CONTROLLING SPRINKLER IRRIGATION RUNOFF, EROSION, AND PHOSPHORUS LOSS WITH STRAW AND POLYACRYLAMIDE

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ABSTRACT. *Controlling runoff and soil erosion are important for maintaining soil productivity and reducing off-site impairment due to sediment and nutrient enrichment. Previous research has shown that crop residue and polyacrylamide (PAM) can reduce runoff and soil erosion. We compared the combined effects of surface residue and PAM on runoff, soil loss, and phosphorus loss from sprinkler irrigated soil in the laboratory. We hypothesized that surface residue would enhance the effectiveness of sprinkler-applied PAM by allowing PAM to stabilize the soil surface with less disturbance by water drops. Steel boxes (1.5 m long, 1.2 m wide, and 0.2 m deep) were filled with Roza loam (fine, smectitic, mesic xerertic Haplocambids) and irrigated at 80 mm h $^{-1}$ for 15 min. Wheat straw was applied for two separate tests (70% and 30% straw cover). The PAM was applied at 0, 2 or 4 kg ha^{-1} during the first irrigation, followed by two water-only irrigations. Applying PAM to straw-covered soil controlled runoff, erosion, and phosphorus losses equally or better than using either PAM or straw alone. The 70% straw cover reduced cumulative runoff for the three irrigations 75 to 80% compared to 30 to 50% reduction with PAM alone. Polyacrylamide alone or 30% surface cover alone produced similar results, both reducing cumulative runoff 10 to 20% compared to untreated bare soil. Since runoff, erosion and phosphorus loss were reduced when PAM and surface residue were used individually and to a greater extent when used together, management choices should depend on overall costs and control needed to meet water quality and production goals.*

Keywords. *Sprinkler irrigation, Surface residue, PAM, Erosion control.*

Most semiarid and arid soils that support irrigated agriculture have thin surface soil horizons prone to erosion and decreased productivity if not well managed (Carter, 1993). Runoff and soil erosion control are important not only for soil and water conservation, but also to reduce nutrient discharge with runoff. Some water quality impaired streams will be subject to total daily maximum load (TMDL) for phosphorus and sediment in the near future (US EPA, 1998). Using conservation tillage to leave crop residue on the soil surface reduces soil erosion compared to clean tilled fields, but does not necessarily reduce runoff (Ghidey and Alberts, 1998; Lindstrom et al., 1998; Baker and Laflen, 1983; Dickey et al., 1984). Conservation tillage practices are often ineffective in reducing loss of water soluble nutrients, but can reduce total nutrient losses by reducing erosion (Seta et al., 1993; Sharpley et al., 1991; Mostaghimi et al., 1988; Alberts and Spomer, 1985; Barisas et al., 1978; Johnson et al., 1979).

An alternative practice to conservation tillage is polyacrylamide application with irrigation water. Applying anionic polyacrylamide (PAM) at 1 to 2 kg PAM ha^{-1} reduced furrow irrigation erosion by more than 90% (Lentz et al., 1992; Trout et al., 1995; Sojka and Lentz, 1997). The PAM application can also reduce total and soluble phosphorus loss in furrow irrigation runoff (Lentz et al., 1998). Greater amounts of PAM are needed to control sprinkler irrigation induced soil erosion, and results generally are not as dramatic. Spraying a high PAM concentration liquid on the soil at 20 kg PAM ha^{-1} before simulated rainfall significantly reduced runoff and soil erosion (Ben-Hur, 1994; Levin et al., 1991). Zhang and Miller (1996) also used a high concentration PAM solution at 15 and 30 kg ha^{-1} and measured increased infiltration and decreased erosion, but the effects decreased with subsequent simulated rains. Stern et al. (1991) showed that PAM also reduced runoff from natural rainstorms when applied at 5 or 20 kg PAM ha $^{-1}$. They found no statistical differences between the two PAM rates. Applying 3 to 12 kg PAM ha^{-1} with simulated rainfall can also reduce runoff and erosion (Ben-Hur et al., 1989; Levy et al., 1992). During the initial irrigation in a laboratory simulation, applying 2 to 4 kg PAM ha^{-1} with 20 mm of water reduced runoff 70% and soil loss 75% compared to untreated soil (Aase et al., 1998). However, after two subsequent irrigations with only water, runoff was similar between untreated and PAM-treated soil. In a field plot study with silt loam soil, Flanagan et al. (1997 a,b) found increased water infiltration rate when they applied 10 mg L^{-1} of PAM with tap water on "wet" runs. Sediment concentration in runoff, however, was greater from PAM-treated plots than from untreated plots; but total runoff and sediment losses were not reported.

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The purpose of our laboratory study was to compare runoff, soil loss, and phosphorus loss from soil with and without surface residue that was irrigated with and without PAM in irrigation water. We hypothesized that surface residue would improve the effectiveness of PAM to reduce runoff and soil erosion by allowing PAM to stabilize the soil surface with less destruction of surface soil structure by water drops. We further hypothesized that PAM would reduce soluble phosphorus loss in runoff by increasing infiltration when used in combination with surface residue.

