed a majority of the E. coli measured in the run-off. Total coliform concentrations averaged 153 and 544 times greater than the concentration of generic E. coli in the run-off in the 2007 and 2008 trials, respectively.

Concentration of *E. coli*$_{rif}$, generic *E. coli,* and coliform bacteria were not statistically different among treatments at the inlet and outlet of the ditches for the 2007 and 2008 trials (Table 4). Similarly, the difference in concentration between the inlet and outlet of the ditches was not statistically different among treatments for both years of the trial (data not presented). One exception was that less coliform bacteria were measured in run-off at the inlet of treatments with PAM in the irrigation water in 2008 (Table 4). Although the PAM treatment reduced the concentration of coliform bacteria in the run-off 2.5 times less than the untreated control, the concentration in the PAM run-off remained higher than most food safety and regulatory water quality targets.

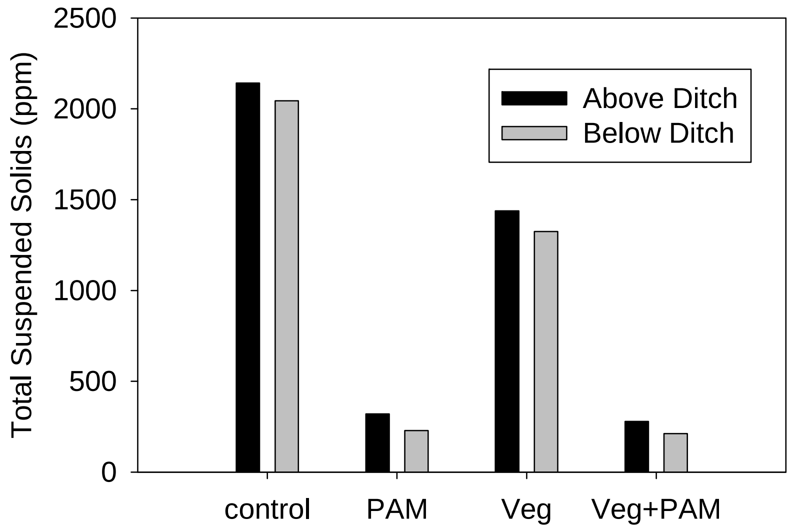
Discussion and Conclusions

The lack of effectiveness of the vegetated treatment to reduce the concentration of suspended sediment and nutrients in run-off may be explained by a combination of factors. Flow rates of the run-off were high relative to the length of the vegetated ditch such that the residence time was less than 45 min. A majority of the biomass of the wild rye that was planted on the bottom of the ditches was 6 inches above the soil surface and would have been unlikely to interact with the run-off flowing in the ditches. Finally, the concentration of suspended sediment in the run-off was significantly higher than concentrations found in run-off of other vegetative ditch studies due to the use of impact sprinklers and that the trial was conducted on a highly erodible soil. Despite these limitations we expected to measure at least a small reduction in sediment concentration between the inflowing and out-flowing run-off from the vegetated ditch. These results suggest that it may be challenging to design vegetated treatment systems that are effective for run-off with high volumes and high sediment loads.

The addition of polyacrylamide polymer to irrigation water at concentrations of 5 ppm and less reduced suspended sediments in sprinkler run-off by an average of 90% and total N and P by approximately 70% for both years of the trials. Because PAM presumably flocculated suspended sediment in run-off water, insoluble forms of N and P associated with the sediments would have also been retained in the field rather than carried in the run-off. More surprising was the result that the addition of PAM significantly, albeit modestly, reduced the concentration of soluble P and NO_3-N in run-off during the 2008 trial. The reduction in soluble P and NO_3-N concentration of about 30% under the PAM treatment was relatively small compared to the effect of PAM on total nutrient and sediment concentration; and therefore it was not surprising that no significant reduction in these soluble nutrients was measured for the PAM treatment during the 2007 trial.

