Subsurface Flow Barriers to Reduce Nitrate Leaching

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Introduction

Groundwater is a very important natural resource which directly affects many human lives. In the United States, groundwater is the source of about 22 percent of the freshwater used. About 53 percent of the total population and 97 percent of the rural population use groundwater supplies for their drinking water (Moody, 1990). Although contamination of groundwater can occur naturally, agriculture is considered to be one of the most widespread non-profit sources of groundwater contamination. Among agricultural chemicals, nitrogen-fertilizer has been used most extensively, especially by corn producers. About one million tons of nitrogen-fertilizer are used annually in Iowa. In some studies, more than 50 percent of the applied fertilizer nitrogen is not removed by the crop or stored in the soil, and leaching as a form of nitrate is thought to be a major reason for the losses (Blackmer, 1987). Leached nitrate may enter groundwater supplies. Nitrate-nitrogen concentrations found in unsaturated soil below the rootzone of agricultural fields are in the range of 5 to 100 mg/L (Bouwer, 1990). Nitrate-nitrogen concentrations in tile drainage below row crops often exceed 10 mg/L, the U.S.A. drinking water standard (Gast et al., 1978; Baker and Johnson, 1981; Timmons and Dylla, 1981; Baker et al., 1985).

Surface and Subsurface Water Management

One approach for reducing nitrate leaching is to use surface soil management to alter flow paths of infiltrating water. Hamlett et al. (1990) showed that the leaching of nitrate and tracer bromide placed in a ridge tillage system was reduced compared to a flat tillage configuration. The ridge configuration directed excess rain water away from the fertilizer band, towards the
furrows. Kay and Baker (1989) also reported that leaching loss of nitrate from the ridge-till plots was significantly lower than from chisel-plowed plots. However, another study did not indicate that ridges had any significant effect on reducing nitrate leaching (Bowers et al., 1975). Ridge height and location of fertilizer nitrogen within the ridge should be studied further.

Another approach of reducing anion leaching is use of a subsurface water flow barrier. Studies have indicated in theory that the presence of a localized impermeable subsurface barrier should direct infiltrating water away from the barrier and reduce the flow rate in the vicinity of the barrier (Maaledji and Malavard, 1973; Babu, 1979; Kirkham and Horton, 1990). Thus, it is conceivable that nitrate leaching should be reduced if the fertilizer is placed in a low-flow region just above or below such a barrier (see Fig. 1).

Soil compaction crushes the large voids and channels that may readily conduct rain water in the upper soil profile. The high bulk density of the compacted soil makes it difficult for water to permeate through the compacted soil (Reicosky et al., 1981). If compaction occurs in zones, much of the infiltrating water is directed away from the compacted soil layer and toward more permeable uncompacted soil. Further, water flow just above and below the compacted soil layer should be reduced. Nitrate placed just below a compacted zone of soil is less likely to be immediately carried down by the infiltrating water.

The same principles might be applied to conventional fertilizer banding with a knife applicator. During normal operation, knife applicators create a furrow partly filled with loose soil directly above the fertilizer band. Undoubtedly, the soil above the fertilizer band is very permeable and provides pathways for preferential water flow directly through the band. Therefore, filling in the knife furrow and compacting the soil above the fertilizer band may redirect some of the water flow away from the fertilizer.

Zonal compaction need not be detrimental to crop growth because plant roots are capable of compensating for the reduction of growth caused by unfavorable conditions, such as soil compaction, in part of the rootzone by proliferating in more favorable soil zones (Willis et al., 1963; Russel, 1977; Garcia et al., 1988). Thus, it is expected that corn roots can encounter banded fertilizer by growing around a compacted soil zone.

**Results of Lab and Field Studies**

Laboratory studies were performed in order to determine how well subsurface barriers can delay or reduce chemical leaching rates through soil. One preliminary study was to use different sized subsurface barriers. Fig. 2 shows the results of chemical concentrations in drainage water when 3, 4, and 5-cm subsurface barriers were used. The chemical itself was placed below the subsurface barriers, and it was just covered by the 3-cm barrier. The drainage concentrations indicate that subsurface barriers are effective in reducing leaching of mobile chemicals. In this case the chloride would move through soil similar to nitrate. The study also indicates that a
barrier large enough to cover the chemical completely and overhang 1-cm is enough to significantly slow down leaching rates.

