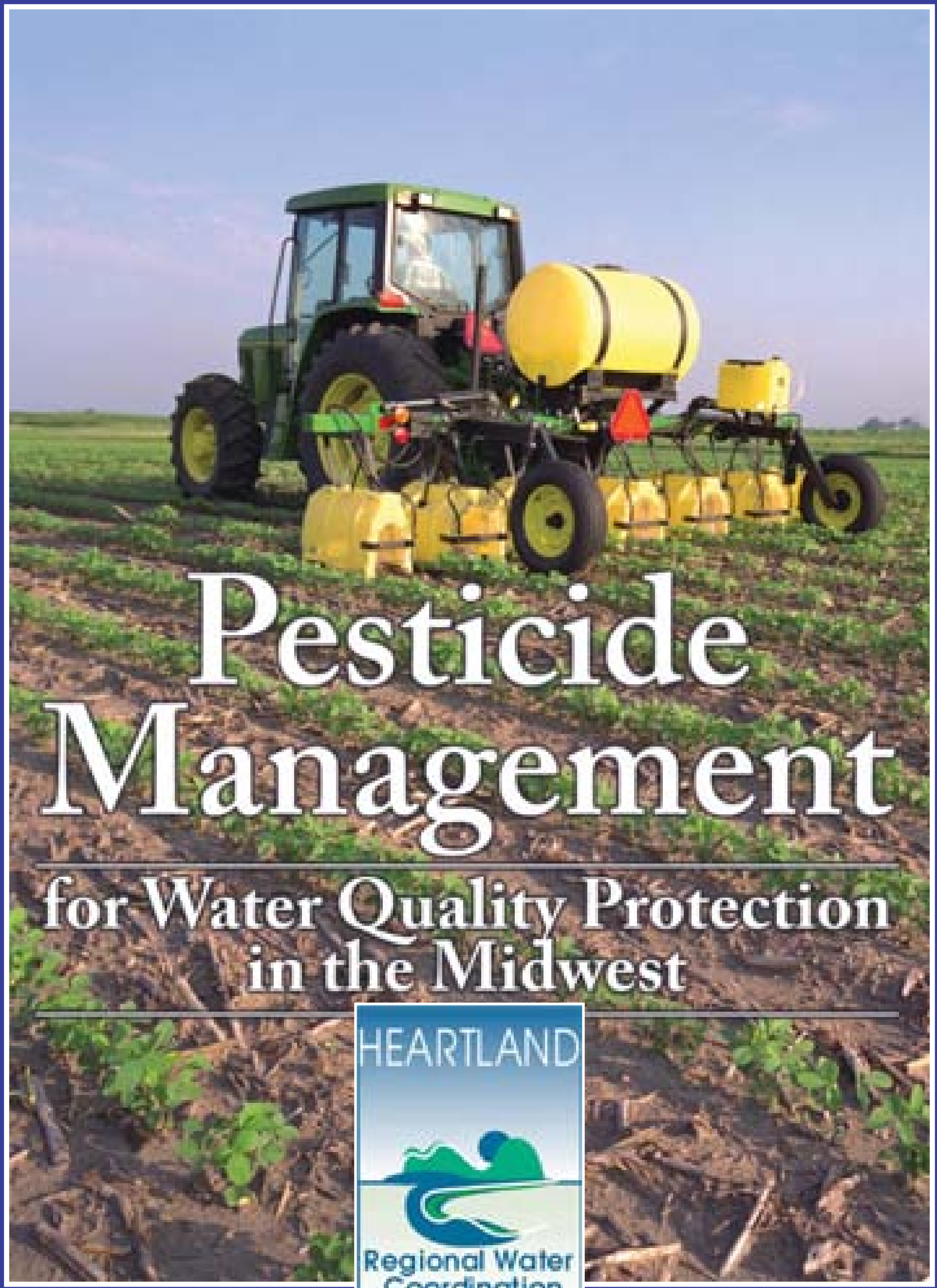
Pesticide Management for Water Quality Protection in the Midwest



HEARTLAND Regional Water Coordination Initiative

EPA Region VII

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Chapter 1. Pesticides in Agriculture and the Environment

Introduction

Pesticides are used to control weed, disease, and insect pests of plants in agricultural, urban, and natural settings. Appropriate pesticide use can enhance the quantity and quality of food, feed, and fiber production and the appearance of landscape plants and areas. However, inappropriate or poorly planned use of pesticides can result in the degradation of surface water and groundwater. It is in society's best interest that we understand how pesticides affect the environment, what mechanisms control their movement, and which management practices minimize their adverse affects.

This publication provides an overview of factors influencing pesticide movement into groundwater and surface waters in the four-state region of Iowa, Kansas, Missouri, and Nebraska. First, it discusses the benefits of appropriate pesticide use and highlights the risks associated with pesticide movement into groundwater and surface water. Second, it describes chemical processes and landscape characteristics that affect pesticide movement and behavior in soil and water. Third, it presents best management practices (BMPs) that can be applied to minimize off-site movement of pesticides. Finally, it details legislation and policies that are used to regulate the use of pesticides.

Benefits of Appropriate Pesticide Use

Many farmers believe pesticides are essential to reduce losses from weeds, insects, and diseases and to increase profitability. It was estimated in 2005 that the use of herbicides increased crop production 20 percent (*www.croplifefoundation.org*). Increased yields limit the amount of land that must be cropped, which protects marginal lands from erosion and increases habitat for wildlife.

Herbicides have allowed fewer farmers to manage the same number of total acres by reducing the amount of labor required to control weeds. Herbicides have replaced tillage for both preplant and in-crop weed control, and this has allowed increased adoption of reduced- and no-till systems. Reduced tillage systems minimize soil lost to erosion, which contributes to cleaner waterways and air. In addition, reduced tillage systems improve moisture conservation and have allowed an intensification of cropping systems in western Nebraska and western Kansas.

Pesticides in Groundwater and Surface Water

Most fields in the heartland region receive one or more pesticide applications annually. In 2002, herbicides were applied to 16.7 million acres in Iowa, 10.3 million acres in Kansas, 6.4 million acres in Missouri, and 11.3 million acres in Nebraska. With this widespread application of chemicals comes the potential for these pesticides to move off-site into groundwater or surface water and pose possible health risks.

It is common to find detectable concentrations of pesticides in streams and groundwater in the heartland region. The ability to detect pesticides, even at very low concentrations, has increased as analytical methods have improved. Usually, the pesticides that are most commonly detected are those applied in the greatest quantities. In general, the occurrence of pesticides in surface water and groundwater follows patterns in land and pesticide use.

The source of pesticide contamination is defined as coming from either "point" or "nonpoint" sources. Potential point sources include pesticide mixing and loading facilities, storage facilities, sprayer cleanout areas, and private or public water supply or irrigation wells. When regulations and common sense are followed at point sources, the risk of pesticide contamination is small. However, significant contamination to groundwater and surface water has been caused by spills that are not contained, or by improper disposal of excess pesticides.

Nonpoint sources include runoff to streams from agricultural and nonagricultural land, leaching (or seepage) of pesticides to groundwater, and volatilization of pesticides into the atmosphere that are later deposited with percipitation. Nonpoint sources can cause contamination over an extended area or an extended period of time because the pesticides are applied at a relatively low concentration to a wide area.

Pesticides are detected less often in groundwater than in surface water. The pathway for a pesticide to move to groundwater is slower and there is generally a greater potential for that pesticide to be degraded before reaching the groundwater. The path of a pesticide to surface water can be relatively short, especially when a precipitation event causes runoff shortly after a pesticide application. Management practices that reduce runoff of pesticides to surface waters can result in a substantial reduction of pesticide loading to surface waters.

Pesticides in Surface Water. Herbicides are the most widely applied pesticides. Herbicides are also the pesticides most commonly detected in surface waters in the heartland region. Late spring and early summer is the most common time to detect herbicide residues in rivers and streams. This corresponds to when most herbicides are applied and when the heaviest precipitation and most runoff occur. It is common to have concentrations of certain pesticides, particularly atrazine herbicide, at levels above the aquatic life standards in surface waters in the spring for brief periods of time following application. Pesticide concentrations in surface waters are generally greatest closest to the location where they were originally applied. Generally, as water containing pesticide runoff moves through the surface water system, pesticide concentrations decline due to dilution and degradation.

