REDUCING NUTRIENT LOSSES IN RUNOFF FROM FURROW IRRIGATION

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ABSTRACT

Few studies have comprehensively examined nutrient losses in runoff from furrow-irrigated fields, but the rising cost of fertilizer and finite nature of the resource encourages further research. A 2-yr experiment measured runoff losses of sediment, particulate P and N, and dissolved NO_3-N, NH_4-N, K, and reactive P (DRP) from fertilized, manured, or non-amended fields. Average nutrient losses were substantial, including 15.6 lbs ac^{-1} yr^{-1} dissolved N, P, and K and 73.6 lbs ac^{-1} yr^{-1} particulate N and P. The cost or replacing these nutrients with inorganic fertilizers was not trivial, at $54.69 ac^{-1} yr^{-1}. Relative to non-amended soil, manure increased dissolved K, NO_3-N, and DRP in runoff by 2.1x, 1.5x, and 2.7x, respectively. Other experiments evaluated the influence of furrow management practices on runoff nutrient loads from soils amended with manure in late summer and irrigated in the fall or following spring. We measured sediment, dissolved NO_3-N, NH_4-N, DRP, and TP concentrations in irrigation furrow runoff. Delaying the first irrigation until spring or treating the fall irrigation with polyacrylamide (WSPAM) reduced runoff component losses by 80 to 100% relative to Fall-Controls. In the spring irrigation, moldboard plowing reduced runoff DRP mass losses by ~60% compared to rototill. The buried lateral furrow system decreased runoff mass losses for sediment, DOC, and TP by >80% relative to conventional irrigation. This research demonstrated that several management practices may be successfully employed to substantially reduce offsite nutrient transport during the first irrigation on furrow-irrigated, manure-amended fields.

INTRODUCTION

Irrigated cropland produces a large share of the total crop value in the U.S. Of the U.S. irrigated acreage, furrow irrigation is employed on about one-quarter or 5 million hectares (USDA, 1998). While furrow irrigation provides several important advantages over other crop irrigation methods, an important consequence is that furrow irrigation runoff is permitted to leave the field. This runoff can transport nutrients and other materials applied onsite to offsite environments where they may generate negative ecological consequences. These materials include sediment, organic carbon, salts, nutrients such as nitrate, ammonium, potassium, and phosphorus, trace elements, pesticides, and microorganisms.

Fertilizer's rising costs and dwindling reserves are driving the need to utilize this resource more effectively in agriculture. Few studies have comprehensively examined nutrient losses in runoff from furrow-irrigated fields or investigated how management practices can influence these losses. We initiated a series of experiments to address these questions. In Exp. 1 we determined the annual nutrient losses in runoff from fertilizer or manure amended, furrow-irrigated soils in south-central Idaho. An additional three experiments investigated how different management practices influenced runoff nutrient losses from manure-amended fields: In Exp. 2 we evaluated the use of soluble polyacrylamide (WSPAM) amended inflows; in Exp. 3 we examined effects of tillage and irrigation timing; and in Exp. 4 we compared buried vs. conventional furrow irrigation systems.

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Table 1. Descriptions of treatments used in experiments 1, 2, 3, and 4.

Exp.	Treatment Name	Tillage[H]	WS-PAM[I]	Irr. Type	1st Irrigation	Num. of Irr.	Rain[§]
							in
1 (2003)	Control Fertilizer Manure	roller harrow	No	conv.	10 Jun	7	6.6
1 (2004)	Control Fertilizer Manure	roller harrow	No	conv.	15 Jun	6	2
2	Fall-Control	rototill	No	conv.	20 Sep 1999	1	0.04
	Fall-WSPAM	rototill	Yes[I]	conv.	20 Sep 1999	1	0.04
3	Spring-Control	rototill	No	conv.	30 May 2000	1	6.5
	Spring-WSPAM	rototill	Yes[I]	conv.	30 May 2000	1	6.5
	Spring-Plow	moldboard	No	conv.	30 May 2000	1	6.5
4	Conventional	rototill	No	conv.	24 May 2000	1	6.5
	Buried Lateral	rototill	No	buried	24 May 2000	1	6.5

[H] Manure was incorporated with offset disking to 4-in depth, followed by either rotary tillage to 4-in depth or moldboard plowing to 7-in depth, or roller harrow.