MATERIALS AND METHODS

Six steel boxes were constructed for the laboratory study. Each box was 1.5 m long, 1.2 m wide, and 0.2 m deep; the down-slope side was only 0.15 m deep to provide for affixing a runoff trough to funnel water and sediment into catch containers. The boxes were equipped with drain tubes (13 mm diameter) to collect excess water. However, our irrigation scheme did not cause water to percolate through the 0.15 m of soil to the drain tubes. The boxes were hinged so surface slope could vary from 0 to 15%. All tests were conducted with a surface slope of 2.4%.

We collected Roza loam (fine, smectitic, mesic xerertic *Haplocambids*) topsoil (0 to 0.1 m depth) and stored it in a covered metal box. Soil texture, determined by the hydrometer method, was 36% clay, 43% silt, and 21% sand. Soil organic matter was 14 g kg^{-1}, saturated paste extract pH was 6.4, saturated paste extract electrical conductivity (EC) was 0.5 dS m^{-1}, and sodium adsorption ratio (SAR) was 0.7. The soil contained 24 mg PO_4 kg^{-1} and 31 mg P kg. Large clods were removed or broken prior to filling the boxes by passing the air-dried soil through a 6.4 mm screen. To avoid layering and segregation, the soil surface was stirred and mixed prior to leveling, which achieved a uniform 0.15 m soil depth with a lightly packed surface. The resultant bulk density was about 1.0 Mg m^{-3} in all tests. The soil surface and soil depth mimicked a dry, freshly tilled, field seedbed.

We conducted this study as two separate irrigation tests. For Test 1, we applied 2500 kg ha^{-1} of wheat (*Triticum aestivum* L.) straw (about 70% surface cover, based on visual estimate) to three of the six boxes before the first irrigation. Wheat straw was collected from the back of a combine after harvest, air dried, and stored in large plastic bags until use in this study. Fifteen percent of the straw was vertically inserted into the soil by hand in 18-cm-wide rows, parallel to the slope, while the remaining straw was broadcast to simulate an untilled, harvested small grain field. For Test 2, we broadcast all of the straw at 670 kg ha^{-1} resulting in about 30% surface cover, which simulated the soil surface of a conservation tilled field.

Polyacrylamide was added in the first irrigation for both tests, followed by two water-only irrigations. The soil was allowed to dry for 7 to 10 days between each irrigation. The three PAM rates used were: 0, 2, and 4 kg ha^{-1} (0, 10, and 20 mg PAM L^{-1}). A 1920 mg PAM L^{-1} stock solution was prepared from dry granular polyacrylamide copolymer with molecular weight of 12 to 15 Mg $mole^{-1}$ and 18% negative charge density (Superfloc A-836, marketed by American Cyanamid Co.). We mixed the stock solution with water in 210 L containers to create the desired PAM concentrations. The irrigation water was then pumped to the irrigation simulator and applied to the previously dry soil surface.

Irrigation water was applied through an oscillating sprinkler similar to one described by Meyer and Harmon (1979). A Veejet nozzle (8070) was mounted 3 m above the soil surface. Well water (EC = 0.73 dS m^{-1}, pH = 7.2, and SAR = 1.7) was used at a nozzle pressure of 76 kPa, providing a median drop size of 1.2 mm diameter. Droplet energy striking the soil surface was about 25 J kg^{-1}, calculated as described by Kincaid (1996). This relatively high energy was necessary to achieve the desired water application rate of 80 mm h^{-1}. Each soil box was irrigated for 15 min to apply 20 mm of water.

As soon as runoff stopped, water collected from each box was weighed. The runoff did not contain any straw. Two, 50-mL water samples were taken for phosphorus analysis. One sample was filtered (0.45 μm), stabilized with boric acid, and refrigerated until analysis for orthophosphorus (Watanabe and Olsen, 1965). The second sample was unfiltered and refrigerated prior to analysis for total phosphorus (Greenberg et al., 1992). All remaining runoff was filtered to determine the sediment mass eroded during the irrigation. A filtered and an unfiltered water sample were also collected from inflow water during each irrigation to determine phosphorus applied with the irrigation water.

We conducted a supplemental test to determine the possible phosphorus contribution from wheat straw by covering the soil in one box with plastic and applying either of the two straw rates on top of the plastic. The straw was irrigated for 15 min. with tap water. We also irrigated the 2500 kg ha^{-1} straw rate with the two PAM rates to determine if PAM affected phosphorus loss from the straw. Runoff water samples were collected for phosphorus analysis following the same procedures as previously described. Each straw and PAM rate was replicated three times. Between replications, all straw was removed, the plastic was rinsed with distilled water, and fresh straw was spread on the plastic.