Contaminated waters often contain a mixture of several pesticides, including transformation products of those pesticides. Atrazine, a herbicide used for weed control in corn, sorghum, and fallow fields, is the herbicide that is detected most frequently. In United States Geological Survey (USGS) studies, atrazine was found in two-thirds of all samples from agricultural streams across the United States, often occurring year-round. Fortunately, the average concentration of pesticides or their transformation products rarely exceed water quality standards set to protect human health.

Pesticides in Groundwater. Pesticides were detected in about one-third of the shallow groundwater samples collected by USGS across the United States. The most common pesticide detected was atrazine and one of its transformation products, deethylatrazine. The lower rate of atrazine detection in groundwater compared to surface water results from longer travel times and greater opportunity for sorption or breakdown.

Pesticide Effects on Human Health

Pesticides are designed to kill or otherwise affect the growth or behavior of some type of organism. Therefore, there are concerns about the effects of pesticides on humans. Exposure to high levels of pesticides can cause blurred vision, headaches, salivation, diarrhea, nausea, vomiting, wheezing, eye problems, skin conditions, seizure, coma, and even death. Pesticide poisoning also may mimic asthma, bronchitis, and gastroenteritis.

The effect of a pesticide on humans depends on both the toxicity of the pesticide and exposure to that pesticide. Pesticide effects can be either acute (immediate effects resulting from short-term exposure to a high level), or chronic (effects that occur over a long period due to continual exposure at a low level). Acute toxicity is measured by the amount or concentration of pesticide required to kill 50 percent of the animals in a test population. The lower the LD_{50} (lethal dose) or LC_{50} (lethal concentration) of a pesticide product, the greater is its toxicity to humans and animals. Chronic toxicity is determined by exposing animals to the pesticide active ingredient over an extended period of time. The health effects from chronic exposure to pesticides are more difficult to determine than is acute toxicity. Some pesticides can pose a high risk to humans while other pesticides pose a low risk. The product label contains information regarding the relative risk of a product.

Pesticides are generally of greatest risk to those that handle and apply them. Typically, pesticides applied according to the label do not pose a significant risk to individuals not directly involved with applying or handling the pesticide. In both surface water and groundwater, pesticides are typically not present in high enough concentrations to cause acute health problems.

Human Health Benchmarks for Pesticides in Drinking Water. The Maximum Contaminant Level (MCL) is the maximum concentration of a pesticide allowable in public drinking water supplies. MCLs are enforceable standards developed and issued by the U.S. Environmental Protection Agency (U.S. EPA). MCLs have not been established for all pesticides.

The Lifetime Health Advisory is the concentration of a pesticide in drinking water that over a lifetime exposure will not cause any adverse, noncarcinogenic effects. This is not a legally enforceable U.S. EPA standard, but is a technical advisory to federal, state, and local agencies. It assumes a lifetime consumption of 2 liters (0.53 gallons) of water per day by a 70 kg (154 pound) adult and that 20 percent of the exposure to the pesticide comes from drinking water. The remaining 80 percent of the exposure is assumed to come from other sources.

Pesticide Effects on Aquatic Organisms and Wildlife

Pesticides can have adverse effects on aquatic organisms and wildlife. Pesticides may impact aquatic organisms through direct effects (chronic or acute toxicity), or through indirect effects such as damage to habitat or reduction in the availability of food sources.

Pesticides vary in their toxicity to aquatic organisms. Acute exposures kill or sicken aquatic organisms, such as fish kills caused by pesticide residues that run off or drift to lakes, ponds, or rivers. Serious problems with acute exposures are rare in the heartland region. Chronic exposures occur over an extended period of time and at pesticide concentrations that are not immediately lethal. Examples of effects caused by chronic exposures are weight loss and reproductive problems.

Chapter 2. Pesticide Behavior and Movement in a Landscape

Pesticides have had a positive effect on food and fiber productivity in the United States. When pesticides remain where they are applied (target site), there are generally few concerns. However, off-site movement of pesticides from leaching and runoff can cause significant contamination of groundwater and surface water. The U.S. EPA and state regulatory agencies have established maximum contaminant levels (MCL) or total maximum daily loads (TMDL) or other environmental regulations for pesticides and other pollutants in streams, lakes, and groundwater resources. These regulations help ensure water is safe for humans and other organisms. Too often, pesticide concentrations exceed MCLs or TMDLs and jeopardize the quality of some water resources because of losses from application sites. Pesticide use may be more strictly regulated or banned when MCLs, TMDLs, or other environmental regulations are exceeded.

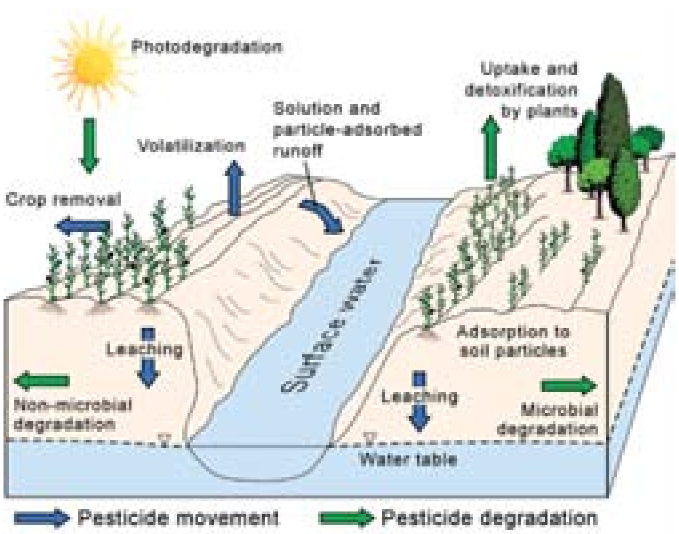

Figure 1. *Many processes determine the fate of pesticides in the environment. Pesticides may move off an application site by volatilization, runoff, and leaching through soil.*

Pesticides move off target by runoff, soil erosion, and leaching, which are among the many processes influencing the fate of agrichemicals in the environment (Figure 1). Runoff occurs when water from rainfall or irrigation is unable to infiltrate the soil, and instead flows into streams and lakes. Pesticides dissolved in water may be carried great distances through large networks of streams. On some soils, runoff may cause soil erosion, and the moving water carries soil particles with attached pesticides great distances, degrading streams and lakes. Water that infiltrates the soil may eventually return to surface water through tile drains, subsurface flow, and seepage. The water also may leach through the soil profile into groundwater.

The likelihood or mechanism of off-site pesticide movement depends on the chemical properties of the pesticide and a number of climatic, soil, and landscape factors. Understanding how these characteristics affect pesticide fate and movement allows individuals involved in recommending or applying pesticides to better manage pesticide use to reduce the potential for contamination. This chapter discusses properties of pesticides and soils, landscape characteristics, and climatic factors that influence pesticide leaching and runoff.

Pesticide Properties affecting Movement

The movement and fate of a pesticide in soil and water primarily depends on its solubility in water, adsorption (retention) by soil, and persistence. Volatilization and photodecomposition losses affect the amount of a pesticide available for movement.

Solubility is the extent to which a chemical dissolves in a liquid. It is often expressed as parts per million (ppm), or the maximum number of parts of a pesticide active ingredient that will dissolve in one million parts water. Pesticide active ingredients that are hydrophilic (water-loving) typically have high solubilities, while those that are lipophilic (oil-loving) have lower solubilities. Solution pH also can affect pesticide solubility. For example, the solubility of sulfonylureas and imidazolinone herbicides increases as the solution pH increases. The U.S. EPA considers chemicals with solubilities greater than 30 ppm to have a high potential to leach or run off from soil. However, because pesticides are generally applied at relatively low rates per acre, field applications usually result in soil and water concentrations that are well below the water solubility of the pesticide. Consequently, solubility alone does not adequately gauge the potential for pesticide movement. However, differences in solubility may be a significant factor when comparing extremely soluble and insoluble pesticides.

