Deep Percolation and Preferential Flow Under Conventionally and PAM-Treated Irrigation Furrows

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Abstract

Water-soluble anionic polyacrylamide (PAM), a nontoxic polymer, is employed in furrow irrigation to control soil erosion and increase infiltration. We hypothesized that post-irrigation deep percolation and preferential-flow patterns for the PAM treatment would differ from that of the conventionally irrigated (CI) furrows. Portneuf silt loam plots 179 m long were planted to corn and irrigated using either CI or PAM treatment. We added PAM to advancing irrigation furrow streams at10 ppm. Inflow rates during furrow advance were 3X greater than that of conventionally irrigated furrows. Vacuum assisted percolation samplers at 1.2 m depth and neutron probe access tubes were installed at locations 30 m down furrow to monitor soil water flux and soil wetting patterns. Daily deep percolation volumes were collected after two irrigation events in 1998, and analyzed for nitrate-N and Cl concentrations. Two general patterns for daily percolation rate emerged. Under CI, percolation rate started high the first day after irrigation, declined during the second and third days to a value about half that of the first day, then rose to a second peak between 6 and 7 days after irrigation. PAM percolation rate started low on the first day after irrigation, peaked at about twice the initial rate on day two or three, declined through day four or five, then rose to a second peak between 6 and 8 days after irrigation. Water moved rapidly downward from CI furrows after irrigation, and included bypass flow that diluted nitrate concentrations in deep percolation water. PAM treatment inhibited initial rapid downward movement of applied water, possibly by reducing preferential flow.
Keywords: bypass flow, infiltration, erosion, polyacrylamide

Introduction

Additions of 10 mg L^{-1} PAM in advancing furrow irrigation streams reduces irrigation-induced soil erosion losses by an average 94%, increases infiltration 15%, and increases lateral wetting 25% relative to untreated furrows (Lentz et al., 1992; Lentz and Sojka, 1994). PAM use also improves water quality of irrigation return flows compared to untreated furrow runoff by decreasing P, N, and pesticide concentrations (Lentz et al., 1998b). The PAM treatment is simply applied, economical practice that has gained wide acceptance among farmers in the irrigated western U.S.

Runoff and drainage losses from furrow irrigation are greater than from other surface methods and sprinkler irrigation. Opportunity time for infiltration is longer in soils near furrow inflow ends, hence these soils receive more water and experience a greater leaching potential than soils near furrow outflow ends (Childs et al., 1993). Carter et al. (1971) reported that significant subsurface drainage losses of nitrogen occurred under irrigation tracts in southern Idaho. Furrow irrigation moves soluble or particulate organic matter, N, and P from the soil to drainage (Carter et al., 1971).

During an infiltration event, preferential flow permits rapid transfer of water to deeper depths. When preferential flow dominates the drainage regime, nutrient concentrations in the drainage water will reflect that which enters the macropores. This water may be similar to that of infiltrating surface water (Shuford et al., 1977) or to water entering macropores from within the soil profile, eg. from a perched, saturated soil layer receiving lateral flow (Hergert et al., 1981).

We wished to compare effects of PAM and CI treatments on soil preferential flow processes by determining their influence on percolation rates and percolate solute concentrations beneath irrigation furrows.

Materials and Methods

Soil water percolating to a 1.2-m depth was monitored for CI vs PAM-managed irrigation furrows. Conventional furrows were irrigated with 15 L min^{-1} untreated inflows for the entire irrigation. During the furrow

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advance phase, PAM furrows were irrigated using 45 L min^{-1} inflows amended with 10 mg L^{-1} PAM. When advancing waters began to runoff the field, inflows in PAM furrows were reduced to 15 L min^{-1}. Duration of irrigations was varied with treatment so that average net infiltration for both treatments would be equivalent. The PAM used was a water soluble anionic form having a molecular weight of 12 to 15 Mg mol^{-1} and charge-density of 18%.

The 179-m-long field plot of Portneuf silt loam (Coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcids) had a 1.5% slope. The study included two treatments and three replicates, for a total of six plots. Monitoring sites were installed in each plot, at an upper position in the furrow (30 m downstream from the inflow end of the furrows). We installed 18 vacuum extraction soil water percolation samplers at 1.2 m depth, three at each monitored site. This installation was part of a larger study described by Lentz et al. (1998a). Instruments were installed in the vertical face of a backhoe trench dug beside the monitored furrow. The vacuum extraction system designed for this experiment was discussed in detail by Lentz et al. (1998a) and Kincaid and Lentz (1999). A field deployed precision vacuum pump and tank were connected via a gas dryer to a polyethylene tube main line that supplied each sampler via manifolds at each site. Each manifold supplied 1-L vacuum flasks connected to individual samplers. An electronic vacuum controller (with data logger and soil tensiometer) set extraction vacuum independently for each site according to local soil water conditions. The line extractor-soil suction ratio was 1.4 to 1.5 (Lentz et al., 1998a).

Instrument installation was completed by late August, 1996. Prior to two irrigations in September 1996, $CaCl_2$ (112 kg ha^{-1}) was applied to the surface of the plots as a drainage marker. In spring 1997, 168 kg ha^{-1} urea was applied and plots were planted to a short-season corn. Soil water percolation was monitored over 3 to 5 day periods during the 1997 irrigation season. In 1998, percolation samples from the more productive samplers were monitored daily for 1 to 2 weeks after each of two irrigations. Water sample volumes were measured and collected, treated with boric acid to curtail biologic activity, and stored at 2° C. for later chemical analysis. Sample NO_3-N, and Cl were determined with standard flow injection analysis (FIA) procedures.