[I] Water soluble polyacrylamide (WSPAM) was injected at 10 ppm concentration into furrow inflows from the start and ended after the furrow stream advanced to the end of the furrow. The set was finished with untreated irrigation water.

[§] Rainfall received by plot soils between the manure application and the monitored first irrigation.

MATERIALS AND METHODS

We conducted the experiments at two sites with semiarid climates near Kimberly, ID, in field plots prepared in Portneuf silt loam soils (coarse silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid). All experiments were randomized complete blocks with three replicates.

Experiment 1 was established at site 1, which had 1.5% slopes and had not received manure in the previous 16 yrs. The experiment included three treatments: stockpiled dairy manure, inorganic fertilizer, and no amendment or control (Table 1). The fertilizer and manure treatments were applied to corn (Zea mays L.) each year of the 2-yr study (Table 2**).** Plots were 187-ft long. In 2003 and 2004, we measured sediment, total P (TP), and dissolved NO_3-N, NH_4-N, and K, and reactive P (DRP) concentrations in runoff from 6 or 7 irrigations yr^{-1} from the furrow irrigated field plots. Total N in sediment was also determined (Lentz and Lehrsch, 2010).

Table 2. Bulk and nutrient application rates (dry wt. basis) and application date for manure and fertilizer in experiments 1, 2, 3, and 4.

		-------- Stockpiled Dairy Manure ---------						-------------- Inorganic fertilizer --------------					
Exp.	**Crop Year**	**Applic. Date**	**Bulk Appl.**	**C**	**NΗ**	**P**	**K**	**Type**	**Bulk Applic.**	**Applic. Date**	**N**	**P**	**K**
			tons ac^{-1}		**----**	**lbs ac^{-1}**	**----**		**lbs ac^{-1}**		**-----**	**lbs ac^{-1}**	**-----**
1	2003	10 Oct 02	5.8	1.7	216	102	354	Urea	169	6 May 03	70	0	0
	2004	24 Mar 04	15.2	2.4	304	129	479	$NaNO_3$	1219	12 May 04	174	0	0
2,3,4	1999	Aug 99	20.1	4.9	651	-	-	None	-	-	-	-	-

Η N=Total N

Experiments 2, 3, and 4 (Lentz and Westermann, 2010) were established on 4% slopes at site 2, which had not received manure for ten years, and was fallow in the previous 2 years. Manure was applied (Table 2) to the entire site in early August 1999 and incorporated to the 4-in depth with an offset disk in late August 1999. In April 2000 the field was planted with a mixture of alfalfa (*Medicago sativa*) and various pasture grasses in combination with oats (*Avena sativa*). Irrigation furrows at the site were 581-ft-long, spaced 60 in apart, and were nonwheel trafficked.

Experiment 2 included Fall-control and Fall-WSPAM treatments (Table 1). The plot was rototilled to the 4-in depth in mid-Sept. 1999. Since this area was conventionally furrow irrigated on 20 Sept. 1999, soils in this area were fallow when irrigated. The manure amended soil had received little rainfall prior to the irrigation (Table 1).

Experiment 3 included Spring-Control, Spring-WSPAM, and Spring-Plow treatments (Table 1). Each plot was rototilled to the 4-in depth in mid-May 2000 except for three, which were moldboard plowed to 7-in-depth. The area was conventionally furrow irrigated for the first time after manure application on 30 May 2000, and received 6.4 in of rainfall between the time manure was applied and the irrigation (Table 1). Irrigation inflows for some WSPAM furrows were adjusted upward early in the irrigation to speed furrow advance and thus improve water application uniformity (Lentz and Sojka, 2000). Stock solutions of 2400 ppm a.i. WSPAM (Kemira Water Solutions; 15 to 20 x 10^6 g mol^{-1} molecular weight; 18% charge density) were injected into furrow streams to attain the desired target concentration (Table 1).

Experiment 4 included conventional and buried-lateral furrow irrigation treatments (Table 1). In mid-May 2000 the field was rototilled to 4-in depth and four furrows were cut into each plot. One of the four furrows in the conventional block was monitored. The plot received 6.5 in of rainfall between the time manure was applied and the irrigation (Table 1).