Adsorption is the relative tendency of a pesticide to adhere (adsorb) to soil particles. Adsorption is the most critical factor determining how much pesticide will leach or run off from a field. The soil adsorption coefficient (Kd) is the relative distribution of a pesticide between the soil and water. The Kd is the best indicator of adsorption potential for a pesticide in a specific soil. However, because soils can vary greatly, even within a field, the most reliable indicator of relative adsorption potential among pesticides is the organic carbon partition coefficient (Koc). The Koc indicates the affinity of a pesticide for organic matter, the most important constituent for adsorption in soils. A larger Koc value indicates a greater tendency of the pesticide to be adsorbed to organic matter and thus less loss in runoff or leachate. Pesticides with a Koc less than 50 are not strongly adsorbed and are at the highest risk of moving offsite by leaching or runoff. As Koc increases, the tendency to leach decreases while the potential for loss in runoff water increases. Pesticides with a very large Koc (>5,000) are strongly adsorbed and are primarily lost with eroded soil leaving the field in runoff water.

When no leaching occurs, runoff losses will be primarily in water for weakly to moderately adsorbed pesticides and with soil particles (via erosion) for strongly adsorbed pesticides (Figure 2). However, when both leaching and runoff occur (Figure 3), weakly adsorbed pesticides (Koc < 50) will tend to leach out of the mixing zone (top ¼ to ½ inch of soil). Pesticides with moderate Koc values will not leach as readily from the soil surface and may be present in the mixing zone when runoff begins. They also are more likely to be present in runoff water than those that are readily leached below the mixing zone. Although soil loss may be significant during some runoff events, the volume of runoff water is usually much greater. As a result, the majority of pesticides lost in runoff are those dissolved in water (weakly to moderately adsorbed pesticides). Because pesticides tend to become more strongly adsorbed with time, the amount available for movement with water will decrease with time after application. Thus, irrigation or rainfall immediately after application that causes runoff or leaching is more likely to result in greater pesticide loss than events occurring longer after application.

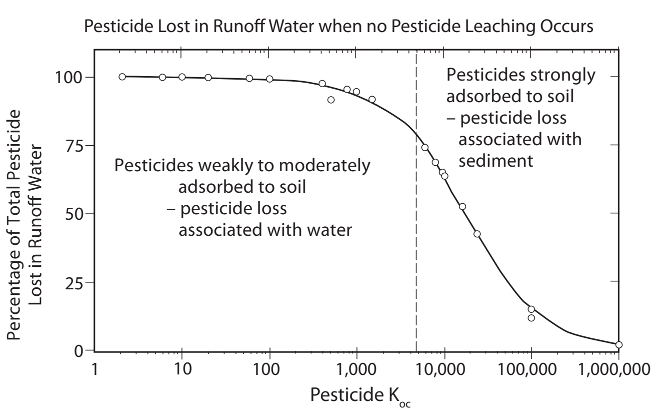

Figure 2. *Relationship between pesticide Koc value and percentage of pesticide runoff lost with runoff water. The figure illustrates results from simulation where no pesticide leaching occurs and only runoff losses are significant. In this graph, all pesticides are assumed to have a half-life of 60 days. [original source: Nebraska Cooperative Extension Circular EC96-145]*

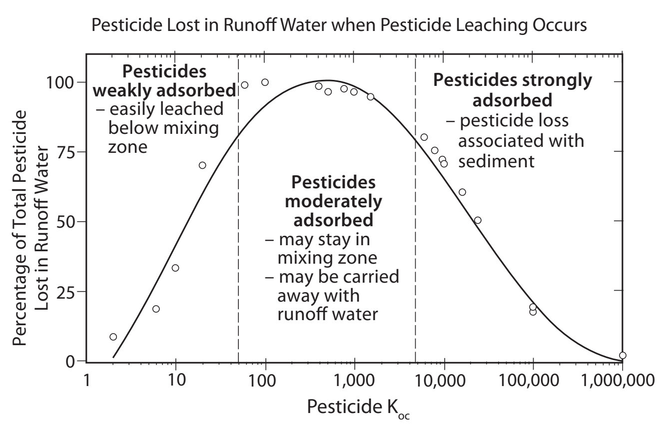

Figure 3. *Relationship between pesticide Koc value and percentage of pesticide runoff lost with runoff water. The figure illustrates results from simulation where both runoff and leaching losses occur. In this graph, all pesticides are assumed to have a half-life of 60 days. [original source: Nebraska Cooperative Extension Circular EC96-145]*

Adsorption and solubility are generally inversely related: as solubility increases, less adsorption can be expected. For example, the adsorption of the sulfonylurea and imidazolinone herbicides decreases (and solubility increases) as pH increases. This is because these herbicides can become anions at pH levels above their dissociation constants (pKa values). Compounds with smaller pKa values will more readily form anions with increasing pH than those with larger pKa values. In addition to being more soluble, anions are repelled from most soil surfaces. Exceptions to this rule are glyphosate, glufosinate, and the "quats" (paraquat, diquat, difenzoquat). These herbicides have high water solubilities but are also strongly adsorbed. This is because of complexing with metals present on the soil surface (glyphosate, glufosinate) or binding of positively charged molecules to cation exchange sites.

Persistence is the length of time a pesticide will remain in the environment before being degraded. An indicator of the relative persistence of a pesticide is its half-life. Half-life is the time required for half of the original amount of pesticide to be degraded to other products. A pesticide with a half-life of 2 months will degrade to one-half of its original amount in 2 months. Two more months will be required to degrade half of the remaining amount (leaving one-quarter of the original). A shorter half-life means less time will be required to degrade the pesticide.

The average half-life of a pesticide is determined from laboratory measurements under controlled conditions. However, pesticide persistence in a field can vary considerably because degradation rates are affected by soil temperature, moisture, oxygen, fertility, and by differences in microbial populations and their activity. Because of the many factors affecting degradation, pesticides with small differences in half-life may show similar persistence. Because of the short time scale of most runoff events, half-life is more likely to influence pesticide loss by leaching than by runoff.

Pesticides are primarily degraded through the action of soil microorganisms. While pesticides may sometimes be used as a carbon energy source by a microbe, degradation is more often indirect, occurring passively as other soil constituents are decomposed. Because microbial activity is generally greatest at near-neutral pH, we can expect most pesticides to be less persistent (and thus a smaller leaching risk) in soils with near-neutral pH than in highly acidic or alkaline soils.

Microbial degradation is strongly affected by prior pesticide use, pesticide concentration, soil temperature, water, oxygen, organic matter and fertility. Repeated application of a herbicide may build microbial populations adapted to degrading the herbicide, and may shorten its persistence in that environment. Microbial activity is greater when soils are warm, moist, well-aerated, and relatively high in organic matter and fertility. These factors change dramatically with soil depth. Soil horizons located deeper in the soil profile are cooler, generally contain much less organic matter, and are less fertile. These changes reduce microbial activity and pesticide degradation rates. As pesticides migrate 6 to 12 inches below the soil surface, retention and degradation can be expected to decrease.

Some pesticides can be degraded by nonbiological hydrolysis. Hydrolysis occurs when a water molecule is added to the active ingredient, thereby changing its properties. Hydrolysis can be a rapid degradation process. Soil pH has a significant effect on hydrolysis. For example, acid-sensitive pesticides, such as the triazine herbicide atrazine and many sulfonylurea herbicides, will hydrolyze in acidic soils (low pH), while alkaline-sensitive pesticides such as the organophosphate (OP) insecticides will hydrolyze in alkaline soils (high pH). The intermediate products of degradation have properties different from the parent compound and are usually, but not always, less toxic. For example, the first degradation product of the herbicide isoxaflutole is responsible for its phytotoxic effect. In a second example, most of the degradation products of atrazine lose their herbicidal effectiveness; however, deethylatrazine is similar to atrazine in toxicity to weeds.

Volatilization is the process by which liquids transform from a liquid to a gas. Volatility is usually measured in units of vapor pressure (mm Hg or Pascals [Pa]). The potential for pesticide loss by volatilization increases as its vapor pressure increases. Vapor losses are usually low for pesticides with vapor pressures below 1.0×10^{-7} mm Hg (1.33×10^{-5} MPa) but may be significant for those with vapor pressures above 1.0×10^{-4} mm Hg (1.33×10^{-2} MPa). Vapor pressure increases with temperature so more vapor loss can be expected when pesticide applications are made on warmer days than on cooler days. Volatilization also will increase with air movement and can be greater from a field with an unprotected smooth surface than from fields with rough surfaces or wind breaks. Soil incorporation or immediate irrigation is recommended after application of highly volatile pesticides to reduce vapor loss.

