Water and Agricultural-Chemical Transport in a Midwestern, Tile-Drained Watershed: Implications for Conservation Practices

The study of agricultural chemicals is one of five national priority topics being addressed by the National Water-Quality Assessment (NAWQA) Program in its second decade of studies, which began in 2001. Seven watersheds across the Nation were selected for the NAWQA agricultural-chemical topical study. The watersheds selected represent a range of agricultural settings—with varying crop types and agricultural practices related to tillage, irrigation, artificial drainage, and chemical use—as well as a range of landscapes with different geology, soils, topography, climate, and hydrology (Capel and others, 2004). Chemicals selected for study include nutrients (nitrogen and phosphorus) and about 50 commonly used pesticides. This study design leads to an improved understanding of many factors that can affect the movement of water and chemicals in different agricultural settings. Information from these studies will help with decision making related to chemical use, conservation, and other farming practices that are used to reduce runoff of agricultural chemicals and sediment from fields (Capel and others, 2004). This Fact Sheet highlights the results of the NAWQA agricultural chemical study in the Leary Weber Ditch Watershed in Hancock County, Indiana. This watershed was selected to represent a tile-drained, corn and soybean, humid area typical in the Midwest.

Introduction

An understanding of water movement and chemical properties is necessary for understanding how agricultural chemicals (nutrients and pesticides) move from the field surface to streams and ground water. Effective conservation practices should account for the interdependent influences between water movement and chemical properties to reduce agricultural-chemical transport to streams and ground water. Environmental managers need to understand that conservation practices designed to control agricultural-chemical transport along one pathway, for example in runoff, may have an undesirable effect in controlling transport along another pathway, for example through soils.

Study Area

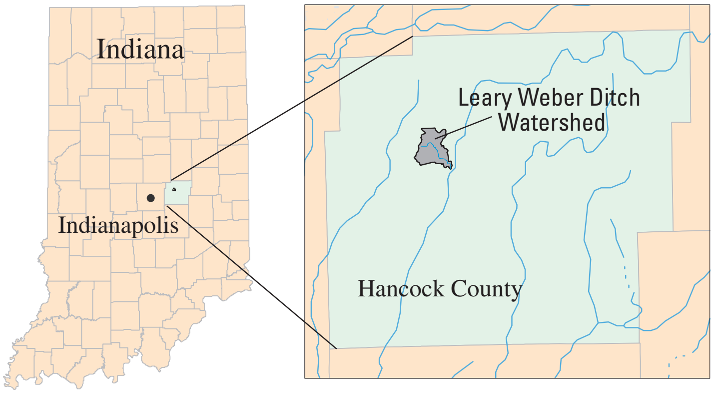


Figure 1. Location of Leary Weber Ditch Watershed, Hancock County, Ind.

Leary Weber Ditch in Hancock County, Indiana (fig. 1) was used as a case study to demonstrate the importance of understanding water movement in chemical transport to streams and ground water in a tile-drained, Midwestern, agricultural watershed. Leary Weber Ditch Watershed is typical of many areas throughout Indiana and the Midwest in terms of farming practices and watershed characteristics. Leary Weber Ditch is a 2.73-mi^2, intensively farmed watershed dominated by poorly drained soils and a nearly flat land surface (Lathrop, 2006). Corn and soybeans are grown on 87 percent of the watershed. Growing crops on this land requires lowering the water table and removing ponded water by draining the fields through subsurface drains (commonly referred to as tile drains).

Water-Transport Pathways

Water enters the Leary Weber Ditch Watershed through precipitation (rain and snow); most of the water entering the watershed is lost through evaporation and plant uptake (evapotranspiration) (fig. 2). Because the land surface is flat and tile drained, most of the excess water (30 percent) moves through soils (infiltrates) to tile drains and ground water (fig. 2). In general, tile drains tend to decrease surface runoff while increasing infiltration (Kladivko and others, 2001).

Water that infiltrates moves through soils by preferential and matrix flow. Preferential flow is water that drains quickly through large pores in the soil (such as shrink-swell cracks, worm burrows, and root casts). Matrix flow is water that drains slowly through small pores between soil particles. Once water reaches the tile drain it quickly flows into the ditch. In the Leary Weber Ditch Watershed, tile drains typically stop flowing in July. Excess water in the soils has drained and crops are mature enough to take up most of the moisture provided by rainfall (Baker and others, 2006).

Less than 10 percent of water entering the watershed flows across the land surface as runoff that flows directly into the ditch (fig. 2). Runoff contributes water to the ditch during high-intensity rainfall; however, storms with high-intensity rainfall are sporadic throughout the year. The total annual contribution of water from surface runoff to the ditch is much less than the tile-drain contribution (Baker and others, 2006).

