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Nitrate and herbicide leaching as affected by conservation tillage

Abstract
Conservation tillage is widely promoted because it has been demonstrated to help reduce erosion. But soil conservation concerns must be balanced against the possibility that such tillage may allow greater chemical leaching (removal of fertilizers and pesticides from the root zone of the soil by downward-percolating water), thus degrading water quality.

Keywords
Water quality, quantity and management

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Water Resource Management
Nitrate and herbicide leaching as affected by conservation tillage

Goals

Conservation tillage is widely promoted because it has been demonstrated to help reduce erosion. But soil conservation concerns must be balanced against the possibility that such tillage may allow greater chemical leaching (removal of fertilizers and pesticides from the root zone of the soil by downward-percolating water), thus degrading water quality.

This study considered conservation tillage’s effects on nitrate and herbicide leaching.

Specifically, the objectives of this project were to

• compare the effects of tillage on macropore existence in the upper root zone and the resulting effects on chemical leaching;
• determine the effects of rainfall intensity and tillage on chemical concentrations and leaching losses;
• evaluate the total impact of a "wetting" rain, and combinations of wetting, "gentle," and "intense" rains on leaching losses; and
• measure how solute type and soil adsorption (see Findings), along with rain and tillage, affect leaching.

Approach

This study used a rainfall simulator to mimic natural rainfall conditions, including the energy impact of rain. The simulator approximated the drop sizes and energy of natural rainfall to help assess the impact on water infiltration.

Researchers extracted undisturbed soil columns 8 inches (in.) in diameter and 12 in. long from moldboard-plowed, chisel-plowed, and no-tilled fields. Two anions, nitrate (NO\textsubscript{3}-) and bromide (Br), the latter as a tracer, were applied to the soil surface in the columns at rates of 120 pounds (lb)/acre each one day before rain. (Anions are charged molecules or ions with a negative electrical charge; the soil has little capability for holding these ions.) Atrazine, a herbicide, was also applied one day prior to rain at a rate of 2 lb/acre.

To determine if rainfall patterns in combination with conservation tillage did affect leaching, researchers used four rainfall patterns:

• Rain I consisted of 0.4 in. per hour (h) for 7.5 h (“gentle” rain);
• Rain II was 2 in./h for 1.5 h (“intense”);
• Rain III comprised 0.4 in./h (“wetting”) for 1 h followed a day later by 0.4 in./h (gentle) for 6.5 h; and
• Rain IV was 0.4 in./h for 1 h (wetting) followed a day later with 2 in./h for 1.3 h (intense).

Because the chemicals studied are surface applied, the timing and intensity of rainfall striking the soil are important in their subsequent dissolving and leaching. For example, a light rain occurring right after chemical application might move the chemical into the soil and decrease its later leaching with more rain as opposed to an immediate intense rain.

An intense rain might cause more leaching of a chemical on the surface by movement through soil macropores (cracks, open channels, wormholes) as opposed to a longer, more gentle rain, and it is commonly believed that tillage influences the existence of macropores. This influence was also measured in this study.
All columns received a total of 3 in. of rain. During the simulation, three columns were placed on funnels inset in holes cut in a plywood sheet supported by sawhorses (see Fig. 1). Heavy rubber gasketing draped over the bottles skirted the columns and prevented rainwater from entering the funnels directly. Collection bottles were clamped in place under the plywood, and a rain gauge attached to each of the three columns determined when the intended rainfall amounts had been applied.

Researchers collected column drainage in increments as a function of time. After recording collection times, they stoppered and refrigerated the collection bottles until analysis time. They normally collected five to seven samples of drainage per column and recorded the time it took for drainage to begin. The last sample was taken after the columns finished draining overnight.

The researchers also analyzed the columns for the existence of macropores after the rainfall experiment. A 4.3-in.-diameter hole cutter (the kind used for golf greens) cored the center of each column in 1-in. increments. The twisting action of the cutter "broke" the soil as it removed it. Each increment was photographed, and the resulting slides were projected onto a grid where they were magnified about five times. The approximate area of each macropore, identified by sight, was estimated according to the grid; calipers measured diameter.