Prior to each irrigation we took two, 19-mm-diameter soil cores from each box to determine antecedent soil water content in the 0 to 75 mm and 75 to 150 mm depths. Holes left by the core sampler were filled with soil and packed to prevent preferential flow. Surface soil (0-75 mm) water content varied from 120 to 160 g kg^{-1} during this study, but varied less than 15 g kg^{-1} among treatments for a given irrigation. Four or five days following the third irrigation, except for the first replication of Test 1, we took 5-mm-deep surface soil samples from four locations in each box for wet aggregate stability determinations. The soil samples were lifted from the soil surface with spatulas, sealed in plastic bags, and refrigerated prior to analysis according to the procedure described by Kemper and Rosenau (1986) as modified by Lehrsch et al. (1991). After collecting aggregate stability samples, we removed about 40 mm of surface soil from all boxes to ensure that no residual PAM remained (Malik et al., 1991). New soil was then added and mixed with the remaining soil in preparation for the next test or replication.

We analyzed each irrigation test as a separate randomized complete block with six treatments (three PAM rates on bare or straw-covered soil) and three replications in time. Again, the straw rate for Test 1 was 2500 kg ha^{-1}

(about 70% surface cover) and for Test 2 was 670 kg ha^{-1} (about 30% surface cover). Duncan's multiple range test was used to separate means when treatments were significantly different ($P < 0.05$). A two-way factorial analysis was also conducted to identify significant interaction between straw and PAM. For Test 1, no runoff occurred from the 4 kg PAM ha^{-1} rate on straw covered soil during the first irrigation for two of the three replications. Since concentrations are undefined without runoff, this treatment was removed from the analysis of variance for concentration parameters for the first irrigation of Test 1. Soil and total-P loss data for both Test 1 and 2 were log transformed based on Bartlett's test for homogeneity of variances (Little and Hills, 1978). Tabular data show arithmetic means for each treatment, not transformed values. Since we did not collect soil samples for aggregate stability analysis from the first replication of Test 1, analysis of variance was not used for aggregate stability data, but means and 95% confidence intervals are reported instead.

RESULTS

Straw spread on the soil surface was a greater source of phosphorus than irrigation water. The tap water used for irrigation simulations averaged 0.02 mg L^{-1} ortho-P and 0.04 mg L^{-1} total-P, which added minimal amounts of phosphorus to the soil or runoff. Tap water supplied only 4 g ha^{-1} ortho-P and 8 g ha^{-1} total-P for a 20 mm irrigation. Phosphorus concentrations in runoff from tests with straw placed on plastic averaged 0.57 mg L^{-1} ortho-P and 0.73 mg L^{-1} total-P for the 2500 kg ha^{-1} straw rate (Test 1) and 0.09 mg L^{-1} ortho-P and 0.15 mg L^{-1} total-P for the 670 kg ha^{-1} straw rate (Test 2). The PAM in the irrigation water had no effect on either ortho-P or total-P concentrations in runoff from straw spread on plastic. These results indicated that straw potentially contributed 146 g ha^{-1} total-P to the soil or runoff during the first irrigation of Test 1 and 30 g ha^{-1} total-P during the first irrigation of Test 2.

TEST 1

As expected, 70% straw cover significantly reduced runoff, sediment, total-P and ortho-P losses for all three irrigations (table 1). The primary reason for decreased sediment and phosphorus losses was that straw greatly reduced runoff, especially when PAM was applied. Straw cover also decreased sediment and total-P concentrations during the first irrigation. Decreased sediment and total-P concentrations probably resulted from straw cover reducing soil detachment by raindrops and transport by the small amount of water that ran off the soil. Straw also reduced ortho-P concentration for the first irrigation compared to bare, non-PAM treated soil (table 1). This was unexpected because the straw was an ortho-P source (0.57 mg L^{-1} ortho-P in runoff from straw spread on plastic). Average time before runoff began during the first irrigation on bare, untreated soil was 4.5 min compared to 10 min on straw-covered soil. The increased infiltration on straw-covered soil probably caused the readily desorbed phosphorus on the straw and surface soil to leach into the soil profile (Baker and Laflen, 1982; Mostaghimi et al., 1988; Pote et al., 1999), removing it from the primary mixing zone where phosphorus is transferred to runoff water (Zhang et al., 1999).