Results and Discussion

Three to four samplers per treatment at the upper field position provided consecutive daily percolate for 7 to 13 days during the monitored irrigations. Each graph in Fig. 1 presents data from an individual sampler. Data for at least two sampling sites were included for each treatment. Plotted values represent the percolate sample volume obtained during the previous 24 h, and component concentrations of the 24-h cumulative sample.

Percolation rate and percolate NO_3-N and chloride concentrations changed with time after irrigation. Percolation rate for CI treatment was high on the first day after irrigation, decreased over the next 2 to 4 days, then increased to a second maximum 6 to 7 days after the irrigation (Fig. 1). The second percolation maximum was of similar magnitude to the first. Nitrate-N and chloride concentrations in CI treatment percolate increased as percolation rate decreased after day one, then generally continued to increase as the percolation rate ascended to its second peak on day 6 or 7.

In contrast, percolation rate in PAM furrows started low on day one, increased through day 2 or 3, declined during days 4 and 5, attained a second maximum on days 6 to 8 that was greater than the first, then declined (Fig. 1). Percolate concentration patterns for PAM furrows were similar to those for CI with the following exception. On the first day, concentrations began low and increased with percolation rate on days 1 and 2 after irrigation; whereas for CI, percolate concentrations on days 1 and 2 increased as percolation rates declined.

The early high percolation rate for CI and not for PAM furrows suggests that preferential flow dominates the CI's early drainage regime more than the PAM. The second percolation-rate peak 6 to 8 days after the irrigation appears to be the result of a pulse of irrigation water moving down through the soil matrix, and occurs in both CI and PAM furrows. The percolate concentration data support this interpretation of percolation rate information. Preferential flow occurring early after irrigation in CI corresponded to low component concentrations, particularly NO_3-N. Percolate solute concentrations were diluted by surface irrigation waters that had bypassed the soil matrix. Component concentrations in CI increased as percolation rate decreased during the first 2 to 3 days after irrigation ceased, which is consistent with diminishing effects of surface water dilution, caused by the rapid decline in preferential flow.

These results indicate that PAM treatment influenced the nature of the drainage regime in silt loam soil profiles subjected to furrow irrigation. Without further analysis, it was not clear whether the effect is caused primarily by application of PAM or by the high inflow rates used in PAM furrows during the furrow advance, or by a combination of the two. Relative to CI, PAM caused increased lateral wetting from furrow towards the planted row (Lentz et al., 1992). This may have decreased the amount of water available for wetting the soil beneath PAM

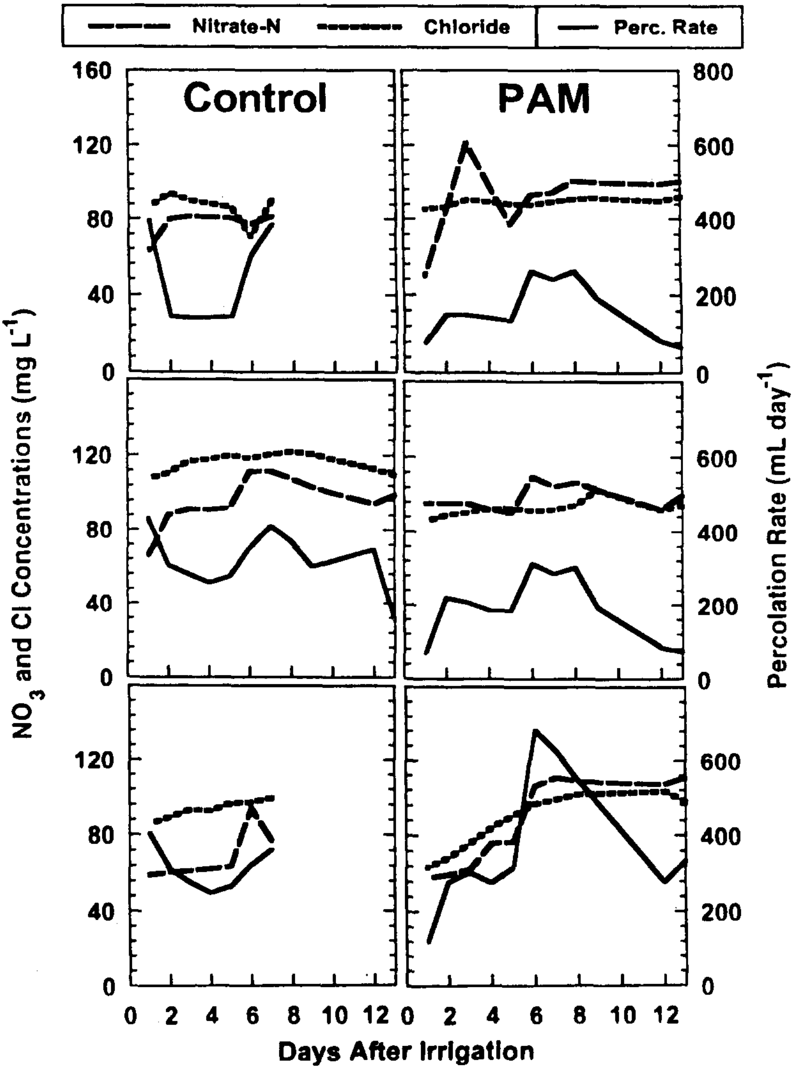

Fig. 1. Daily percolation rates and percolate nitrate-N and chloride concentrations from six individual samplers located in control (left) and PAM-treated (right) plots in the upper field. These samplers were selected for monitoring because they consistently produced percolate volumes that were large enough to permit analysis.

furrows compared to CI, and reduced soil saturation below the furrow enough to eliminate flow in macropores, and therefore prevent preferential flow.

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