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Can Denitrification Reduce NO₃ in Shallow Ground Water?

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Vol. 30, No. 1, 1997 CAN DENITRIFICATION REDUCE NO₃-IN SHALLOW GROUND WATER?

 $M.S.$ Coyne, E. Montgomery, and G.W. Thomas.

INTRODUCTION

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> Systematic sampling of springs, tiles, and wells in Kentucky, as part of a recent statewide program to assess agricultural impacts on water quality, showed that $NO₃$ concentrations in these shallow ground water sources varied tremendously. The $NO₃$ concentration could be correlated with flow rate; higher when ground water recharge flushed $NO₃$ from soil in winter and spring, and lower or non detectable in summer and fall when less $NO₃$ leaching occurred. Depending on the season, $NO₃$ concentrations ranged from ≤ 1 to >10 ppm $NO₃$ -N in almost half of the sites. For example, the water in one site, a shallow well over a naturally occurring spring in Bourbon county, varied from 0 to 12 ppm $NO₃$ -N during the year (Figure 1).

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There is an alternative explanation for this variability, an explanation that isn't based on ground water recharge events. An interaction between flow rate and biological activity could explain some of the variability of $NO₃$ concentration in this and similar sites. Since the water percolated through a sediment layer in the Bourbon county well before it could be sampled, it seemed likely that biological denitrification (a

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microbial process in which bacteria convert NO₃ -N to N₂ gas) during low flow periods might account for the low $NO₃$ concentrations. When water flow was high, $NO₃$ movement through the sediment layer would be too rapid for complete biological removal. We tested this idea by recreating flow-dependent $NO₃$ concentrations in a series of laboratory studies.

METHODS

We collected sediment from the spring-fed well in Bourbon county and used it to fill 7 inch-tall PVC cylinders about half full. During an experiment, a 10 ppm $NO₃$ -N solution was pumped into the bottom of the cylinders at either a fast, slow, or intermediate rate (10 ppm is the maximum allowable $NO₃ -N$ concentration for drinking water in Kentucky). Outflow at the top of the cylinders was analyzed for NO_3^- -N, nitrite $N (NO_2^-$ -N), and ammonium N (NH $_4$ ⁻-N). We also used an inhibitor to stop the last step in denitrification, and measured the intermediates that accumulated. Two cylinders were used for each experiment to show that the results were reproducible. Multiple experiments were conducted, and multiple measurements were

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taken within each experiment to demonstrate that the trends were consistent.

cylinders in the laboratory varied as they had in denitrification, as easily as $NH₄$. However, if the spring-fed well: they were highest when flow the spring-fed well; they were highest when flow we found nitrous oxide (N_2O) , an intermediate
of denitrification which can be detected easily rates were highest, lowest when flow rates were or denitrication which can be detected easily
lowest and of intermediate concentration when with a gas chromatograph, it would be evidence lowest, and of intermediate concentration when flow rates were intermediate (Figure 2). Since that denitrification removed $NO₃$. Acetylene the NO₃ concentration in the water supply was (C_2H_2) inhibits N₂O reduction to N₂ and constant, something other than flow caused the causes N_2O to accumulate. So, if denitrification changes in NO_3 concentration in the sediment was the reason NO_3 disappeared, N_2O would outflow. We assumed that by creating laboratory appear in the headspace of the cylinders once outflow. We assumed that by creating laboratory conditions which reproduced NO₃ -N variability C_2H_2 was added, and flow was reduced. Just as in the spring-fed well, we could also reproduce we expected, N₂O appeared as soon as we in the spring-fed well, we could also reproduce mechanisms causing that variability. added C_2H_2 . Denitrification was clearly

When oxygen becomes deficient in when oxygen becomes denotent in
wolved in NO_3 reduction in this sediment,
waterlogged soils (because microbes can
and based on the initial and final NO_3 -N consume oxygen faster than it is supplied by and based on the initial and final NQ_3 -N
concentrations we observed during these flowing water) a biological process such as concentrations we observed during these - experiments, it removed between 60 and 68% of $NO₃$ reduction can occur. The rate of $NO₃$ reduction depends on the size and activity of the the added NO_3 . microbial population, and how long they have access to NO_3 . If the rate of NO_3 flowing into sediment was less than the rate at which it was reduced, then $NO₃$ concentrations would decline. That's exactly what happened when flow rates decreased (Figure 2). If $NO₃$ flow through the sediment exceeded the $NO₃$ reduction rate, then NO₃ concentration should rise; this also happened (Figure 2). As soon as the NO_3 flow rose to an intermediate rate, the $NO₃$ concentration in the sediment outflow increased. It didn't increase to its original level, which meant that some of the NO_3 was still being reduced.

The $NO₃$ could disappear by being converted + - + to $NH₄$. If NO₃ were reduced to NH₄, the $NH₄$ -N concentration should have increased as flow rate decreased. However, the NH_4 -N concentration in sediment didn't change much when flow rate changed (Figure 3) even though

 $NO₃$ concentrations fluctuated.

The $NO₃$ could disappear by being converted **RESULTS AND DISCUSSION** to N₂ (denitrification). We can't measure The NO₃ concentrations leaving the nitrogen gas (N_2) , the final product of

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CONCLUSION

Assessing agriculture's contribution to NO₃ contamination of ground water has been difficult because of varying $NO₃$ concentrations. In addition to fluctuating $NO₃$ concentrations due to ground water recharge, some of the variability of NO₃ concentrations in watersheds could be due to biological denitrification. Our results indicate that when conditions are right for denitrification (for example, low flow, long residence time, poor water recharge and oxygenation, and abundant carbon), $NO₃$ in shallow ground water can be reduced if it percolates through saturated layers of sediment.

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Figure 1. Nitrate N concentrations measured in a spring-fed Bourbon County well for 1 year.

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Figure 3. Nitrate, NO_2 ⁻-N, and NH_4 ⁺-N concentrations in sediment subjected to variable flow.

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