Ground water is not a major source of water to Leary Weber Ditch (Baker and others, 2006). Field observations show that the ditch stops flowing when the tile drains stop flowing, indicating that the tile drains are the primary source of water to the ditch between storms (Baker and others, 2006).

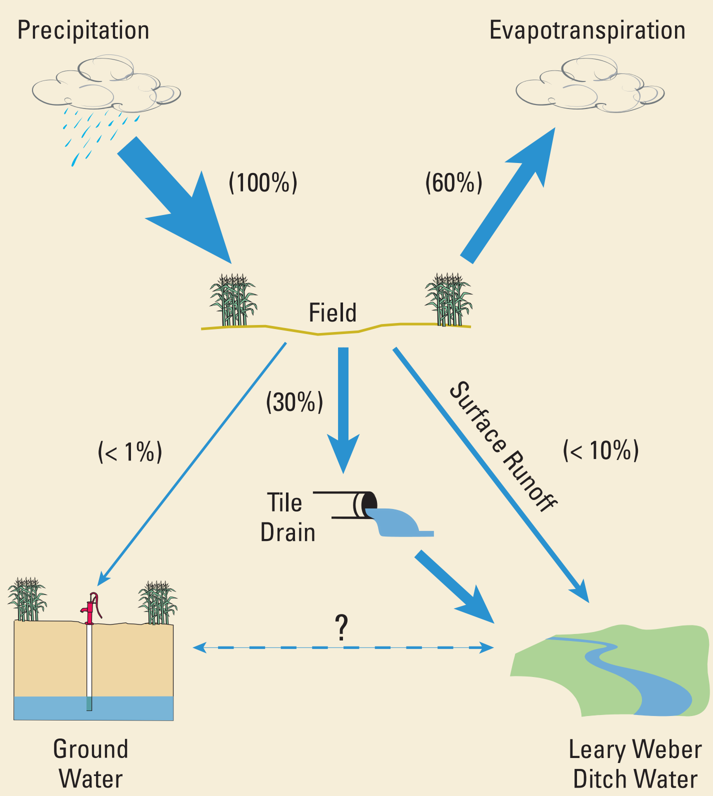


Figure 2. Water-transport pathways in Leary Weber Ditch Watershed, Hancock County, Ind. Numbers in parenthesis are relative average yearly transport amounts. Arrow is dashed and queried where pathway is uncertain.

Nutrient-Transport Pathways

Nutrients primarily enter the watershed through application of fertilizers to crops (fig. 3). The greatest loss of nitrogen applied to crops leaves the watershed through plant uptake and harvest; most of the phosphorus applied to crops attaches to soil particles and remains in the soil (fig. 3) (Schnepf and Cox, 2006).

Much of the nitrogen that is not taken up by plants moves through soils (as nitrate) to tile drains which flow to the ditch (Baker and others, 2006). Runoff is not the major pathway for the movement of nitrate to Leary Weber Ditch; tile drains decrease surface runoff losses of nitrate while increasing losses through tile-drain water (Kladivko and others, 2001). Also, because nitrogen fertilizer may be injected into the soil, the direct runoff of nitrate to streams is small and the potential for nitrate movement to tile drains is further increased.

The highest nitrate concentrations in the watershed were measured in samples collected from water in the soils (Baker and others, 2006). While some nitrate moves directly to tile drains, excess nitrate also may accumulate in the soil over a period of months to a few years before moving into tile drains and streams after rainfall (Eckert, 1995). The potential for nitrate movement is greatest during and immediately after rainfall regardless of when the nitrate was applied (Kladivko and others, 1999). Very low nitrate concentrations were found in ground-water samples in the watershed (Baker and others, 2006). This is because the small amount of nitrate that moves below tile drains converts to gaseous forms of nitrogen (undergoes denitrification) in the saturated ground-water soils (Schnepf and Cox, 2006, and Johnson and others, 2005).