Photodecomposition occurs when light-sensitive pesticides are exposed to sunlight. Sensitivity to photochemical degradation varies greatly among pesticides. These reactions often occur indirectly as a result of reactions with other chemicals that readily absorb light. Photochemical reactions do not affect pesticides after they migrate into soil because the soil absorbs the radiant energy. However, photochemical reactions can be important in air and water or on soil and plant surfaces. Some of the pesticide that moves into surface waters may be photodegraded, but this process will only degrade pesticide molecules that are near the surface of the water.

Soil, Landscape, and Climatic Factors Affecting Pesticide Movement

The pesticide properties described above – solubility, adsorption, and persistence – interact with soil texture, soil organic matter, pH, and microbial populations to determine whether a pesticide is available to move off-site. If a pesticide is available, off-site movement is largely dependent on water movement, and water movement is determined by factors such as soil hydraulic conductivity, topography, erodibility, and climate.

Soil texture can vary significantly across a watershed, and even within a field. The textural class of a soil is a measure of its relative amounts of sand, silt, and clay, and is determined using the textural triangle. Soils high in sand ("coarse textured" or "light" soils) typically have low organic matter content, low water-holding capacity, and lower microbial populations. These characteristics mean sands have limited capacity to adsorb pesticides and pesticides may persist longer than in clay soils. Consequently, pesticides may be more available for transport with water in sands than in clays. Leaching of pesticides is generally a greater concern than pesticide runoff on sandy soils because of relatively high water infiltration rates. Clay soils have a greater capacity to adsorb pesticides, but adsorption varies greatly among pesticides and with clay type. Expanding clays, such as montmorillonite, generally are more adsorptive than non-expanding clays such as kaolinite. Soils high in clay typically have high water-holding capacity, and if the pesticide remains in the mixing zone, it may be readily available for runoff. Leaching can occur in clay soils, but if water movement is slow enough, most of the pesticide may degrade in the surface 6 to12 inches, limiting the risk of groundwater contamination. Many of the properties of a silt soil are intermediate to those of sand and clay. However, silt particles, like sand, have a very low capacity to adsorb pesticides.

Soil organic matter is a mixture of complex molecules resulting from the decomposition of biological material. It is primarily composed of carbon, hydrogen, oxygen, and nitrogen. Organic matter content can vary widely across a landscape (Figure 4) and within a soil profile. It is typically very low on eroded soil and higher in areas where eroded soil is deposited. All pesticides have some affinity for organic matter because it contains both lipophilic and hydrophilic components. Organic matter content is the most important factor determining pesticide adsorption and availability on soil. Organic matter also has a strong influence on infiltration and soil water holding capacity because of its effect on soil structure.

Soil pH is a measure of the acidity or alkalinity of a soil, and may vary widely across a landscape (Figure 5). As discussed previously, soil pH can have a major influence on the activity of microbial populations, the fate of pesticides sensitive to acid or alkaline hydrolysis, and the potential for acidic pesticides to form anions at a pH above their pKa values. In addition, kaolinitic clays and soil organic matter become more negatively charged as soil pH increases, which can decrease the adsorption of acidic herbicides. Decreases in adsorption or degradation means relatively more pesticide is available for off-site movement.

Soil hydraulic conductivity is a measure of water movement into and through a soil. It is generally measured on soils devoid of vegetation. The amount of precipitation that is absorbed by the soil before runoff occurs depends on soil type and roughness (extent of small depressions). The rate of infiltration into a soil is generally greater in sandy soils or in soils with high organic matter and blocky structure. Infiltration is also affected by the water content at the time of the precipitation or irrigation event (the antecedent water content). If the antecedent water content is high, runoff is more likely to occur. Overland flow occurs when the rainfall rate exceeds the infiltration rate, or when saturated areas near channels produce runoff from incoming rainfall. Interflow (through-flow) occurs via lateral movement through an unsaturated matrix or macropores in the

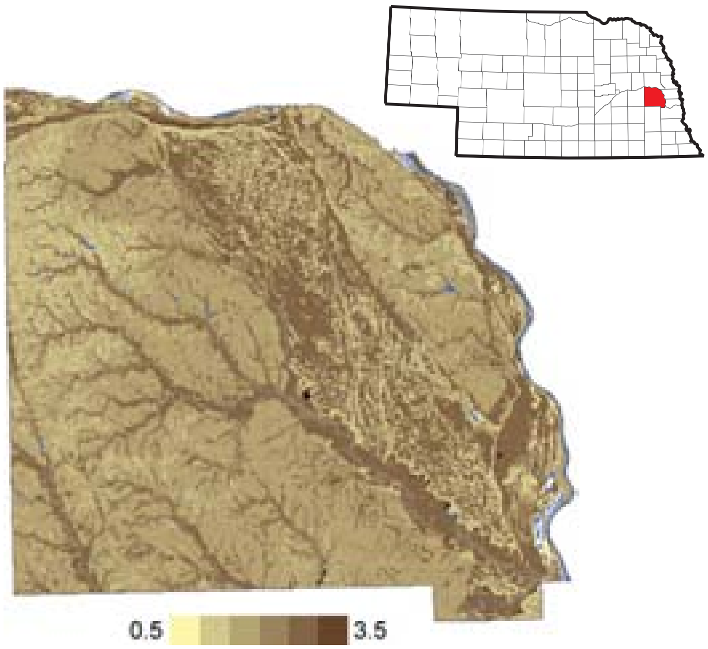

Figure 4. *Map showing the range of soil organic matter content (0.5 to 3.5 percent; 5.0 percent in black) in Saunders County, Nebraska (location shown in map at upper right). Organic matter has accumulated in drainage ways, the Todd Valley (abandoned Platte River Channel) and the current Platte river valley. Water is shown in blue. Gravel pits and dams are not colored.*

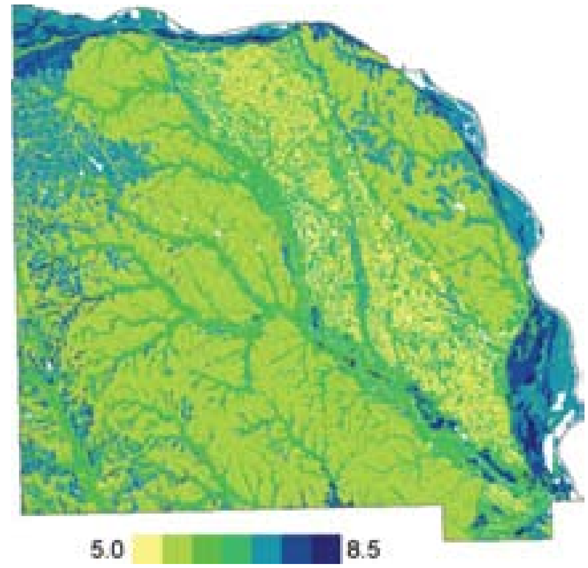

Figure 5. *Map showing range in soil pH (5.0 – 8.5) in Saunders County, Nebraska. Most upland soils in this area tend to be acidic except where erosion has exposed high pH subsoil (NW) and where high pH till is exposed at the surface (SW). The current Platte River channel tends to have alkaline soils. Water, gravel pits and dams are not colored.*

soil. A claypan, perched water table, or groundwater "mounding" can cause subsurface water flow during storm events.

The saturated *hydraulic conductivity* (K_{sat}) is a measure of water movement through saturated soil. It depends on the intrinsic permeability of the soil, which is a function of soil texture and structure. Soils with smaller K_{sat} values are less permeable and more prone to pesticide runoff, especially if rainfall occurs shortly after application.

We usually think of pesticide leaching as gradual movement through small pore spaces. However, water and dissolved chemicals can be rapidly moved to subsoil through shrink-swell cracks and macropores. Soils containing significant amounts of expanding clay will swell as they are wetted and shrink and crack when they dry. Macropores result from worm burrows and decayed root channels. Rainfall or irrigation may rapidly move water and pesticides through these large open spaces in soil.

Topography describes the relief and features of a landscape. The topography of a watershed has a strong influence on how water moves within the area. The topographic aspect determines radiation incidence angle, shading of the terrain, and the direction of gravitational flow. Slope controls the convergence and divergence of surface and subsurface water flows. Gently sloping landscapes may be dominated by subsurface flows while overland flows are more prevalent in landscapes with hills and valleys (dissected landscape). The shape of a catchment area controls the timing of flooding events at the outlet of the basin. Proximity to bodies of surface water and flooding potential are important in determining the potential for pesticide contamination by solution and particle-adsorbed runoff. Vegetative cover, coupled with soil characteristics, can have a large influence on water movement. For example, organic soils with a well-aerated surface horizon and a mature forest cover have infiltration rates so high that little surface runoff occurs in the typical summer storm. A forest canopy cover intercepts a substantial fraction of the initial precipitation, resulting in negligible runoff compared to a land cover disturbed by agricultural activities. In contrast, little water infiltrates on impervious surfaces, and runoff is almost equal to the amount of precipitation, regardless of storm intensity.