Field studies in lysimeters provided results similar to the lab studies. The statistical analysis for the amount of nitrate in lysimeter drainage is shown in Table 1 (NB, PA, PB, and C are initials for no barrier, plastic above, plastic below and compacted soil treatments, respectively). Numbers in the table are the ratio of the average total nitrate leached out to that applied to each lysimeter as a fertilizer expressed as percentage. According to the Duncan's multiple range test, nitrate leaching was significantly reduced when subsurface barriers were used. There was no statistically significant difference among subsurface barriers on the average total leaching loss of nitrate.

Table 2 summarizes the statistical analysis for nitrogen in the shoots of corn plants. Numbers reported are the ratio (percentage) of total amount of nitrogen in the shoots of fertilizer applied to each lysimeter. Day 21, 38, and 49, correspond to cumulative drainages of 13.9, 27.0, and 30.5 cm, respectively. In general, the amount of nitrogen in the shoots of corn plants was negatively correlated to the cumulative nitrate leached. At 13.9 cm of the cumulative drainage, the PB treatment had the lowest nitrate concentration in drainage effluent samples and the smallest fraction of the applied nitrate leached out resulting in the highest amount of nitrogen in the shoots. At 27.0 cm of the cumulative drainage, the PA and PB treatments resulted in significantly larger amounts of plant nitrogen. At 30.5 cm of the cumulative drainage, the PA treatment had the least nitrate leached out and significantly higher plant nitrogen. As a total, the PA and PB treatments had a significantly higher plant nitrogen than any other treatments. The C treatment resulted in more plant nitrogen than the NB treatment but the difference was not statistically significant.

Conclusion

Our preliminary lab and field studies have shown that subsurface barriers have the potential to reduce nitrate leaching and enable plant roots to readily take up soil nitrogen. We will continue to perform field studies to further test and develop methods of producing effective subsurface water and chemical transport barriers.
References


Table 1. Average leaching losses of chloride and nitrate (1989) after 35 cm of drainage. Values in the table are the ratio of mass of leached chloride or nitrate to mass of the applied chloride or nitrate expressed as percentage.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Chloride</th>
<th>Nitrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>92.50</td>
<td>42.85</td>
</tr>
<tr>
<td>PA</td>
<td>70.32</td>
<td>33.72</td>
</tr>
<tr>
<td>PB</td>
<td>75.91</td>
<td>37.72</td>
</tr>
<tr>
<td>C</td>
<td>81.47</td>
<td>37.62</td>
</tr>
</tbody>
</table>

* Numbers with same letter are not significantly different according to Duncan's multiple range test.
Table 2. Total plant nitrogen analysis (1989). Values in the table are the ratio of mass of nitrogen in plant samples to mass of nitrogen applied as a fertilizer expressed as percentage.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Day 21</th>
<th>Day 38</th>
<th>Day 49</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>1.04  b</td>
<td>2.21  bc</td>
<td>1.72  bc</td>
<td>4.79  b</td>
</tr>
<tr>
<td>PA</td>
<td>1.15  b</td>
<td>4.24  a</td>
<td>4.13  a</td>
<td>9.52  a</td>
</tr>
<tr>
<td>PB</td>
<td>1.59  a</td>
<td>3.79  a</td>
<td>2.54  b</td>
<td>7.92  a</td>
</tr>
<tr>
<td>C</td>
<td>1.02  b</td>
<td>2.44  b</td>
<td>2.10  bc</td>
<td>5.77  b</td>
</tr>
<tr>
<td>N**</td>
<td>0.60  c</td>
<td>1.24  c</td>
<td>0.97  c</td>
<td>2.81  c</td>
</tr>
</tbody>
</table>

* Numbers with same letter are not significantly different according to Duncan's multiple range test.

** Numbers for the check (N) treatment are calculated as the ratio of mass of nitrogen in plant samples to mass of nitrogen applied as a fertilizer to other treatments.
Figure 1. Water flow lines around a subsurface barrier at relative depth of 0.3
Figure 2. Effects on leaching of different sized subsurface barriers placed above chloride solutions.