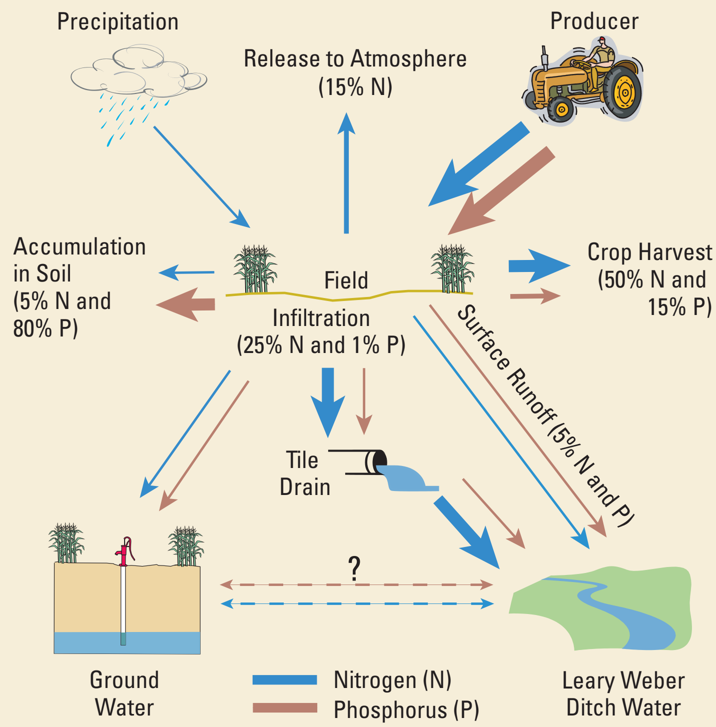


Figure 3. Nutrient transport pathways in Leary Weber Ditch Watershed, Hancock County, Ind. Numbers in parenthesis are approximate transport amounts for a typical rain-fed watershed (Schnepf and Cox, 2006). Arrow is dashed and queried where pathway is uncertain.

Most of the phosphorus that has not accumulated in soils or is not taken up by plants moves in runoff to the ditch (fig. 3). Phosphorus concentrations increase in tile drains in response to increased rainfall; however, concentrations are only one tenth as large in the tile drain as in runoff (Baker and others, 2006). Phosphorus concentrations are low in tile drains between storms, indicating that phosphorus moving in matrix flow attaches to soils before reaching tile drains. For the same reason, negligible amounts of phosphorus move into ground water.

Understanding Nutrients

The specific chemical form that nitrogen and phosphorus take in the environment determines how readily these nutrients attach to soil particles.

- Nitrogen occurs naturally in many different organic or inorganic forms. Inorganic nitrogen, found in commercial fertilizers, is usually applied to crops as urea, urea ammonium nitrate, or anhydrous ammonia. Nitrogen from fertilizers is eventually converted to nitrate by the process of nitrification. Nitrate does not readily attach to soils, readily dissolves in water, and can be taken up by plants. Denitrification occurs in saturated soils when bacteria use nitrate as an oxygen source resulting in the conversion of nitrate to gaseous forms of nitrogen (Johnson and others, 2005).

- Inorganic phosphorus, found in commercial fertilizers, can be taken up by plants. It readily reacts with iron, aluminum, and calcium ions to form substances that can attach to soil particles, reducing the potential for transport through soils (Hyland and others, 2005).

Pesticide-Transport Pathways

Pesticides are applied to fields to control weeds, insects, or fungi on crops. Pesticides move from the field into the air, in runoff, or through soils to tile drains or ground water (fig. 4). Rainfall and runoff immediately following application generally cause the greatest movement of pesticides (Kladivko and others, 1999). Pesticides transported in runoff reach the ditch soon after rainfall begins; concentrations typically peak when flow in the ditch peaks (Baker and others, 2006).

Infiltration through the soils to tile drains also is a major pathway for pesticides that readily dissolve in water such as acetochlor and atrazine (Baker and others, 2006). These pesticides are transported in preferential flow in greater quantities than pesticides that readily attach to soil particles. Concentrations of atrazine were much lower in normal tile flow than concentrations found in peak flow in tiles (Baker and others, 2006). Because of its persistence (fig. 5), atrazine has a greater potential to move to ground water than less persistent pesticides; however, pesticides were rarely detected (the few detections that occurred were low concentrations) in ground water in Leary Weber Ditch Watershed (Baker and others, 2006).

Infiltration through the soils is not a major transport mechanism for pesticides such as chlorpyrifos and glyphosate. When transport does occur, it is primarily in runoff and eroded soils. These pesticides readily attach to soil particles and are retained in the upper soil layers. Tile drains decrease surface runoff and erosion resulting in an overall decrease in the transport of these pesticides (Kladivko and others, 2001). Glyphosate and chlorpyrifos were found in tile drains at much lower concentrations than found in runoff. Glyphosate and chlorpyrifos transport through soils generally occurs by preferential flow soon after rainfall (Stone and Wilson, 2006); however, very low concentrations of glyphosate were found in some ground-water samples indicating that small amounts of glyphosate can be transported relatively long distances through soils (Baker and others, 2006).

