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PERCOLATION PHOSPHORUS LOSSES IN CALCAREOUS FURROW-IRRIGATED SOILS

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ABSTRACT

Groundwater seepage contributes to irrigation return flows and surface waters. Knowledge of phosphorus (P) concentrations and loads in percolation water that enters the vadose zone and groundwater is necessary to assess and manage water quality. We measured the P in water leached below the crop root zone in a furrow-irrigated Portneuf silt loam. Vacuum operated percolation samplers were used to monitor soil water flux, and molybdate-reactive-P (MRP) and total P concentrations in leachate during the cropping season. The samplers were placed at 4 ft depths at 100 ft and 500 ft across a 590-ft-long corn field that was furrow irrigated using either conventional or PAM treatment. We found no irrigation treatment effects on cumulative amounts of water or P leached. The MRP concentrations in leachate ranged from 0.01 to 2.0 ppm and averaged 0.58 ppm during three irrigation seasons. The MRP concentrations in lower-field leachate were nearly 10X greater than those from the upper-field. The P mass losses during the irrigation season were less than 0.1 lb acre^{-1}. The P concentrations in leachate were 2 to 20 times greater than ortho-P equilibrium concentrations measured in the subsoil water (i.e. dilute $CaCl_2$ extractable ortho-P). P concentrations in drainage water appeared to be reflective of percolate volume and soil chemistry.

INTRODUCTION

Groundwater seepage supplies a portion of flow to irrigation return and surface waters. Knowledge of these additions is needed to manage phosphorus (P) total mean daily loads in streams draining irrigated crop lands. In the past, water percolating through surface-irrigated calcareous silt loam soils was thought to make insignificant P contributions to groundwater. However, recent studies suggest that P may be more mobile in calcareous soils than originally expected. It is not known whether an alternative furrow irrigation practice, which uses polyacrylamide (PAM) for erosion control (Lentz et al., 1992; Lentz and Sojka, 1994) may influence P losses.

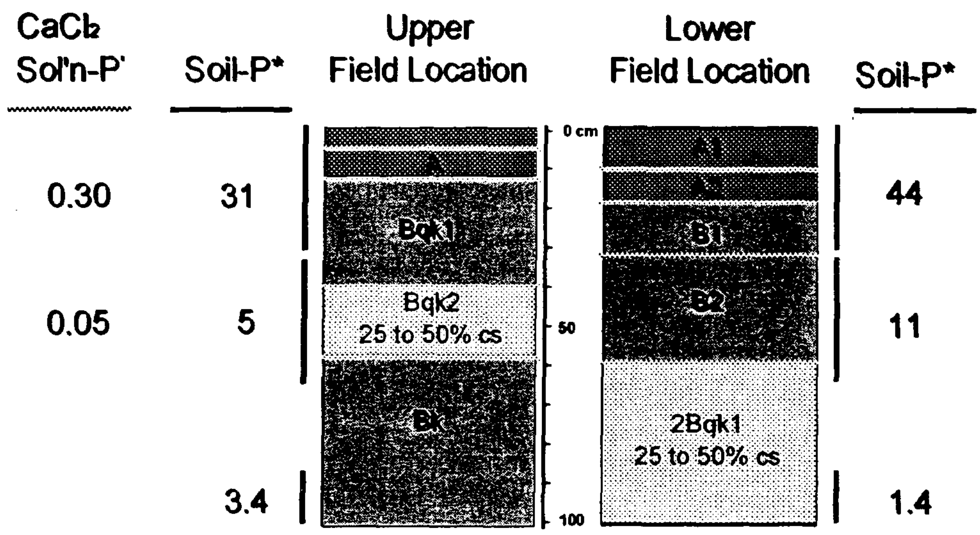
OBJECTIVES

We designed vacuum-assisted soil water percolation samplers that were used to monitor percolation water flux and P concentrations in water draining below the crop root zone in a furrow-irrigated Portneuf silt loam. Two furrow irrigation approaches were compared, conventional and polyacrylamide-managed.