Straw cover more effectively controlled runoff, erosion and phosphorus losses than PAM applied at 2 or 4 kg PAM ha^{-1} with the first irrigation. Applying PAM on bare soil decreased runoff about 40% for the first irrigation compared to untreated bare soil. However, straw cover without PAM decreased runoff more than 80% for the first irrigation compared to untreated bare soil (table 1). Similar

Table 1. Test 1 results for 70% straw cover (parameter values with similar letters within an irrigation are not significantly different, P < 0.05)

	PAM		Sediment		Total-P		Ortho-P	
Soil Cover	Treatment (kg ha^{-1})	Runoff (mm)	Concentration (g L^{-1})	Loss (kg ha^{-1})	Concentration (mg L^{-1})	Loss (g ha^{-1})	Concentration (mg L^{-1})	Loss (g ha^{-1})
Irrigation 1								
bare	0	10.3a	4.9a	500a	2.8a	290a	0.073a	7.4a
bare	2	6.3b	3.8a	240ab	2.9a	180ab	0.065ab	4.0b
bare	4	5.7b	2.6b	150b	2.2ab	130b	0.052bc	3.0b
straw	0	1.5c	1.7c	24c	1.1bc	16c	0.038c	0.5c
straw	2	0.2d	1.8c	3d	0.6c	1d	0.032c	< 0.1c
straw	4	< 0.1d	*	< 1e	*	< 1d	*	< 0.1c
Irrigation 2								
bare	0	10.6a	6.8a	690a	2.6ab	270a	0.053a	5.8a
bare	2	7.7d	4.1ab	310ab	2.9a	220a	0.075a	6.0a
bare	4	7.3d	3.3b	240ab	3.0a	220a	0.071a	5.6a
straw	0	3.1c	3.9b	88b	1.2bc	32b	0.044a	2.0b
straw	2	1.2c	1.2c	16c	1.0c	13b	0.050a	0.6b
straw	4	1.3c	1.4c	15c	1.3bc	13b	0.064a	1.0b
Irrigation 3								
bare	0	11.8a	7.1a	840a	4.1ab	480a	0.084a	9.9a
bare	2	9.7b	5.3ab	500a	4.9a	450a	0.071a	7.1a
bare	4	10.5ab	3.7ab	400a	2.6abc	270a	0.071a	7.8a
straw	0	4.8c	0.7c	25b	1.4bc	66b	0.071a	3.6b
straw	2	2.2d	1.3bc	31b	1.0c	23b	0.059a	1.3b
straw	4	2.9cd	2.3abc	41b	1.1c	31b	0.064a	2.6b

* No runoff occurred from straw-covered soil with the 4 kg PAM ha^{-1} rate for two of the three replications. This treatment was removed from the analysis of variance for concentration parameters.

trends occurred for sediment, total-P, and ortho-P losses for irrigation 1.

There were no significant differences between 2 and 4 kg ha^{-1} PAM rates for any parameter or irrigation (table 1). Some significant effects of PAM treatments occurred for irrigations 2 and 3, but the beneficial PAM effects were most evident during the first irrigation, when PAM was applied. Thus, these data do not indicate that straw cover improved the residual effects of PAM. Furthermore, applying PAM did not reduce ortho-P loss from straw covered soil. However, PAM was more effective when applied to soil with 70% straw cover than to bare soil as indicated by a significant interaction between straw and PAM for runoff, sediment loss and total-P loss during irrigation 1. PAM treatments reduced runoff more than 85% on straw-covered soil but only about 40% on bare soil during irrigation 1. For the same irrigation, PAM reduced sediment loss more than 85% on straw-covered soil and 50 to 70% on bare soil (table 1). The interaction between straw and PAM was also significant for ortho-P loss during irrigation 1 because PAM reduced ortho-P loss from bare soil but not from straw-covered soil (table 1). The interaction between straw and PAM was not significant for any other parameters or irrigations.

Both 70% straw cover and PAM significantly decreased cumulative runoff and sediment loss for the three irrigations (fig. 1). Straw cover alone and PAM applied to straw-covered soil decreased cumulative total-P loss while only straw cover decreased cumulative ortho-P loss (fig. 2). Applying PAM during the first irrigation was not as effective as 70% straw cover for reducing cumulative runoff, sediment, and phosphorus losses during the three irrigations.

TEST 2

Both 30% straw cover and PAM significantly reduced runoff, sediment, total-P, and ortho-P losses for the first irrigation (table 2). PAM-treated soil with straw cover had significantly less runoff, sediment, total-P and ortho-P losses than untreated bare soil for all three irrigations. Sediment losses were not statistically different between untreated straw-covered and PAM-treated bare soil for any irrigation, indicating that PAM was about as effective as 30% straw cover at reducing soil loss.

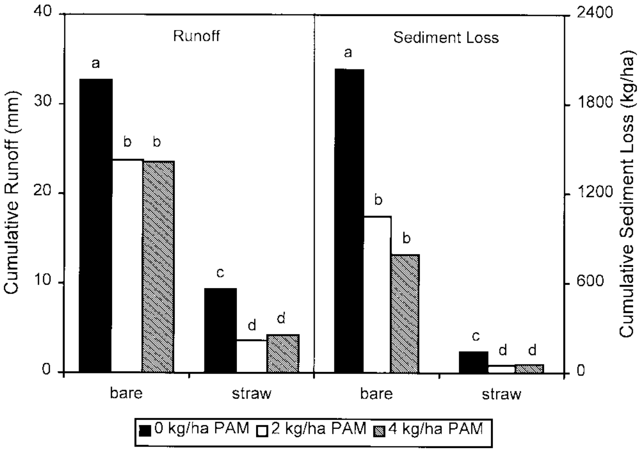

Figure 1–Cumulative runoff and sediment loss for three irrigations of Test 1 comparing three PAM treatments on bare soil and 70% straw cover. Columns for a parameter with similar letters are not statistically different (P < 0.05).