Soil erodibility is a measure of the potential of a soil to contribute to particle-adsorbed pesticide runoff. The Revised Universal Soil Loss Equation (RUSLE) is an accepted method to estimate erosion rates and can be used to predict erosion in a watershed. The RUSLE equation follows the form, Erosion (tons/acre/year) = RKLSCP, where R is the rainfall impact coefficient, K is the soil erodibility (a characteristic of texture, structure and organic matter that varies from 0.15 to 0.43 depending upon soil type), LS is a tabular coefficient based on slope length, C is a value based on cropping system and tillage practices, and P is a value based on the increase in in-field sedimentation because of conservation practices such as terraces.

Values for RKLS typically range from 5.3 to 940 tons per acre per year. CP factors vary substantially according to the land cover and tillage practices. For completely bare, plowed ground, the C-value is 1.0. As crops become established, it reduces to 0.05 or less. Typical factors often used for corn vary from 0.63 at seedling stage to 0.26 at maximum growth. Practical values for conservation tillage vary from 0.10 for terraces on flat ground to 0.90 for contouring on steep ground. Strip cropping provides intermediate values in the range of 0.25 to 0.45, depending upon slope.

Climate is the description of temperature, light, wind, and precipitation patterns for a given region. The timing, frequency, and amount of precipitation after pesticide application can have a major influence on the extent of leaching, the concentration of pesticides in runoff water, and the total amount of pesticide lost. The shorter the interval between pesticide application and a precipitation event that causes runoff or leaching, the greater the risk for off-site movement of pesticides. The most critical period, a "window of vulnerability," is usually defined as 10 to 14 days immediately following pesticide application when the potential for pesticide leaching or runoff losses is greatest (Figure 6). The length of the window of vulnerability may be shorter or longer, depending on how quickly the pesticide degrades or adheres tightly to the soil, which is determined by the landscape, soil, and chemical properties discussed.

Climatic factors have their greatest effect on runoff losses when the greatest rainfall potential coincides with the "window of vulnerability." Seasonal rainfall patterns differ regionally and over short distances within an area. Therefore, knowing the potential for the most rainfall, especially high intensity storms, is important in determining when the greatest potential for pesticide runoff losses will be. Avoiding application during this time period can greatly reduce pesticide losses. However, this can be difficult to do. For example, in much of the midwestern United States, the heaviest precipitation events occur from April to June, which coincides with the period when most herbicides are applied. Not applying herbicides may have a negative effect on weed control, but application at this time results in a relatively high risk of pesticide loss because of the high probability of heavy precipitation events.

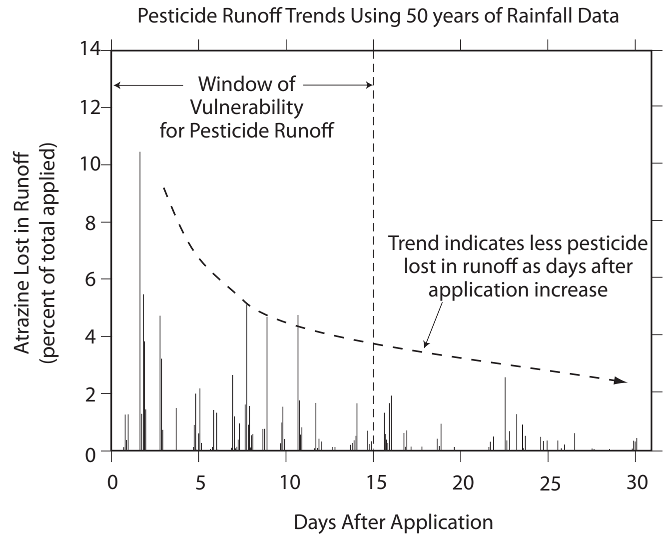

Figure 6. *Percentage of atrazine lost in first runoff event for 50 different years. Trend indicates greatest losses generally result when the first runoff event occurs within 10 to 15 days after pesticide application. [original source: Nebraska Cooperative Extension Circular EC96-145]*

Pesticide Selection

Because the chemical characteristics of pesticides affect their leaching and runoff losses, these factors should be carefully considered when selecting pesticide products. Less mobile (large Koc) and less persistent (short half-life or "low residual") products are less likely to contaminate groundwater and surface water. Thus, pesticides with these properties should be selected when possible, particularly in vulnerable landscapes. If leaching is a concern, it may be possible to use less leachable formulations such as esters rather than salts. Figure 7 shows how the potential for leaching and runoff can vary greatly based on the properties of the selected pesticides.

Protecting our Water Resources

Having defined the major mechanisms and processes that determine the fate of pesticides in the environment, this information can be used to help guide management decisions. Table 1 summarizes factors that may lead to groundwater or surface water contamination. Under each factor is a list of conditions that increase the potential for contamination. The more conditions present, the greater the chances for contamination.

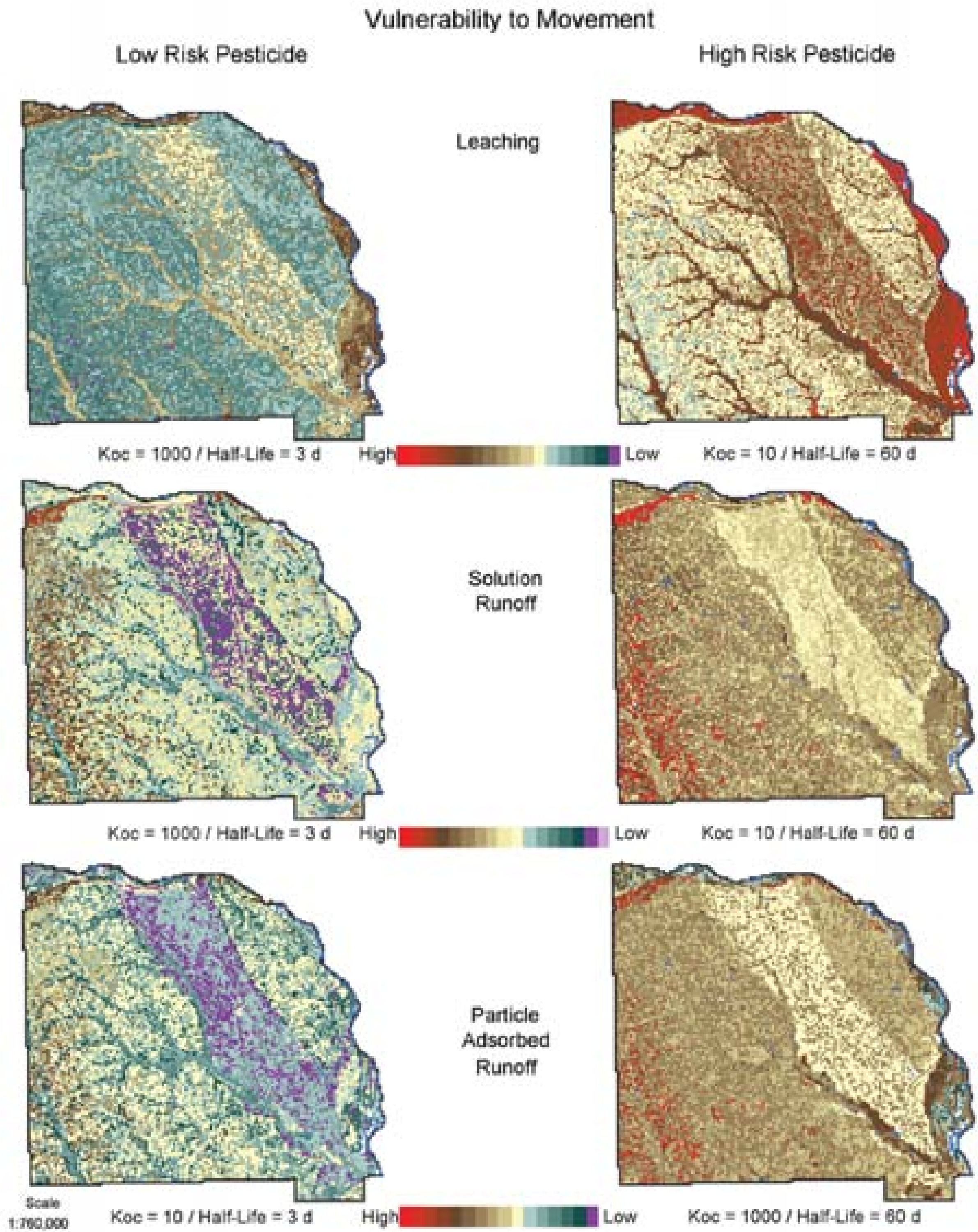

Figure 7. *Landscape vulnerability to pesticide leaching, solution runoff, and particle-adsorbed runoff for low and high risk pesticides in Saunders County, Nebraska. Output was developed from independent models describing vulnerability to leaching, solution runoff, or movement with soil particles. Water, gravel pits and dams are not colored.*