Findings

The low soil adsorption (the tendency of soil particles to cling to, or hold, chemicals) typical of anions had a dramatic effect on chemical leaching. Concentrations of the non-adsorbed anions started high, with Br averaging 78 milligrams per liter (mg/L). Depending on the rain pattern, they either increased or decreased somewhat over time, with an overall average leaching loss, in the 2-in. of drainage for the Br tracer, of 34% of that applied. Concentrations and losses of NO$_3$-N (nitrate-nitrogen) were about one-third higher because NO$_3$-N is naturally present in the soil.

However, with the atrazine, a soil-adsorbed herbicide, concentrations started at 0.007 micrograms per liter (μg/L), a much lower concentration even when one considers that only 1/60th as much of this chemical was applied. Moreover, the atrazine concentration decreased with time, and leaching losses averaged 0.07% of that applied. The overall average concentration in drainage from the recently treated columns of soil was 3 μg/L, which is atrazine's lifetime health advisory limit (the estimated level at which an individual could consume a substance or chemical in water over a lifetime with no adverse effect).

For a gentle rain, anion concentrations started lower and increased slightly with time; the opposite was true for the intense rain, and the
net result was similar losses for both rains. When a wetting rain preceded these two rains, anion losses were decreased. Compared to moldboard-plowed soil, no-till tended toward the lowest anion losses with gentle rain but toward the greatest losses with the intense rain (with or without the preceding wetting rain). Both of these results indicate the possible influence of macropores.

With one exception for Br where no-till had greater chemical concentrations, chisel-plowed soil had the highest average chemical concentrations and leaching losses. The fact that far more NO$_3$-N and Br than atrazine were lost to leaching illustrates how soil adsorption plays a role in reducing chemical leaching.

For atrazine, gentle rain preceded by a wetting rain produced the highest initial atrazine concentration (11 μg/L) in drainage water, but the largest loss (0.089%) occurred when a wetting rain preceded an intense rain. The lowest atrazine loss (0.036%) and lowest initial drainage-water concentration (3 μg/L) were for the single gentle rain. Rainfall-tillage interaction, which was similar to that of the anions, showed that no-till had the lowest atrazine losses with the gentle rains but the greatest losses with the intense rains. Again, researchers attribute these results to the macropores present.

Nevertheless, analysis of the macropores in the soil columns did not show large differences among tillage practices. Chisel-plowed and no-till soils had slightly more macropores than the moldboard-plowed soils; in all tillage types, the number of macropores increased with depth. Because the no-till field in this study was mechanically cultivated each year, the no-till and chisel-plow similarities are not surprising. When results are averaged over all tillages, NO$_3$-N, Br, and atrazine losses were greatest in the chisel-plowed soil, next highest in the no-till, and lowest in the moldboard plowed soil—but the ranges were narrow: 41-52% for NO$_3$-N, 30-40% for Br, and 0.04-0.09% for atrazine.

**Implications**

The results of this experiment on chemical leaching show that conservation tillage in the forms of chisel plowing and no-till increased anion concentrations and losses only about 10-20% relative to moldboard plowing, compared to a 50-60% relative increase for atrazine. The increase in atrazine losses was greater, but atrazine concentrations in drainage from the 30-cm-long (about 12-in.) soil columns were only 3.5 and 3.0 μg/L for chisel plow and no-till, respectively.

These numbers compare favorably to atrazine's lifetime health advisory level of 3.0 μg/L. Considering that the root zone is five feet or deeper, later drainage (and at deeper depths) would result in even lower concentrations.

On the basis of these numbers, the benefits of soil conservation with conservation tillage should outweigh the possible negative effects of potentially increased chemical leaching. These researchers believe that the use of conservation tillage should continue to be promoted. Furthermore, with additional study and chemical application method development, macropores and water flow through them may be used to potential advantage; that is, by applying chemicals in areas of the soil where water moves less, farmers may be able to reduce chemical leaching.

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