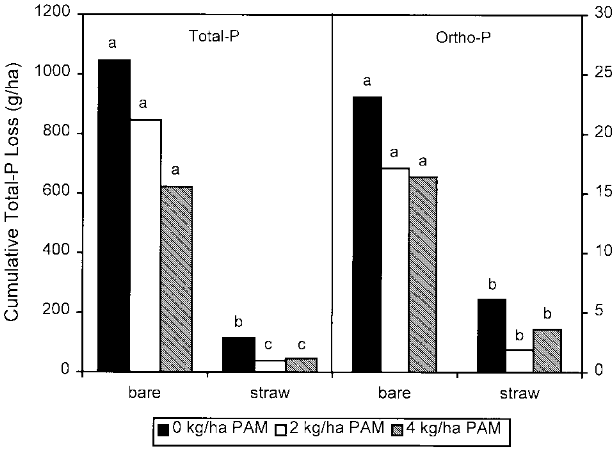

Figure 2–Cumulative total-P and ortho-P losses for three irrigations of Test 1 comparing three PAM treatments on bare soil and 70% straw cover. Columns for a parameter with similar letters are not statistically different (P < 0.05).

Similar to test 1, straw cover did not increase ortho-P concentration in runoff. Neither straw cover nor PAM treatments significantly affected total-P concentrations for any irrigation or ortho-P concentrations for irrigations 1 or 2 (table 2). However, applying PAM to straw-covered soil decreased sediment concentrations for irrigations 1 and 2 compared to untreated bare soil or untreated straw-covered soil. Typically sediment and total-P concentrations are directly related (Andraski et al., 1985; Carter et al., 1974). Significant relationships ($P < 0.01$) between sediment concentration and total-P concentration occurred for both PAM-treated and untreated soil, but sediment concentration only explained 37 and 18% of the total-P concentration variability, respectively (fig. 3). Interactions among PAM, straw, runoff, sediment, and phosphorus probably caused the significant treatment differences for sediment concentration and not for total-P concentration.

Runoff and phosphorus losses were not significantly different between the two PAM rates for any irrigation (table 2). Sediment concentrations for irrigations 1 and 2 and sediment loss for irrigation 2 were reduced by applying 4 kg PAM ha^{-1} compared to 2 kg PAM ha^{-1}. Unlike Test 1, there was not a significant interaction between straw and PAM. PAM still reduced runoff, erosion and phosphorus losses when applied to bare soil or soil with 30% residue cover; it just was not more effective on straw-covered soil than on bare soil.

Cumulative runoff and sediment loss for both bare and straw-covered soil were significantly reduced by both PAM rates (fig. 4). The PAM-treated, straw-covered soil had significantly less cumulative total-P and ortho-P losses than untreated bare soil or untreated straw-covered soil (fig. 5). Applying PAM to bare soil reduced cumulative runoff more than 30% straw cover without PAM. However, cumulative sediment, total-P and ortho-P losses were similar between PAM-treated bare soil and untreated straw-covered soil.

Table 2. Test 2 results for 30% straw cover (parameter values with similar letters within an irrigation are not significantly different, $P < 0.05$)

Soil Cover	PAM Treatment (kg ha^{-1})	Runoff (mm)	Sediment Concentration (g L^{-1})	Sediment Loss (kg ha^{-1})	Total-P Concentration (mg L^{-1})	Total-P Loss (g ha^{-1})	Ortho-P Concentration (mg L^{-1})	Ortho-P Loss (g ha^{-1})
Irrigation 1								
bare	0	11.6a	7.9a	920a	3.5a	400a	0.109a	12.7a
bare	2	8.3c	5.6ab	470b	2.6a	220b	0.088a	7.4b
bare	4	8.4c	4.3bc	370b	2.1a	180bc	0.078a	6.7b
straw	0	9.9b	4.6b	450b	2.5a	250ab	0.134a	13.2a
straw	2	5.5d	3.0c	170c	2.4a	130cd	0.070a	3.8b
straw	4	6.5d	1.9d	120c	1.5a	95d	0.078a	5.0b
Irrigation 2								
bare	0	12.7a	8.5a	1100a	3.6a	460a	0.124a	15.8a
bare	2	10.0bc	4.7bc	480b	3.0a	310ab	0.102a	10.3bc
bare	4	10.0bc	4.9b	490b	3.6a	370ab	0.113a	11.4abc
straw	0	11.4ab	4.6bc	520b	2.5a	290ab	0.104a	11.9ab
straw	2	9.0cd	3.2c	290c	2.0a	180bc	0.079a	7.2bc
straw	4	8.1d	2.1d	170d	1.8a	140c	0.082a	6.7c
Irrigation 3								
bare	0	13.7a	8.2a	1100a	2.7a	370a	0.103ab	14.1a
bare	2	12.0bc	5.2a	620ab	2.6a	310a	0.111a	13.4ab
bare	4	12.1bc	4.6a	550ab	2.5a	310a	0.114a	13.8a
straw	0	12.4b	6.7a	820ab	2.3a	280ab	0.078b	9.7c
straw	2	11.4c	3.1a	360b	1.7a	200c	0.079b	9.0c
straw	4	11.4c	3.1a	350b	1.9a	220bc	0.089ab	10.2bc