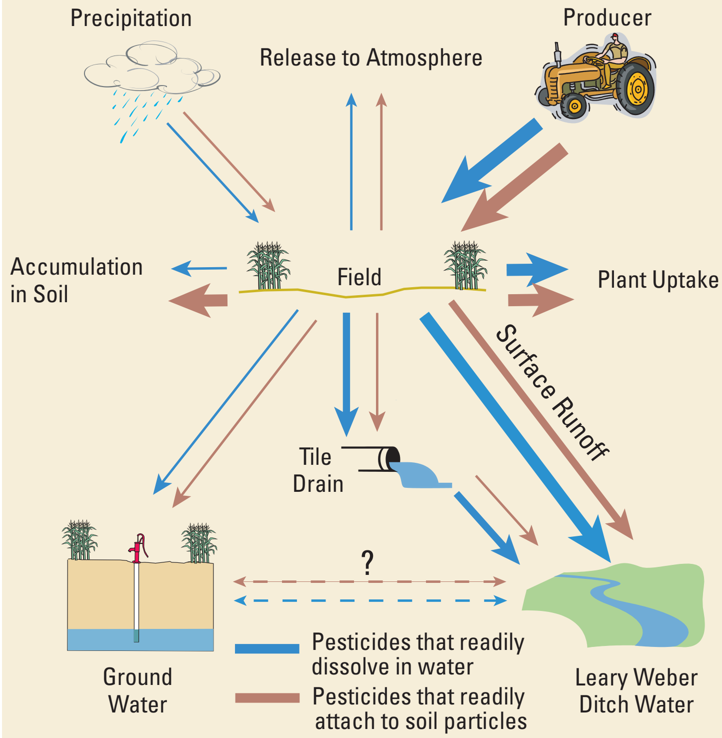
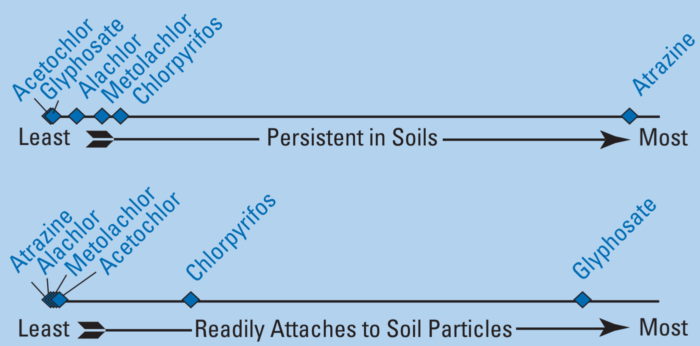


Figure 4. Pesticide transport pathways in Leary Weber Ditch Watershed, Hancock County, Ind. Size of arrow indicates relative transport amounts and is dashed and queried where pathway is uncertain.

Understanding Pesticides

Pesticides detected most frequently in streams and ground water are primarily those with the greatest use, mobility, and persistence (Gilliom and others, 2006). Pesticides that are most commonly used on corn and soybeans are the herbicides acetochlor, alachlor, atrazine, glyphosate, and metolachlor, and the insecticide chlorpyrifos (Gilliom and others, 2006).

- Pesticides that readily dissolve in water can move to streams and ground water in greater quantities than chemicals that readily attach to soil particles (Kladivko and others, 2001).
- Persistent pesticides remain in their original form in the environment for long periods and may be transported for long distances or accumulate in soils, sediment, or biota (Gilliom and others, 2006).



[Pesticide trade names: atrazine, Aatrex; acetochlor, Harness; alachlor, Lasso; chlorpyrifos, Lorsban; glyphosate, Roundup; metolachlor, Dual]

Figure 5. Relative persistence and ability to attach to soil particles for commonly used pesticides on corn and soybeans. Sources: Gilliom and others, 2006; Accinelli and others, 2004; European Commission, 2002.

What are the Implications for Conservation Practices?

Many conservation practices have been developed to manage soil, water, nutrients, and pesticides. The goal of these conservation practices is to reduce soil erosion which prevents the loss of valuable soil and nutrients, and to protect water quality by reducing sediment, nutrient and pesticide transport to streams and ground water. Nutrients that enter surface water can cause excessive algae growth that depletes oxygen (hypoxia) and may cause harm to animals in the water. Excess nutrients from the Midwest have been linked to hypoxia in the Gulf of Mexico (Alexander and others, 2000). Pesticides in water may be toxic to plants and animals living in or drinking the water.