A primary concern when applying pesticides is to determine if the application site is vulnerable to groundwater or surface water contamination. In most instances, if the field is level and not close to surface waters, the chances for pesticide runoff will be minimal. If the depth to groundwater is great on fine-textured soils, the chances for deep percolation are reduced, while sandy soils low in organic matter are highly vulnerable to pesticide leaching. Informed pesticide selection and management decisions are critical to protecting water resources. The next chapter focuses on using best management practices to prevent off-site movement and contamination of water by pesticides.

Table 1. Factors contributing to greater risk for surface and groundwater contamination from pesticides.		
Water Quality Risk Factors	**Surface Water**	**Groundwater**
Pesticide		
• high solubility in water	X	X
• low soil adsorption coefficient (indicated by small Koc value)	X	X
• long persistence (indicated by a large half-life value)	X	X
Soil		
• highly permeable soil or soil with preferential flow through macropores, cracks, and root channels		X
• low organic matter content	X	X
Site		
• shallow water table		X
• sloping land	X	
• proximity to streams, ponds and other water bodies	X	

For More Information

Pesticide Runoff & Water Quality in Nebraska, Nebraska Cooperative Extension Circular EC96-145 (out of print; available at *www.oznet.ksu.edu/waterquality/Pest%20Workshop/Pesticide%20Runoff%20and%20WQ%20in%20NE%20(EC%2096-143).PDF*)

Understanding Pesticides and Water Quality in Nebraska, Nebraska Cooperative Extension Circular EC94-135 (out of print; available at *www.oznet.ksu.edu/waterquality/Pest%20Workshop/Pesticides%20and%20WQ%20in%20NE%20(EC%2094-135).PDF*)

Pesticide Movement: What Farmers Need to Know, Iowa State University Extension PAT 36 June 1999 (available at *http://www.extension.iastate.edu/Publications/PAT36.pdf*)

Reference

Winter, T.C. 2001. The concept of hydrologic landscapes. J. Amer. Water Resources Association 37:335-349.

Chapter 3. Using Best Management Practices to Prevent Off-Site Movement of Pesticides

Pesticide BMPs are designed to minimize pesticide runoff and leaching and maximize the benefit of the pesticide to the farmer. BMPs are designed to: (1) apply the most effective pesticide and rate to be used in a field; (2) reduce the availability of pesticides for loss before, during, and after application; (3) provide a mechanism for deposition of the pesticide before it leaves the field; and (4) reduce the impact of the first runoff event on pesticide loss. BMPs include the place, time, method, and rate of pesticide application, and physical and vegetative barriers to pesticide transport in runoff and erosion.

During and after rainfall, pesticides can leave the field through a number of mechanisms. These mechanisms include: 1) leaving the field by surface runoff or soil erosion; 2) infiltrating the soil and migrating downward to groundwater; and 3) infiltrating into the soil and eventually leaving through subsurface flow or through tile drainage lines. These mechanisms are discussed in detail in Chapter 2.

Each individual pesticide and pesticide chemical family has unique chemical characteristics that influence which BMPs are most effective at preventing its movement. As discussed in Chapter 2, the most important chemical characteristics are adsorption and persistence. Adsorption is the chemical's tendency to bind or "stick" to soil particles, primarily clay and organic matter. Pesticides, such as trifluralin and glyphosate, that are tightly bound to soil particles (strong adsorption) are most likely to leave the field with eroding soil particles. Pesticides, such as atrazine or metolachlor, that are less strongly adsorbed, are more likely to leave the field dissolved in runoff water.

BMPs, such as conservation tillage and other conservation practices, that reduce soil losses from fields, are effective at reducing water contamination by pesticides that are tightly adsorbed to soil particles. However, controlling erosion is less effective at reducing water contamination by pesticides that are less tightly bound and more commonly lost through runoff or leaching. Most pesticides found in surface water or groundwater are only moderately adsorbed.

This chapter describes BMPs that may be effective for a broad range of pesticides. For a specific pesticide or situation, contact your local extension office for additional information.

Reducing Pesticide Availability

Incorporate pesticides. This is a viable BMP for pesticides, such as atrazine, that move off fields in runoff water. Incorporation with a tillage implement before planting the crop reduces the amount of pesticide left on the soil surface and available for runoff. This BMP should only be used if tillage is planned and the pesticide incorporation can be part of a planned tillage operation. Using tillage unnecessarily can lead to increased soil erosion.

Delay applications when soil is saturated or rainfall predicted. Pesticide concentrations in runoff depend on how saturated the soil is at application, the interval between herbicide application and the first runoff event, and the intensity and amount of rainfall. The first runoff event following application is responsible for most pesticide runoff. Peak rainfall intensity occurs in mid- to late May, and the majority of runoff occurs between April and early July. It is common to have soils saturated during those times of the season. The greatest pesticide loss in runoff water occurs when rainfall immediately follows pesticide application to wet soil. If rain is expected, pesticide application should be delayed until there is less chance of a storm. This is most critical for poorly drained soils on sloping land. Chapter 2 discusses soil and landscape factors affecting runoff.

Using band applications of pesticides rather than broadcast applications. Banding herbicides or other pesticide applications over the row as a 10- to 15-inch band reduces the total amount of pesticide applied to field, resulting in a corresponding reduction in pesticide runoff or leaching compared to a broadcast surface application without incorporation. Banding can also reduce pesticide costs. If using herbicides for weed control, weeds in the untreated middle of the rows can be removed by in-season cultivation. This system works well for ridge tillage and other situations where cultivation may be used.

Use integrated pest management strategies. Integrated pest management strategies combine prevention, suppression, monitoring, and pesticides to control pests while minimizing the amount of pesticide used. Crop rotation, preplant tillage, in-season cultivation, hand-roguing, changes in row spacing, planting date, or seeding rate, crop scouting, cover crops, variety/hybrid selection, and spot treatments can reduce pest infestations, improve a crop's ability to compete with a pest, and reduce the amount of pesticide needed.

Buffer zones. Establish buffer zones around wells and surface water (50 to 100 feet is recommended) where pesticides are not applied. Some pesticides also have setback buffer requirements on their labels.

Alternative pesticides. If a specific pesticide is a leaching or runoff concern, that pesticide might be replaced with an alternative pesticide that reduces environmental risk.

Light irrigation after application. In fields with sprinkler irrigation available, a light sprinkler irrigation following application incorporates a soil pesticide (example, atrazine herbicide) and reduces runoff by moving some of the pesticide off the soil surface where it is vulnerable to runoff. This BMP is not effective if the soil surface is saturated.

Distance and separation of pesticide application from water. For sprayer loading, storing, use, and during cleanup stay a minimum of 50 feet and preferably 100 feet from wells. Also, leave a buffer zone around sensitive areas, such as streams, ponds, buildings, wells, wetlands, where applications are prohibited.

Use proper mixing, loading, and disposal practices. Mix or load in the field or on an impervious pad to minimize risks of spills, leaks, or rinse water contaminating water resources. Use backflow prevention devices when filling sprayers or mixing tanks. Triple rinse empty containers. Do not drain rinse water into ditches, ponds, lakes or other water sources.

Using Conservation Practices and Structures

Conservation practices and structures that slow or reduce water runoff and soil erosion from a field will reduce pesticide runoff. Most conservation practices and structures reduce soil erosion, but may not adequately reduce solution runoff.