For Exp. 2, 3, and 4, we measured sediment, TP, and dissolved NO_3-N, NH_4-N (inorganic N), and DRP concentrations in runoff.

Snake River water was used for irrigation. The conventional furrow irrigation system consisted of a gated pipe, which conveyed irrigation water across each of the plots at the head, or inflow-end, of the furrows. Adjustable spigots in the gated pipe supplied water to each furrow, typically 3.4 gal min^{-1} for Exp. 1 and 4 to 6 gal min^{-1} for Exp. 2, 3, and 4. The buried lateral furrow irrigation system included a gated pipe at the inflow-end of the furrow and two 3-in diam. PVC pipes aligned perpendicular to the furrows and buried at 12-in depth. One of these buried laterals was located at a distance of one-third of a furrow length and a second at two-thirds of a furrow length down field from the furrow inflow end. The buried lateral system effectively reduced the irrigated furrow length and furrow stream flow rates used in the plots. During irrigation of the buried system treatment, water was cycled to individual gated pipe or buried lateral pipes sequentially such that water flowed into the furrows at 1 gal min^{-1}. Total inflow amounts applied to the buried lateral and conventional furrows during the irrigation were equivalent. More details are provided by Worstell (1976) and Lentz and Westermann (2010).

Net infiltration volume for individual furrows was calculated by subtracting the total outflow volume from the total inflow volume, where inflow and outflow volumes were computed by integrating the inflow- and outflow-rate curves with time. Average component concentrations were calculated as flow-weighted means by dividing the total component mass loss by total runoff volume. Cumulative nutrient losses were computed by integrating outflow volumes and runoff concentrations (adjusted for inflow amounts) for the duration of the irrigation.

Table 3. Cumulative, season-long nutrient losses in irrigation furrow runoff in Exp. 1.

		------------------ Dissolved ------------------				---- Particulate ----	
Treatment	**Sediment**	**K**	**NO_3-N**	**NH_4-N**	**DRP**	**TN**	**TP**
2-yr avg.	**tons ac^{-1}**	---------------------------------- **lbs ac^{-1}** ----------------------------------					
Control	16.1	7.24 b[H]	2.48 b	0.28	0.94 b	33.1	33.5
Fertilizer	18.7	9.73 b	3.10 ab	0.21	1.13 b	43.8	37.5
Manure	14.2	15.27 a	3.62a	0.20	2.54 a	36.8	34.2

[H] If followed by a dissimilar lower case letter, individual treatment values for a given experiment are significantly different ($P \leq 0.05$).

RESULTS AND DISCUSSION

The seasonal runoff losses of particulate N and P and dissolved N, P, and K in Exp. 1 averaged 88.6 lbs ac^{-1} yr^{-1}, with particulate nutrient losses exceeding those of soluble nutrients by 4.7-fold, i.e. 73.0 lbs ac^{-1} y^{-1} vs. 15.6 (Table 3). The loss of soluble nutrients from the field represents an immediate loss of available nutrients from the soil, while loss of particulate nutrients corresponds to the removal of a moderately or slowly available nutrient source. In either case, the loss is not trivial and the economic cost associated with replacing the vanished soil nutrients is substantial, especially as farm acreage increases. If the lost nutrients were replaced with inorganic fertilizers, the annual bill would average \$54.69 ac^{-1} yr^{-1} (2011 \$). Of this amount an average \$8.34 ac^{-1} yr^{-1}, or 15%, would be required to replace lost soluble nutrients, and \$46.35 ac^{-1} yr^{-1} would be required to replace nutrients removed in eroded sediment (Table 4). It is clear that a substantial proportion of nutrient value lost during furrow irrigation is associated with lost sediment. However, the costs associated with nutrient losses in sediment are even greater than indicated if one also includes the mineral K removed with the sediment. The concentration of K in soils can be three times greater than that of soil P. Results also show that manure additions to soils increased runoff concentrations and mass losses of K, NO_3-N, and DRP in each irrigation. Manured soils, compared to control soils, produced 2.1 times greater K mass losses, 1.5 times greater NO_3-N losses, and 2.7 times greater DRP losses (Table 3).