MATERIALS AND METHODS

Plots were located near Kimberly, ID on Portneuf Silt Loam, 1.5% slopes (coarse-silty, mixed, superactive, mesic, Durinodic Xeric Haplocalcids). All plots had received dairy manure regularly during the period from 1969 to 1989, ie. 10 to 20 ton acre^{-1} (dry wt.) were applied in two out of every seven years. The irrigation water came from the Snake R. The complete randomized block design included three irrigation treatments, but we monitored soil water in only two of the three treatments. *Control* treatment furrows were irrigated with 4 gpm (15 L min^{-1}) untreated inflows for the entire duration of irrigation events. *PAM* furrows were irrigated with water amended with 10 ppm water soluble, anionic polyacrylamide (high molecular weight, 18% charge density). *PAM*-treated inflows were set at 12 gpm (45 L min^{-1}) while the furrow streams advanced down the furrows. Once water began to runoff the field, PAM application was curtailed, and inflows were reduced to 4 gpm for the remainder of the irrigation set. Irrigation set times were adjusted to provide an equivalent average net infiltration across all treatments.

Twelve monitoring sites were installed, two for each treatment, in each of three blocks, at both the upper and lower portion of the furrow plot (100 & 500 ft along 590-ft-long furrows). Each irrigation was included as a replicate in the study. Soil morphology and P chemistry was determined at both upper and lower furrow positions (Fig. 1).



* soil bicarbonate extractable ortho-P conc., mg kg^{-1}

' Ortho-P extracted in 0.01 $CaCl_2$, mg/kg^{-1}

Fig. 1. Soil profile characteristics, soil bicarbonate extractable ortho-P, and soil ortho-P extracted in dilute $CaCl_2$ for upper and lower field positions

Vacuum Extraction Soil Water Percolation Sampler: The sampler collected downward flowing macropore and matrix soil water at 4 ft depth. The vacuum assist was applied through a ceramic interface (0.5-bar or 50-kPa) air entry pressure; and vacuum amount was varied to track in-situ soil water potentials that ranged from -0.08 to -0.3 bar.

We installed 36 percolation samplers, three at each monitored site. Instruments were installed in the vertical face of a backhoe trench dug beside the monitored furrow. The soil water percolation samplers and field installation for this experiment was discussed in detail by Lentz et al. (1998). A field deployed precision vacuum pump and tank were connected via a gas dryer to a polyethylene tube main line that ran the length of the field. Branch lines off the mainline supplied upper and lower field positions via manifolds at each site. Each manifold supplied 1-L vacuum flasks connected to individual samplers. In 1997, a Bourdon-tube pressure switch and Hg U-tube manometer regulated system vacuum in main and branch lines. For 1998, we designed an electronic vacuum controller and data logger program that set extraction vacuum independently for each site according to local soil water conditions (Kincaid and Lentz, 1998).

Soil Water Sensors: Soil water sensors (Campbell Scientific, Inc. model CS-615) were calibrated, installed with thermocouples in the soil profile beneath the furrow and planted row in 1996. In 1998, neutron probe access tubes were installed in furrow and planted row at upper, middle, and lower field positions. In 1999, neutron probe measurements were made at upper and middle field positions only.

Protocol: Instrument installation was completed by late August, 1996. Plots were planted to silage corn in 1997-99. Planting and irrigations were delayed in 1997 and 1998 because of a cool, wet conditions in early summer. Five irrigations were applied in 1997, beginning on 16 July; five in 1998, beginning on 8 July, and seven in 1999, starting on 22 June. All irrigations were monitored for inflow, runoff, and infiltration. Percolation water volumes were measured and collected every 1-5 days. Samples were composited over three periods (days 1-3, 4-8, and 9-13 after each irrigation), treated with boric acid, and stored at 5° C for later chemical analysis. Percolation samples contained no measurable sediment. Total P was measured on the unfiltered sample after digestion with potassium persulfate. Molybdate-reactive P (MRP) was determined on unfiltered samples using the Murphy and Riley (1962) procedure. Concentration means were time-weighted.

RESULTS AND DISCUSSION

Soil Water Percolation Volume Losses

Whole-field infiltration (Table 1) and percolation losses (Table 2) were highest in 1998 and 1999, most likely due to the greater number and longer irrigation sets employed in those years. An earlier start and more frequent irrigations in 1999 contributed to increased percolation losses in that season.

Percolation loss volumes generally exhibited large variability, with sampler to sampler differences commonly ranging up to 60%. A comparison across years showed that PAM slightly decreased percolation losses at the upper field position, relative to the conventional approach (Table 2). By implication PAM may have slightly increased percolation losses at lower positions compared to controls. This result was attributed to the increased water application uniformity produced in PAM furrows. Infiltration opportunity times for upper and lower positions of PAM furrows were more similar than those of controls because water advanced more rapidly down PAM furrows. The advance period in PAM furrows was about one-third that of controls (Table 1).