Reduced and no-till. Adoption of continuous no-till farming results in an increase in the number, size, and stability of soil aggregates. There is an increase in macropores (spaces between soil aggregates) and root and earthworm channels, which may increase water movement through the surface of the soil profile, possibly increasing the potential for pesticide leaching under no-till farming. However, studies in the heartland region have not found greater pesticide leaching under no-till conditions.

Reducing tillage and increasing surface residue has been shown to significantly reduce soil erosion and nutrient runoff. Reducing tillage and soil erosion reduces the potential for pesticide runoff for those pesticides tightly adsorbed to soil particles. However, for pesticides that are only moderately attached to soil, tillage systems that minimize tillage and maximize surface residue may have a variable impact on runoff losses. For most soils, adopting reduced or no-till systems will increase water infiltration and reduce pesticide runoff. However, on some soils, particularly those that have clay surface and/or subsoils, research has shown that both water and pesticides lost in water may increase. In addition, fields that are in no-till or reduced tillage tend to be wetter in the spring at the time of pesticide application and so may be more prone for greater water and pesticide runoff.

Establish vegetative and riparian buffer areas. Vegetative and riparian buffer areas include grass waterways, field boundaries, and areas along streams and ponds. Buffers are effective at slowing runoff and collecting soil particles from erosion. Therefore, buffers are very effective at trapping pesticides adsorbed to soil particles before leaving the field in runoff. Vegetative and riparian buffers may reduce the amount of water runoff by increasing infiltration of runoff water within the buffer. To the extent that water infiltrates into the buffer strip soils, loss of pesticides that leave the field in solution will be reduced. Vegetative buffers are most effective at reducing water (and pesticide) runoff if the water is spread evenly as it flows across the filter. Many grass waterways concentrate runoff and are not highly effective for reducing pesticide runoff.

Water and sediment control basins. Water and sediment control basins slow and store water and trap soil particles from erosion. Basins are especially effective at reducing soil-bound pesticide losses, and can be effective at reducing other pesticides in runoff water. Basins are most effective when they store water until soil infiltration or evaporation occurs.

Contour farming. Field and planting operations performed at or nearly perpendicular to the slope of the land results in decreased sheet and rill erosion by creating furrows or small ridges perpendicular to the slope. Contour farming also increases the time between onset of rainfall and initiation of runoff, which allows time for some of the pesticide to be moved below the soil surface and reduces pesticide runoff.

Gradient terraces. Gradient terraces are designed to reduce the slope length, erosion, and soil content in runoff water. These terraces are designed to divert runoff to a suitable outlet, such as a grassed waterway. Gradient terraces reduce soil erosion (and subsequent movement of soil-bound pesticides). They may also result in a slight reduction in water runoff from the field by increasing infiltration in the terrace channel.

Tile outlet terraces. Tile outlet terraces are similar to gradient terraces except that water collected in the terrace is diverted from the field through a tile outlet. Tile outlet terraces do an excellent job of reducing soil erosion. However, only a slight reduction occurs in water runoff. Tile outlets that empty directly into a roadside ditch or stream may actually result in increased pesticide losses into surface waters. Moving tile outlets away from surface waterways and spreading out the discharge from the tile outlets across a grass buffer may reduce pesticide runoff losses to surface water.

For More Information

Atrazine Best Management Practices in the Little Arkansas River Watershed, Kansas State University Research and Extension MF-2768, *www.oznet.ksu.edu/library/crpsl2/mf2768.pdf*

Best Management Practices for Atrazine, Kansas State University Research and Extension MF-2182, *www.oznet.ksu.edu/library/h20ql2/mf2182.pdf*

Managing to Minimize Atrazine Runoff, Kansas State University Research and Extension MF-2208, *www.oznet.ksu.edu/library/crpsl2/mf2208.pdf*

Atrazine Management and Water Quality, University of Missouri Extension M167, *http://extension.missouri.edu/explorepdf/manuals/m00167.pdf*

Understanding and Reducing Pesticide Losses, Iowa State University Extension PM1494, *www.extension.iastate.edu/Publications/PM1495.pdf*

Chapter 4. Pesticide Regulations

The U.S. EPA regulates the use of pesticides under the authority of two federal statutes: the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA).

The *Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)* provides the basis for regulation, sale, distribution, and use of pesticides in the United States. FIFRA authorizes the U.S. EPA to review and register pesticides for specified uses. The U.S. EPA also has the authority to suspend or cancel the registration of a pesticide if subsequent information shows that continued use would pose unreasonable risks.

The *Federal Food, Drug, and Cosmetic Act (FFDCA)* authorizes the U.S. EPA to set maximum residue levels, or tolerances, for pesticides used in or on foods or animal feed.

Other relevant pesticide legislation includes the Endangered Species Act, the Food Quality Protection Act of 1996, and the Pesticide Registration Improvement Act of 2003.

The *Endangered Species Act (ESA)* of 1973 prohibits any action that could adversely affect an endangered or threatened species or its habitat. In compliance with this law, the U.S. EPA must ensure that the use of pesticides it registers will not result in harm to the species listed as endangered or threatened by the U.S. Fish and Wildlife Service, or to habitat critical to those species' survival.

The *Food Quality Protection Act of 1996 (FQPA)* amended FIFRA and FFDCA setting tougher safety standards for new and old pesticides and to make uniform requirements regarding processed and unprocessed foods.

The *Pesticide Registration Improvement Act (PRIA) of 2003* establishes fees for pesticide registration actions in three U.S. EPA pesticide program divisions: antimicrobials, biopesticides and pollution prevention, and the registration divisions.

Pesticide Registration

As required by FIFRA, the U.S. EPA must evaluate pesticides thoroughly before they can be marketed and used in the United States to ensure that they will meet federal safety standards to protect human health and the environment. Pesticides that meet the requirements are granted a license or "registration" that permits their distribution, sale, and use according to specific use directions and requirements identified on the label.

The process of registering a pesticide is a scientific, legal, and administrative procedure through which the U.S. EPA examines the ingredients of the pesticide; the particular site or crop on which it is to be used; the amount, frequency, and timing of its use; and storage and disposal practices. In evaluating a pesticide registration application, the U.S. EPA assesses a wide variety of potential human health and environmental effects associated with use of the product. The producer of the pesticide must provide data from tests done according to U.S. EPA guidelines.

These tests evaluate whether a pesticide has the potential to cause adverse effects on humans, wildlife, fish, and plants, including endangered species and nontarget organisms, as well as possible contamination of surface water or groundwater from leaching, runoff, and spray drift. Potential human risks range from short-term toxicity to long-term effects such as cancer and reproductive system disorders. The U.S. EPA also must approve the language that appears on each pesticide label. A pesticide product can only be used legally according to the directions on the label accompanying it at the time of sale. Following label instructions carefully and precisely is necessary for safety and effective pesticide use.

After a pesticide is registered by the U.S. EPA, states can register pesticides under specific state pesticide registration laws. A state may have more stringent requirements for registering pesticides. States also may issue a special local need registration (Section 24(c) registration) for additional uses of federally registered pesticides to meet special local needs or to implement more restrictive labeling under certain circumstances. Ultimately, most states have primary responsibility for pesticides used within their borders.

Pesticide Registration Review

The new registration review program, mandated under the Food Quality Protection Act, ensures that as the ability to assess risk evolves and policies and practices change, all registered pesticides continue to meet the statutory standard of no unreasonable adverse effects.

Changes in science, public policy, and pesticide use practices will occur over time. Through the new registration review program, the U.S. EPA periodically reevaluates pesticides to ensure that, as change occurs, products in the marketplace can still be used safely. The registration review program challenges the U.S. EPA to continuously improve its processes, science, and information management while maintaining a collaborative and open process for decision making.

The Pesticide Label

All label language must be approved by the U.S. EPA before a pesticide can be sold or distributed in the United States. The overall intent of the label is to provide clear directions for effective product performance while minimizing risks to human health and the environment. It is a violation of federal law (FIFRA) to use a pesticide in a manner inconsistent with its labeling. The courts consider a label to be a legal document. As previously indicated, following label instructions carefully and precisely is necessary for safety and efficacy.