AGGREGATE STABILITY

Applying PAM increased wet aggregate stability of surface soil collected after the third irrigation. Both the 2 and 4 kg ha^{-1} PAM rates had greater aggregate stability than untreated soil for the straw treatments, while only the 4 kg ha^{-1} PAM rate had greater aggregate stability than untreated bare soil (table 3). This indicates that surface residue increased the effectiveness of PAM to stabilize soil aggregates.

The aggregate stability of untreated soil (0 kg PAM ha^{-1}) was greater for bare soil than straw-covered soil in both tests. Some soluble elements that leached from the wheat straw to the soil may have reduced aggregate stability. Potassium, for example, can disperse soil particles, but organic carbon should increase aggregate stability. Another possible reason is that the finer sediment and unstable aggregates were eroded from the bare soil but remained on the straw-covered soil. Thus, more stable aggregates remained on the bare soil compared to the straw-covered soil.

CONCLUSIONS

Applying PAM with irrigation water significantly reduced runoff, erosion and phosphorus loss when applied to either straw-covered or bare soil. However, adding straw to the soil surface at rates similar to no-till conditions (70% residue cover) was more effective than applying PAM at 2 or 4 kg ha^{-1} to bare soil. The effectiveness of 30% straw cover and PAM treatments was similar. Using PAM in combination with 30 or 70% straw cover was usually more effective for controlling runoff, erosion and phosphorus losses than using either PAM or straw alone. The data do not indicate that straw improved the residual effects of PAM. Management practices that leave crop

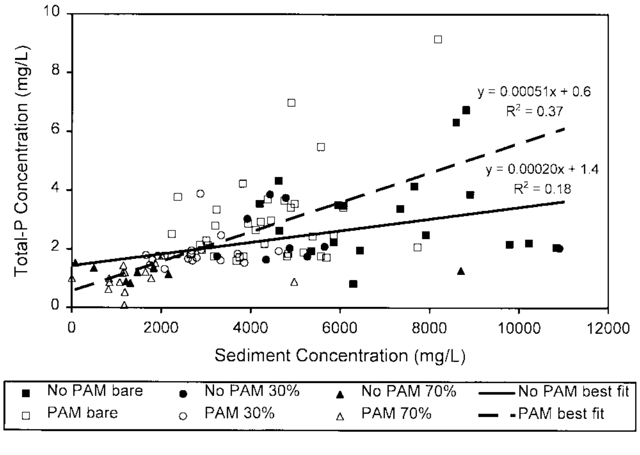

Figure 3–Relationship between total-P concentration and sediment concentration for all irrigations from both tests.

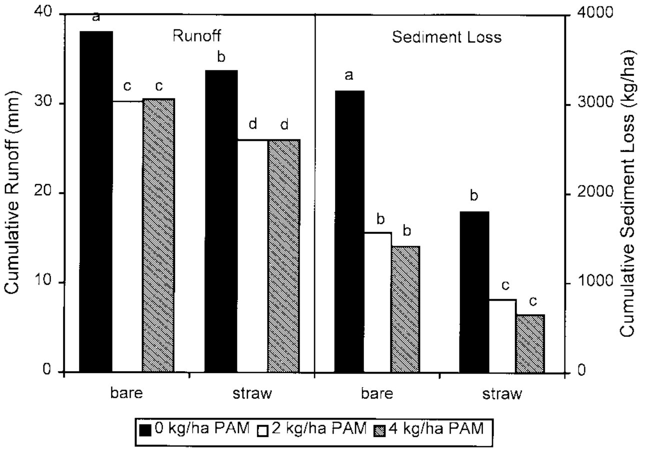

Figure 4–Cumulative runoff and sediment loss for three irrigations of Test 2 comparing three PAM treatments on bare soil and 30% straw cover. Columns for a parameter with similar letters are not statistically different ($P < 0.05$)