Experiment 2: Fall WSPAM Effects. Compared to control furrows, the Fall-WSPAM treatment reduced mean runoff volume by 75% and substantially reduced all component mass losses in WSPAM furrows. The WSPAM reduced cumulative mass losses for sediment by 100%, TP 99%, DOC 94%, NO_3-N 76%, NH_4–N 85.1%, and DRP 90.4% (Table 5).

Experiment 3: Spring Tillage and WSPAM Effects. The moldboard plowing treatment reduced cumulative DRP losses by 60% relative to rototilled soils (Tables 5). While

Table 4. Annual replacement value (2011 $) for N, P, and K nutrients lost in irrigation furrow runoff.

	---------------- Dissolved	----------------	----------------	----------------	Particulate		Total	
Treatment	**K**	**NO_3-N**	**NH_4-N**	**DRP**	**TN**	**TP**	**Soluble**	**Solid**
2-yr avg.	------------------------- $ ac^{-1} yr^{-1}				-------------------------		$ ac^{-1} yr^{-1}	
Control	3.63 b[H]	1.42 b	0.15	0.66	18.95	24.25	5.86	42.52
Fertilizer	4.87 b	1.77 ab	0.11	0.79	25.06	27.17	7.55	51.47
Manure	7.64 a	2.06 a	0.11	1.78	21.01	25.79	11.61	45.05

[H] If followed by a dissimilar lower case letter, individual treatment values for a given experiment are significantly different ($P \leq 0.05$).

Table 5. Furrow flows and runoff component mass losses per irrigation.

N[H]	**Treatment Name**	**Cum. Irr. Flows Inflow**	**Cum. Irr. Flows Runoff**	**Sediment**	**NO_3-N**	**NH_4-N**	**DRP**[H]	**TP**[H]
		------ in -------		tons ac^{-1}		-------- lbs ac^{-1} -------		
	Exp. 2 – Fall Irr.							
2	Control-rototill	3.30	1.26	2.01a[I]	0.025a	0.061a	0.118a	3.019a
	WSPAM-rototill	3.46	0.39	0.00b	0.006b	0.009b	0.011b	0.018b
	Exp. 3 - Spring							
	Control-rototill	2.88	0.92a	0.37a	0.001	0.009	0.023a	1.231a
3	Control-Plow	2.74	0.65ab	0.22a	0.003	0.006	0.009b	0.551a
	WSPAM-rototill	3.53	0.45b	0.00b	0.001	0.003	0.006b	0.029b
	Exp. 4							
4	Conventional	2.20b	0.54	0.25a	0.000	0.009	0.006	0.362a
	Buried Lateral	2.25a	0.39	0.03b	0.001	0.003	0.002	0.067b

[H] N=experiment number; DRP=dissolved reactive phosphorus (filtered sample); TP=total phosphorus (unfiltered sample).

[I] If followed by a dissimilar lower case letter, individual treatment values for a given experiment are significantly different ($P \leq 0.05$). Not Letters are not displayed if effect was not significant in the ANOVA.

mean values for component mass losses from moldboard-plowed soils were often less than in rototilled soils, the differences were significant only for DRP. The Spring-WSPAM reduced DRP by 74% and TP by 98% relative to the Spring-Control (Table 5).

Experiment 4: Conventional vs. Buried Lateral Systems. Relative to conventional furrows, the buried lateral furrow irrigation system reduced furrow runoff rates by 67% and reduced cumulative mass losses of sediment by 89% and TP by 82% (Table 5). In addition, the infiltration fraction (net infiltration/net inflow) for buried lateral furrows was comparable to those of WSPAM furrows, which consistently trended higher than for associated control furrows (**Table 5**). Thus the buried lateral system was an efficient method of irrigation that substantially improved runoff water quality.

Delayed Irrigation Effects: Delaying the first irrigation on the late-summer manure-amended soil from fall to the next spring (Fall-Control vs. Spring-Control) substantially reduced runoff mass losses of sediment by 81%, NO3-N 97%, NH4–N 85%, and DRP 80% (Fig 1). While the mean TP mass loss for the Fall-Control, rototill irrigation (3.02 tons ac^{-1}) was greater than its associated Spring-Control rototill loss (1.23 tons ac^{-1}), the difference was not significant. Since the fall and spring irrigations were similar with respect to total irrigation inflows, runoff, and net infiltration (Table 5), reduced runoff nutrient mass losses resulted primarily from decreased nutrient concentrations in the furrow stream (data not shown). This in turn was at least partly due to the dramatically reduced sediment concentrations (data not shown) in spring furrow streams relative to those in the fall.