P Concentration in Percolation Water

Mean Total P concentrations in water moving below the crop root zone were 0.15 ppm at upper field locations (Fig. 2a) and 1.1 ppm at lower positions (Fig. 2b). These quantities exceeded those expected for soil water in equilibrium with the calcareous sites subsoil, ie. dilute $CaCl_2$ extracted Ortho-P (Robbins et al., 2000). MRP made up 75 to 95% of the total P present in the percolation water.

Higher P concentrations were measured at lower field positions compared to upper sites. This suggested that less infiltration at the lower field produced a greater proportion of matrix-pore flow than at upper field positions, leading to greater soil-water contact and increased solution

Table 1 Hydraulic characteristics of applied irrigations computed on a whole field basis.

Year (No. Irr.)	Treat-ment	Irrigation Average: Net Inflow ‡ (in)	Net Outflow ‡ (in)	Net Infiltration‡ (in)	Furrow Advance (min)	Season Total: Net Inflow‡ (in)	Net Infiltration‡ (in)
1997	Control	2.4*a*†‡	1.0*a*	1.4*a*	117*b*	12.0	7.2
(5)	PAM	2.6*a*	1.1*a*	1.5*a*	37*a*	12.8	7.3
1998	Control	3.9*a*	2.1*a*	1.9*a*	121*b*	19.5	9.2
(5)	PAM	3.9*a*	2.0*a*	1.9*a*	54*a*	19.5	9.5
1999	Control	3.3*a*†	1.5*a*	1.8*a*	144*b*	23.0	12.5
(7)	PAM	3.9*a*	1.9*a*	2.0*a*	48*a*	24.1	14.1

† Similar lower-case letters indicate nonsignificant differences between treatments (P= 0.05)

‡ Note that these whole-field computed parameter values significantly under estimate actual upper-field values and over estimate actual lower-field values.

loading at lower positions. This, however, does not completely explain the overall high P concentrations found in the leachate. Percolation-water P concentrations at upper field locations were slightly but significantly higher under conventional furrow irrigation than for PAM-managed irrigation. No treatment difference was observed at the lower field location.

On a whole-field basis, no treatment effects on P concentrations were discernible. The mean whole-field percolate concentration of MRP was 0.58 ppm and TP was 0.61 ppm.

Table 2 Mean soil water percolation losses and seasonal totals measured from percolation samplers.

Year	Treat-ment	Percolation Losses (in): Irrigation Average: Upper	Irrigation Average: Lower	Season Total: Upper	Season Total: Lower
1997	Control	2.7*a*†*A*‡	0.06*aB*	12.8	0.3
	PAM	2.4*aA*	0.17*aB*	12.1	0.9
1998	Control	1.9*aA*	0.24*aB*	9.7	1.2
	PAM	1.8*aA*	0.35*aB*	8.8	1.7
1999	Control	1.9*aA*	0.18*aB*	13.5	1.3
	PAM	1.9*aA*	0.08*aB*	13.2	0.5

† Similar lower-case letters indicate nonsignificant differences between treatments (P= 0.05)

‡ Similar upper-case letters indicate nonsignificant differences between field positions (P= 0.05)