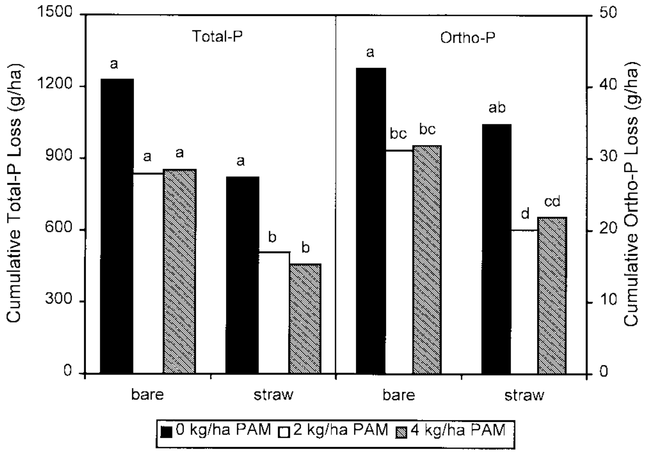

Figure 5–Cumulative total-P and ortho-P losses for three irrigations of Test 2 comparing three PAM treatments on bare soil and 30% straw cover. Columns for a parameter with similar letters are not statistically different ($P < 0.05$).

Table 3. Aggregate stability of surface soil samples collected after the third irrigation (the number in parenthesis is the 95% confidence interval)

PAM Rate ($kg\ ha^{-1}$)	Percent Stable Aggregates			
	Test 1		Test 2	
	Bare Soil	70% Cover	Bare Soil	30% Cover
0	47 (3.8)	35 (3.0)	39 (2.7)	32 (2.2)
2	43 (2.5)	69 (4.6)	40 (1.5)	58 (3.1)
4	63 (4.3)	66 (2.7)	62 (3.3)	66 (2.8)

residue on the soil surface should be considered in combination with PAM application for controlling runoff and erosion under sprinkler irrigation where tillage and residue management alone are not effective.