Pesticide Water Quality Monitoring

Our nation's waters are monitored by state, federal, and local agencies, universities, dischargers, and volunteers. Water quality data are used to characterize waters; identify trends over time; identify emerging problems; determine whether pollution control programs are working; help direct pollution control efforts to where they are most needed; and respond to emergencies such as floods and spills. The following are examples of various national data warehouses that combine water quality monitoring data from one or more sources:

National Water Information System
http://waterdata.usgs.gov/nwis

Provides data from more than 1.5 million sites around the country, including real-time and historic streamflow and stage data, groundwater levels, water quality data, and site information

National Stream Quality Accounting Network
http://water.usgs.gov/nasqan/

Provides ongoing characterization of the concentrations and flux of sediment and chemicals in the nation's largest rivers.

National Water Quality Assessment (NAWQA)
http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:4910671651266958

The U.S. Geological Survey (USGS) began its NAWQA program in 1991, systematically collecting chemical, biological, and physical water quality data from 42 study units (basins) across the nation.

STORET
http://www.epa.gov/storet/

STORET (short for STOrage and RETrieval) is a repository for water quality, biological, and physical data.

Pesticide Storage and Disposal

Improper pesticide storage and disposal can be hazardous to human health and the environment. FIFRA governs the sale, distribution and use of pesticides in the United States. Pesticides are regulated under FIFRA until they are disposed, after which they are regulated under the Resource Conservation and Recovery Act (RCRA), which requires responsible management of hazardous and nonhazardous waste. Some, but not all, pesticides are regulated as hazardous waste when disposed. The U.S. Department of Transportation (DOT) regulates the transport of hazardous materials. Some, but not all, pesticides are regulated as DOT hazardous materials while in commerce.

Pesticide Storage

In general, the following recommendations should be followed when storing pesticides:

- Do not stockpile. Reduce storage needs by buying only the amount of pesticide that you will need in the near future or during the current season.
- Follow all storage instructions on the pesticide label.
- Store pesticides on shelves high enough so that they are out of reach of children and pets. If possible, keep all pesticides in a locked cabinet in a well-ventilated utility area or garden shed.
- Never store pesticides in cabinets with or near food, animal feed, or medical supplies.
- Store flammable liquids outside your living area and far away from an ignition source such as a furnace, car, truck, tractor, outdoor grill, or power lawn mower.
- Always store pesticides in their original containers, which includes the label listing ingredients, directions for use, and first aid steps in case of accidental poisoning.

- Never transfer pesticides to soft drink bottles or other containers. Children or others may mistake them for something to eat or drink.
- Use child-resistant packaging correctly – close the container tightly after using the product. Child resistant does not mean child proof, so you still must be extra careful to store properly – out of children's reach – those products that are sold in child-resistant packaging.
- Do not store pesticides in places where flooding is possible or in places where pesticides might spill or leak into wells, drains, groundwater, or surface water.
- If you cannot identify the contents of the container, or if you cannot tell how old the contents are, follow the advice on safe pesticide disposal.

Safe Pesticide Disposal

Pesticide disposal recommendations and regulations vary significantly by the type of facility and the state in which the facility is located. For information concerning pesticide waste disposal, contact one of the states in the U.S. EPA Region 7:

- **Kansas** – Kansas Department of Health and Environment (KDHE), Bureau of Waste Management, 785-296-1600
- **Missouri** – Missouri Department of Natural Resources (MDNR), Hazardous Waste Program (HWP), 573-751-3176
- **Nebraska** – Nebraska Department of Environmental Quality (NDEQ), Waste Management Section, 402-471-4210
- **Iowa** - The Iowa Department of Natural Resources (IDNR) does not regulate hazardous wastes. Instead, U.S. EPA Region 7 oversees these requirements. Call toll-free at 800-223-0425

In general, the following recommendations should be followed when disposing of pesticides:

- Small amounts of excess pesticides should be entirely used during the application process according to the directions on the label. If you have excess pesticides that you cannot use, ask your neighbors whether they have a similar pest control problem. If so, your neighbor can use the excess pesticide according to directions on the label.
- If all of unwanted excess pesticides cannot be properly used, check with your local solid waste management authority, environmental agency, or health department to find out whether your community has a household hazardous waste collection program or a similar program for disposal of unwanted, leftover pesticides. State and local laws regarding pesticide disposal may be stricter than the federal requirements on the label. These authorities can also inform you of any local requirements for pesticide waste disposal.
- If the container is partially filled, contact your local solid waste agency.
- If the container is empty, do not reuse it. Place it in the trash, unless the label specifies a different procedure (i.e., triple rinsing).
- Do not pour leftover pesticides down the sink, into the toilet, or down a sewer or street drain. Pesticides may interfere with the operation of wastewater treatment systems or pollute waterways. Many municipal systems are not equipped to remove all pesticide residues. If pesticides reach waterways, they may harm fish, plants, and other living things.

Relevant Links

www.epa.gov/pesticides/
U.S. Environmental Protection Agency Pesticides

www.agr.ne.gov/division/bpi/pes/water_quality.pdf
Nebraska Department of Agriculture's Pesticide Label Database: Water Quality Restrictions

www.purdue.edu/dp/envirosoft/pest/src/title.htm
Pesticide Handling and Storage Practices on the Farm (Purdue University)

http://npic.orst.edu
National Pesticide Information Center

www.epa.gov/agriculture/llaw.html
Major Existing U.S. EPA Laws and Programs that Could Affect Agricultural Producers

Glossary

active ingredient – the toxic agent in a pesticide product.

adsorption - retention of a chemical onto the surface of a soil particle.

antecedent water content - relative wetness of the soil immediately preceeding a precipitation or rainfall event.

desorption – the detachment of a pesticide from a soil particle.

dissected landscape – a landscape characterized by hills and valleys.

erodibility – a measure of the potential of a soil to contribute to particle-adsorbed pesticide runoff.

groundwater – water which saturates cracks, sand, gravel and other porous subsurface rock formations (a groundwater resource is referred to as an aquifer when a usable quantity of water is provided)

half-life - time required for one-half of the original pesticide to be degraded into another compound (degradation product, metabolite, or intermediate).

hydraulic conductivity – a measure of water movement through soil that is dependent on the intrinsic permeability of the soil.

hydrolysis – a chemical degradation process resulting from the reaction of a pesticide with water under acidic or alkaline conditions.

infiltrate, infiltration - process of water (from precipitation or irrigation) penetrating into or entering the surface of the soil profile.

leaching – downward movement of a pesticide through soil.

macropore - large diameter conduits in the soil, created by plant roots, soil fauna, or cracks due to soil shrinking and swelling. Macropores increase the hydraulic conductivity of the soil, allowing water to infiltrate faster or for shallow groundwater to flow faster.

maximum contaminant level (MCL) - an enforceable, regulatory health-based standard for maximum permissible concentrations of a pesticide or contaminant in drinking water. MCLs are established under the federal Safe Drinking Water Act.

mixing zone - top ¼ to ½ inch of a soil profile where runoff water penetrates, mixes, and carries away dissolved pesticides.

organic carbon partition coefficient – a universal constant used to describe the tendency of a pesticide to adsorb to the soil organic fraction component of a soil (often abbreviated as Koc).

particle-adsorbed runoff – movement of adsorbed pesticide with soil particles off an application site.

persistence - the length of time a pesticide will remain in the soil before being degraded.

photodecomposition (photodegradation) – breakdown of pesticides from exposure to sunlight.

pKa – the dissociation constant of a pesticide that can lose or gain a proton and the pH at which the relative numbers of charged and uncharged pesticide molecules are the same.

precipitation – deposition of moisture from the atmosphere upon the earth as rain or snow.

RUSLE –Revised Universal Soil Loss Equation, an accepted method to estimate erosion rates and can be used to project erosion in a watershed.

soil adsorption coefficient (Kd) – a unit of measure used to describe the tendency of a pesticide to adsorb to a soil.

solubility - maximum amount of chemical that can be dissolved in water (aqueous solubility) or another solvent.

solution runoff – movement of dissolved pesticide off an application site with water flowing at the surface.

topographic aspect – the direction to which a sloping landscape is facing.

topography – the relief and features of a landscape, including vegetative cover.

total maximum daily load (TMDL) - a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources.

vapor pressure – the numerical unit of measure used to indicate the tendency of a pesticide to volatilize (become a gas). Common units of measure for vapor pressure are Pascals (Pa) or millimeters of mercury (mm Hg).

volatilization - the process by which chemicals transform from a liquid to a gas.

window of vulnerability - timeframe when pesticide runoff is most susceptible to post-application precipitation events. The window of vulnerability is typically 10 to 14 days following pesticide application.

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned.

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