None of the management practices evaluated reduced *E. coli* and coliform bacteria concentrations less than the concentrations measured in the bare control treatment. This result might be expected for the vegetated treatment since vegetation was ineffective in reducing sediment concentration. Despite consistently reducing sediment concentration in the run-off, PAM was ineffective in reducing bacteria concentration. The results of these trials suggested that the majority of the E. coli and coliform bacteria resided in the water and were not associated with suspended sediments. Other studies that have reported that vegetation reduced the load of *E. coli* in irrigation run-off may have lessened the volume of run-off or dropped out bacteria associated with suspended fecal particles. For example, the vegetated buffers in the study of Tate et al. (2006) minimized the bacterial load by enhancing infiltration into the soil and minimizing the movement of cattle feces. In our study, soil was inoculated with E. coli from a point source (sachels of E. coli) and was allowed to migrate in the run-off along the length of the furrows. Because we removed the source of *E. coli* after the first irrigation event, all bacterial collected during subsequent irrigations would have persisted in the soil, presumably in a state that could be readily transported in run-off during irrigation events. Another difference from previous studies was that the reaction time of the vegetated treatment was limited to less than 45 min, which is probably an insufficient time for potential degradation processes to affect bacterial populations. Studies of large constructed wetlands have shown a degradation of E. coli populations during the course of several days. Unfortunately, large vegetated treatment systems designed to handle large run-off volumes associated with overhead sprinklers would be an impractical solution for most of the high valued vegetable production areas on the central coast.

Fig. 1. Vegetated treatment ditches planted with creeping wild rye and red fescue in October 2007 (left) and October 2008 (right). Volunteer grain rye and barley dominated the vegetation during the 2007 trial.



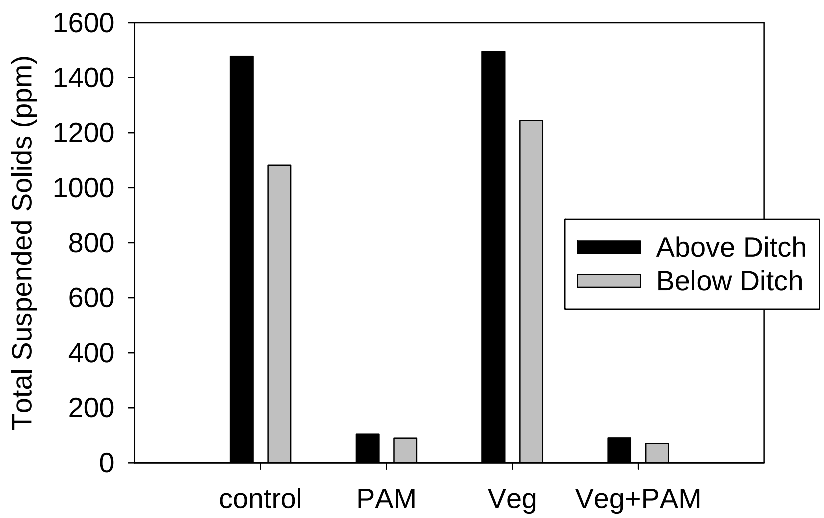


Fig. 2. Average suspended solids concentration in run-off measure at the inlet and outlet of treatment ditches for the 2007 (top) and 2008 (bottom) trials.

Table 1. Concentration of total suspended solids (suspended sediments) and turbidity of run-off sampled at the outlet of the treatment ditches for the 2007 and 2008 field trials. NTU = Nephelometric turbidity units. Low values signify less turbidity.

2007 trial:

Treatment	Total Suspended Solids		Turbidity	
	ppm		NTU	
untreated control (bare ditch)	2044	a	1598	a
PAM 5 ppm (bare ditch)	228	b	135	b
vegetated ditch	1325	c	862	c
vegetated ditch + 2.5 ppm PAM	212	b	117	b

2008 trial

Treatment	Total Suspended Solids		Turbidity	
	ppm		NTU	
untreated control (bare ditch)	1082	a	950	a
PAM 5 ppm (bare ditch)	90	b	104	b
vegetated ditch	1244	a	1022	a
vegetated ditch + 5 ppm PAM	71	b	84	b

Table 2. Concentration of total, nitrate, and ammonium forms of nitrogen in run-off sampled at the outlet of the treatment ditches for the 2007 and 2008 field trials.