REFERENCES

Aase, J. K., D. L. Bjorneberg, and R. E. Sojka. 1998. Sprinkler irrigation runoff and erosion control with polyacrylamide–Laboratory tests. *Soil Sci. Soc. Am. J.* 62(6): 1681-1687.
Andraski, B. J., D. H. Mueller, and T. C. Daniel. 1985. Phosphorus losses in runoff as affected by tillage. *Soil Sci. Soc. Am. J.* 49(6): 1523-1527.
Alberts, E. E., and R. G. Spomer. 1985. Dissolved nitrogen and phosphorus in runoff from watershed in conservation and conventional tillage. *J. Soil & Water Cons.* 40(1): 153-157.
Baker, J. L., and J. M. Laflen. 1982. Effects of corn residue and fertilizer management on soluble nutrient runoff losses. *Transactions of the ASAE* 25(2): 344-348.
_____. 1983. Water quality consequences of conservation tillage. *J. Soil & Water Cons.* 38(3): 186-193.
Barisas, S. G., J. L. Baker, H. P. Johnson, and J. M. Laflen. 1978. Effect of tillage systems on runoff losses of nutrients, a rainfall simulation study. *Transactions of the ASAE* 21(5): 893-897.
Ben-Hur, M. 1994. Runoff, erosion, and polymer application in moving-sprinkler irrigation. *Soil Sci.* 158(4): 283-290.
Ben-Hur, M., J. Faris, M. Malik, and J. Letey. 1989. Polymers as soil conditioners under consecutive irrigations and rainfall. *Soil Sci. Soc. Am. J.* 53(4): 1173-1177.
Carter, D. L. 1993. Furrow irrigation erosion lowers soil productivity. *J. Irrig. Drain. Eng.* 119(6): 964-974.
Carter, D. L., M. J. Brown, C. W. Robbins, and J. A. Bondurant. 1974. Phosphorus associated with sediments in irrigation and drainage waters for two large tracts in southern Idaho. *J. Environ. Qual.* 3(3): 287-291.
Dickey, E. C., D. P. Shelton, P. J. Jasa, and T. R. Peterson. 1984. Tillage, residue and erosion on moderately sloping soils.*Transactions of the ASAE* 27(4): 1093-1099.
Flanagan, D. C., L. D. Norton, and I. Shainberg. 1997a. Effect of water chemistry and soil amendments on a silt loam soil– Part 1: Infiltration and runoff.*Transactions of the ASAE* 40(6): 1549-1554.
_____. 1997b. Effect of water chemistry and soil amendments on a silt loam soil– Part 2: Soil erosion. *Transactions of the ASAE* 40(6): 1555-1561.
Ghidey, F., and E. E. Alberts. 1998. Runoff and soil losses as affected by corn and soybean tillage systems. *J. Soil & Water Cons.* 53(1): 64-70.
Greenberg, A. E., L. S. Clesceri, and A. D. Eaton. 1992. *Standard Methods for the Examination of Water and Wastewater,* 18th Ed. Washington, D.C.: Am. Public Health Assoc., Am. Water Works Assoc., and Water Environment Fed.
Johnson, H. P., J. L. Baker, W. E. Shrader, and J. M. Laflen. 1979. Tillage system effects on sediment and nutrients in runoff from small watersheds. *Transactions of the ASAE* 22(5): 1110-1114.
Kemper, W. D., and R. C. Rosenau. 1986. Aggregate stability and size distribution. In *Methods of Soil Analysis: Physical and Mineralogical Methods*, 2 Ed. Part 1, ed. A. Klute. Madison, Wis.: Am. Soc. Agron.
Kincaid, D. C. 1996. Spraydrop kinetic energy from irrigation sprinklers. *Transactions of the ASAE* 39(3): 847-853.
Lehrsch, G. A., R. E. Sojka, D. L. Carter, and P. M. Jolley. 1991. Freezing effects on aggregate stability affected by texture, mineralogy, and organic matter. *Soil Sci. Soc. Am. J.* 55(5): 1401-1406.
Lentz, R. D., I. Shainberg, R. E. Sojka, and D. L. Carter. 1992. Preventing irrigation furrow erosion with small applications of polymers. *Soil Sci. Soc. Am. J.* 56(6): 1926-1932.
Lentz, R. D., R. E. Sojka, and C. W. Robbins. 1998. Reducing phosphorus losses from surface-irrigated fields: Emerging polyacrylamide technology. *J. Environ. Qual.* 27(2): 305-312.
Levin, J., M. Ben-Hur, M. Gal, and G. J. Levy. 1991. Rain energy and soil amendments effects on infiltration and erosion of three different soil types. *Australian J. Soil Res.* 29(3): 455-465.
Levy, G. J., J. Levin, M. Gal, M. Ben-Hur, and I. Shainberg. 1992. Polymers' effects on infiltration and soil erosion during consecutive simulated sprinkler irrigations. *Soil Sci. Soc. Am. J.* 56(3): 902-907.
Lindstrom, M. J., T. E. Schumacher, N. P. Cogo, and M. L. Blecha. 1998. Tillage effects on water runoff and soil erosion after sod. *J. Soil & Water Cons.* 53(1): 59-63.
Little, T. M. and F. J. Hills. 1978. *Agricultural Experimentation: Design and Analysis.* New York, N.Y.: John Wiley & Sons.
Malik, M., A. Nadler, and J. Letey. 1991. Mobility of polyacrylamide and polysaccharide polymers through soil materials. *Soil Technol.* 4(3): 255-263.
Meyer, L. D., and W. C. Harmon. 1979. Multiple-intensity rainfall simulator for erosion research on row sideslopes. *Transactions of the ASAE* 22(1): 100-103.
Mostaghimi, S., T. A. Dillaha, and V. O. Shanholtz. 1988. Influence of tillage systems and residue levels on runoff, sediment, and phosphorus losses. *Transactions of the ASAE* 31(1): 128-132.
Pote, D. H., T. C. Daniel, D. J. Nichols, A. N. Sharpley, P. A. Moore Jr., D. M. Miller, and D. R. Edwards. 1999. Relationship between phosphorus levels in three ultisols and phosphorus concentrations in runoff. *J. Environ. Qual.* 28(1): 170-175.
Seta, A. K., R. L. Blevins, W. W. Frye, and B. J. Barfield. 1993. Reducing soil erosion and agricultural chemical losses with conservation tillage. *J. Environ. Qual.* 22(4): 661-665.

Sharpley, A. N., S. J. Smith, J. R. Williams, O. R. Jones, and G. A. Coleman. 1991. Water quality impacts associated with sorghum culture in the southern plains. *J. Environ. Qual.* 20(1): 239-244.

Sojka, R. E., and R. D. Lentz. 1997. Reducing furrow irrigation erosion with polyacrylamide (PAM). *J. Prod. Agric.* 10(1): 47-52.

Stern, R., M. C. Laker, and A. J. van der Merwe. 1991. Field studies on effect of soil conditioners and mulch on runoff from kaolinitic and illitic soils. *Australian J. Soil Res.* 29(2): 249-261.

Trout, T. J., R. E. Sojka, and R. D. Lentz. 1995. Polyacrylamide effect on furrow erosion and infiltration. *Transactions of the ASAE* 38(3): 761-765.

U.S. EPA. 1998. Clean water action plan: Restoring and protecting America's waters. 840R98001. Washington, D.C.:U.S. EPA.

Watanabe, R. S., and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soils. *Soil Sci. Soc. Am. Proc.* 29(6): 677-678.

Zhang, X. C., and W. P. Miller. 1996. Polyacrylamide effect on infiltration and erosion in furrows. *Soil Sci. Soc. Am. J.* 60(3): 866-872.

Zhang, X. C., L. D. Norton, T. Lei, and M. A. Nearing. 1999. Coupling mixing zone concept with convection-diffusion equation to predict chemical transfer to surface runoff. *Transactions of the ASAE* 42(4): 987-994.