CONCLUSIONS

This study determined effects of WSPAM, tillage, conventional vs. buried lateral furrow irrigation, and delayed irrigation on runoff water quality after manure application. These four management approaches achieved 60 to 100% reductions in the runoff volume and the cumulative mass losses for sediment and one or more of the nutrients, TP, NO_3-N, NH_4–N, and DRP, in furrow streams.

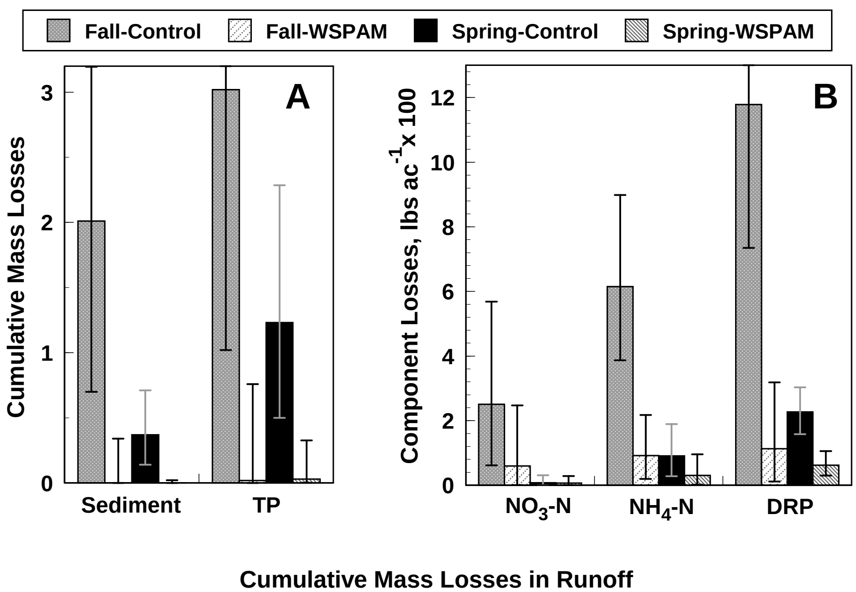

Fig. 1. Cumulative (A) sediment and TP and (B) nitrate-N, ammonium-N, and DRP mass losses in furrow runoff (Fall-Control, Fall-WSPAM) from the fall irrigation of late-summer manure-amended soils (Exp. 2) compared with that from an irrigation on the manure-amended soils (Spring-Control, Spring-WSPAM), which was delayed until the following spring (Exp. 3). All treatments were rototilled. Error bars represent 95% confidence limits on the treatment means.

The use of WSPAM as a management tool is attractive because it effectively controlled runoff sediment and nutrient losses, required minimal initial capital outlay (particularly when compared to the buried lateral system), and can be selectively applied to individual irrigations depending on need. While the buried lateral system was slightly less effective than WSPAM for control-ling runoff nutrient losses and was initially more costly, it was capable of attaining water application effi-ciencies of 90 to 95% (Worstell, 1976). Hence the long-term benefits of buried lat-eral systems may in-clude water savings as well as increased run-off water quality.

One can substantially reduce sediment and nutrient runoff losses by applying manure in the Fall and delaying irrigation until Spring. Moreover, combining the irrigation delay with moldboard plowing, WSPAM, or Buried Lateral irrigation can provide sizeable further reductions in runoff component concentrations and cumulative losses. Moldboard plowing in

Spring, in addition to delaying irrigation provided the least additional benefit. Results from this study and those in the literature suggest that the greatest benefit from moldboard plowing may accrue when the field is plowed soon after the manure is applied, whether or not the irrigation is delayed. Although amending surface irrigated soils with manure generally increases the potential for nutrient loss in runoff, results from this research demonstrate that several management approaches may be successfully employed to substantially reduce offsite nutrient transport associated with furrow irrigation.

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