Interactions between water and chemical transport, chemical properties, and conservation practices are complex in agricultural areas like the Leary Weber Ditch Watershed. By understanding that conservation practices designed to control concentrations of one environmental contaminant may affect concentrations of another, environmental managers may better weigh the pros and cons of implementing a specific conservation practice. For example, conservation tillage may decrease sediment erosion but may cause increased atrazine usage and subsequent movement into streams (Devlin and others, 2000). Environmental gains from decreased runoff of sediment and attached nutrients may help water quality in agricultural areas but cause greater problems for downstream drinking-water facilities needing to remove the atrazine.

Examples of Typical Conservation Practices in Midwestern Watersheds (Schnepf and Cox, 2006)

- Pesticide and nutrient management (managing the amount, source, placement, form, and timing of the application of chemicals) reduces the amount of chemicals available for transport to the air, streams and ground water.
- Installation of tile drains (laying drainage pipe below the field surface connected to outlets at the stream) increases infiltration and reduces surface runoff and erosion.
- Controlled drainage-water management (managing tile-drain flow so that more water is held in the soils during the non-growing season and controlling release at planting time to drain the fields for planting) raises the water table and keeps soils saturated through the non-growing season. This practice reduces infiltration to tile drains and increases surface runoff during the non-growing season, promotes denitrification, and provides more water for evapotranspiration during the growing season.
- Conservation tillage (no-till, mulch-till, and ridge-till) (leaving crop residue on the field) reduces and slows surface runoff and soil erosion, and increases infiltration to the soil.
- Installation of filter strips (planting vegetation along waterways) increases infiltration and reduces and slows surface runoff and soil erosion.
- Installation of grassed waterways (planting vegetation in natural drainage areas such as gullies) directs the flow of water and reduces gully erosion. The vegetation also may trap sediment and absorb some chemicals and nutrients.

Implications

- For pesticides, reducing their use (pesticide management) is likely to be an effective way to reduce their concentrations in watersheds, particularly in streams (other approaches also may be effective) (Gilliom and others, 2006).
- Increases or decreases in pesticide use (pesticide management) can result in rapid corresponding changes in pesticide concentrations in stream water (and tile-drain water)—generally within 1 to 2 years (Gilliom and others, 2006).
- Planting perennial cover crops (nutrient management) results in greater plant uptake of nutrients and decreases both nitrogen and phosphorus losses from fields (Schnepf and Cox, 2006).
- Tile drains may help protect ground water, but increase pesticide and nutrient transport to streams (Gilliom and others, 2006; and Baker and others, 2006)
- Tile drains increase transport of chemicals that readily dissolve in water (nitrate, acetochlor, alachlor, atrazine, and metolachlor) and decrease transport of chemicals that readily attach to soil particles (phosphorus, chlorpyrifos, and glyphosate) (Schnepf and Cox, 2006).
- Controlled drainage reduces nitrate transport (Schnepf and Cox, 2006); however, draining a large amount of water at the start of the growing season may release nitrate that has accumulated in the soil.
- Conservation tillage may reduce transport of chemicals that readily attach to soil particles (phosphorus, chlorpyrifos, and glyphosate) but may increase the transport of chemicals that readily dissolve in water (nitrate, acetochlor, alachlor, atrazine, and metolachlor) by increasing infiltration to tile drains (Schnepf and Cox, 2006).
- Conservation tillage often requires increased pesticide usage resulting in increased transport of pesticides (Schnepf and Cox, 2006).
- Grassed waterways and filter strips filter sediment and may reduce the transport of pesticides that attach to soil particles (chlorpyrifos and glyphosate); they may not reduce the transport of pesticides that readily dissolve in water (and infiltrate soils) (acetochlor, alachlor, atrazine, and metolachlor) (Schnepf and Cox, 2006).

Conclusions

The interactions between water and chemical transport, chemical properties, and conservation practices are complex in the Leary Weber Ditch Watershed. Water transport to tile drains is the primary controlling factor for much of the agricultural-chemical transport in the watershed. Tile drains reduce surface runoff and increase infiltration. Chemicals that readily dissolve in water tend to move through soils and preferential flow pathways to tile drains that flow through outlets to the ditch. Runoff is a major transport pathway for chemicals that readily attach to soils. Runoff also is an important transport pathway for pesticides that readily dissolve in water when rainfall occurs soon after application.

Nutrient and pesticide-management practices that reduce the use of agricultural chemicals are likely to be an effective way to reduce their concentrations in streams. Conservation practices designed to reduce surface runoff and erosion may not reduce the transport to tile drains of chemicals that readily dissolve in water. These conservation practices may reduce the transport of chemicals that readily attach to soils.

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