2007 trial:

Treatment	Total Kjeldahl N		Nitrate-N		Ammonium-N	
	------------------------		ppm		----------------------	
untreated control (bare ditch)	9.7	a	4.1	a	1.04	a
PAM 5 ppm (bare ditch)	3.5	b	4.1	a	1.12	a
vegetated ditch	7.0	c	4.7	a	0.90	a
vegetated ditch + 2.5 ppm PAM	3.4	b	4.2	a	0.96	a

2008 trial:

Treatment	Total Kjeldahl N		Nitrate-N		Ammonium-N	
	-----------------------		ppm		----------------------	
untreated control (bare ditch)	8.4	a	5.6	a	0.7	a
PAM 5 ppm (bare ditch)	2.8	b	4.3	b	0.2	b
vegetated ditch	8.0	a	7.4	a	0.8	a
vegetated ditch + 5 ppm PAM	3.0	b	4.9	b	0.4	b

Table 3. Concentration of total and soluble forms of phosphorus in run-off sampled at the outlet of the treatment ditches for the 2007 and 2008 field trials.

2007 trial:

Treatment	Total P		Soluble P	
	ppm		ppm	
untreated control (bare ditch)	4.4	a	0.58	a
PAM 5 ppm (bare ditch)	1.6	b	0.58	a
vegetated ditch	3.7	a	0.69	a
vegetated ditch + 2.5 ppm PAM	1.2	b	0.57	a

2008 trial:

Treatment	Total P		Soluble P	
	ppm		ppm	
untreated control (bare ditch)	3.3	a	0.9	a
PAM 5 ppm (bare ditch)	1.0	b	0.6	b
vegetated ditch	3.5	a	1.1	a
vegetated ditch + 5 ppm PAM	1.1	b	0.8	b

Table 4. Concentration of marked generic E. coli (rifampicin resistant), total generic E. coli, and coliform bacteria in run-off sampled at the inlet and outlet of the treatment ditches for the 2007 and 2008 field trials. Data are expressed as the log of the number of colonies (MPN) per 100 ml of sample.

2007 trial:

	E. coli $_{rif}$			*E.coli*			Coliform		
Treatment Description	above	below	diff.	above	below	diff.	above	below	diff.
	Log(MPN/100 ml)								
untreated control (bare ditch)	3.5	3.5	0.0	3.3	3.5	-0.2	5.3	5.6	-0.3
PAM 5 ppm (bare ditch)	3.2	3.4	-0.2	3.4	3.7	-0.3	5.5	5.7	-0.2
vegetated ditch	3.3	3.2	0.1	3.5	3.5	0.0	5.3	5.5	-0.2
vegetated ditch + 2.5 ppm PAM	3.4	3.4	0.0	3.3	3.4	0.0	5.3	5.7	-0.4
$LSD_{0.05}$	NS[x]	NS	NS	NS	NS	NS	NS	NS	NS

[x] NS = treatment differences were not statistically signficant

2008 trial:

	E. coli $_{rif}$			*E.coli*			Coliform		
Treatment Description	above	below	diff.	above	below	diff.	above	below	diff.
	Log(MPN/100 ml)								
untreated control (bare ditch)	2.3	2.2	0.1	2.7	3.2	-0.5	5.3	5.5	-0.2
PAM 5 ppm (bare ditch)	2.1	2.0	0.0	2.4	2.5	0.0	4.9	5.1	-0.2
vegetated ditch	1.9	2.3	-0.4	2.5	3.5	-1.0	5.2	5.6	-0.5
vegetated ditch + 5 ppm PAM	2.2	2.1	0.0	2.3	3.0	-0.7	4.9	5.2	-0.3
$LSD_{0.05}$	NS[x]	NS	NS	NS	NS	NS	NS	NS	NS

[x] NS = treatment differences were not statistically signficant

Literature Cited

K. W. Tate, E. R. Atwill, J. W. Bartolome, and G. Nader 2006. Significant Escherichia coli attenuation by vegetative buffers on annual grasslands. J. of Environ. Qual. 35:795-805