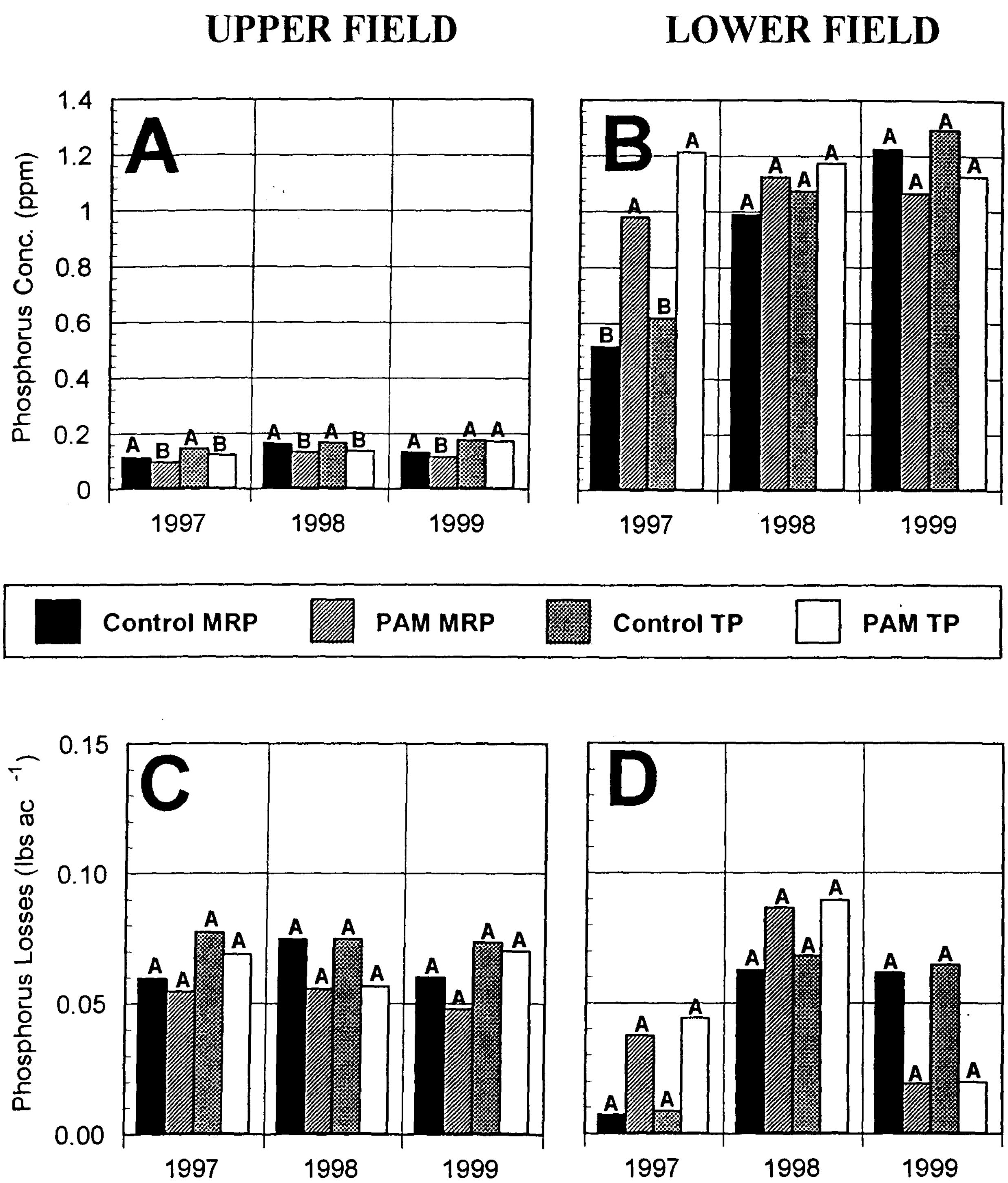


Fig. 2. **Molybdate-reactive phosphorus (MRP) and total phosphorus (TP) concentrations in percolate from upper (A) and lower (B) field positions; and mass losses in percolation water from upper (C) and lower (D) field positions.**

SEASONAL P MASS LOSSES IN PERCOLATION WATER

We observed no significant differences between treatments, or consistent trends with respect to percolation component mass losses. Percolation-P mass losses observed at upper field positions (Fig. 2c) were similar to those at lower field positions (Fig. 2d). Average percolation-P mass loss during the irrigation season was 0.05 lb $acre^{-1}$ for MRP and 0.06 lb $acre^{-1}$ for TP.

Approximately 3.5% of the soil-solution ortho-P present in crop root zone (4 ft) was lost annually in percolation.

CONCLUSIONS

1. Percolation flows were 10X greater at upper-field positions (furrow inflow-ends) than at lower or furrow outflow-end locations. However, because percolate-P concentrations were nearly 10X greater at lower-field positions than at upper locations, P mass losses at the two field locations were similar.
2. While PAM-managed furrow irrigation slightly reduced percolate MRP and TP concentrations at upper field positions relative to conventional furrow irrigation, irrigation treatment had no effect on seasonal cumulative mass losses of P in percolation water
3. Irrigation treatment had no effect on whole-field percolate-P concentrations or P mass losses. The average whole-field percolate-MRP concentration was 0.58 ppm and for TP, 0.61 ppm.
4. MRP of percolation water samples exceeded by 2 to 20 times the field-average ortho-P concentration measured for soil water in equilibrium with Portnuef's 'in situ' calcareous subsoil (Robbins et al., 2000). Cumulative TP and MRP mass losses from these furrow-irrigated soils during the irrigation season were less than 0.1 lb acre -1.
5. Upper field percolation MRP concentrations were less than or equal to ortho-P concentrations expected in topsoil (measured in dilute CaCl2 extracts) or MRP of furrow streams.
6. Lower field percolation MRP concentrations exceeded ortho-P concentrations expected in topsoil or subsoil (measured in dilute CaCl2 extracts) and also exceeded MRP concentrations in furrow streams.

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