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EC96-143 Pesticide Runoff and Water Quality in Nebraska

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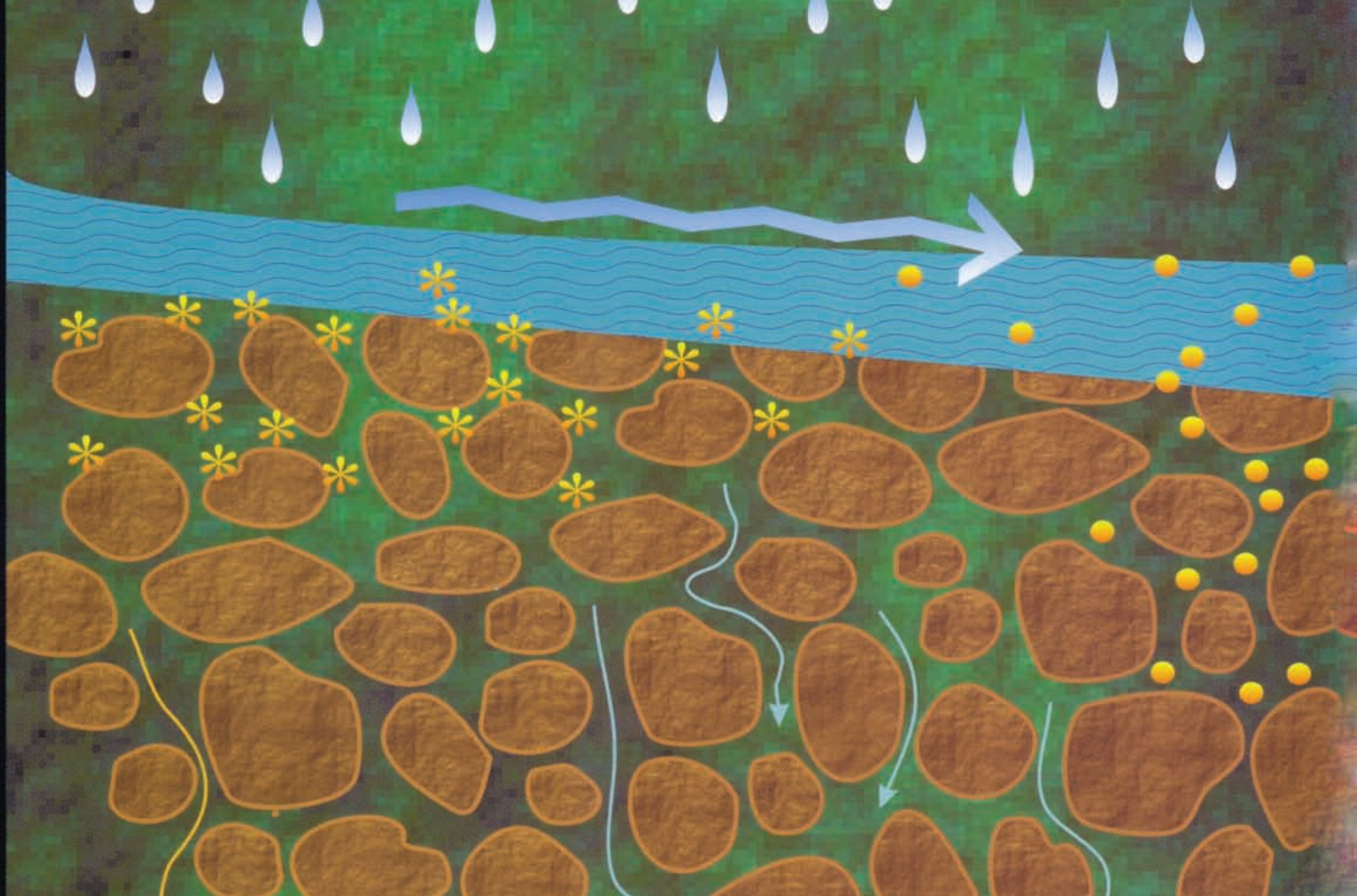
NEBRASKA COOPERATIVE EXTENSION

PESTICIDE RUNOFF

& WATER QUALITY IN NEBRASKA



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Pesticide Runoff & Water Quality in Nebraska

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Nebraska's natural resources provide its residents with an abundance of wildlife, recreation, and agricultural opportunities. Some of the state's most important resources are its lakes, rivers and streams. Nebraska has approximately 16,000 miles of streams and 500 publicly owned or accessible lakes and reservoirs covering approximately 152,000 acres. These surface waters provide year-round habitat for aquatic and terrestrial wildlife, rest stops for migratory birds, and countless hours of enjoyment for outdoor enthusiasts. In addition, surface waters provide a source of drinking water for many Nebraska residents, and are vital for some farming and industrial operations.

The proximity of some surface waters to agriculture and industry has led to runoff or inadvertent discharges of certain chemicals into rivers and lakes. Occasionally, concentrations of pesticides in surface waters have exceeded established drinking water standards or ***maximum contaminant levels*** (**MCL**)* set by the U.S. Environmental Protection Agency (EPA). A series of studies conducted by the United States Geological Survey (USGS) between 1983 and 1992 indicated that in Nebraska's Big Blue River Basin, 369 of 385 (96 percent) surface water samples had detectable concentrations of atrazine. Atrazine concentrations ranged between 0.05 to 166 parts per billion (ppb) with an average concentration of 2.7 ppb. The MCL for atrazine is 3.0 ppb. Additional research conducted near Louisville, NE indicated that during five days in May 1992, the average discharge-weighted atrazine concentration in the Platte River exceeded 12 ppb. These reports, as well as others, confirm that some surface waters throughout Nebraska have been contaminated from pesticide runoff, and on occasion, pesticide concentrations in surface waters have exceeded established MCL's.

To better understand how surface waters become contaminated from pesticide runoff, the various factors and processes influencing runoff must be understood. With this understanding, pesticide applicators will be able to manage pesticides more efficiently and reduce the potential for surface water contamination.

Computer Model Simulations of Pesticide Runoff

One of the best ways to determine which factors influence pesticide runoff is by conducting field experiments that measure runoff losses under various conditions. Unfortunately, this process is expensive, labor intensive, and not practical for every soil, pesticide, and management practice used in Nebraska.

A vast amount of research has been conducted on pesticide behavior in soils. Often this research has focused on defining fundamental relationships between one aspect of pesticide behavior (such as pesticide degradation, mobility, or adsorption) and one soil or environmental variable (soil organic matter, temperature, or irrigation schedules). Defining these relationships is helpful, but this situation is unlike a farmer's field where many soil properties and environmental conditions may change with depth, location or time. To understand how the many factors contributing to pesticide runoff are related, a number of computer simulation models have been developed. A pesticide runoff model is a tool that can be used to sort out some of the complexity encountered in "real-life" situations by allowing one to evaluate how various factors and environmental conditions influence pesticide runoff.

In this extension circular, we used the computer simulation model ***GLEAMS*** (***G***roundwater ***L***oading ***E***ffects of ***A***gricultural ***M***anagement ***S***ystems) to provide examples on how pesticide properties, rainfall patterns, and pesticide rate and method of application influence pesticide runoff. Because rainfall intensity and amounts can vary from year to year, multiple year simulations were conducted to provide a more accurate picture of long-term pesticide runoff trends. In some of the examples shown, long-term trends were obtained by using 50-year rainfall patterns for southeastern Nebraska, near York County. Unless indicated, predictions of pesticide runoff loses were ob-

*Words used in bold italic print are defined in **Glossary of Terms** on page 12.

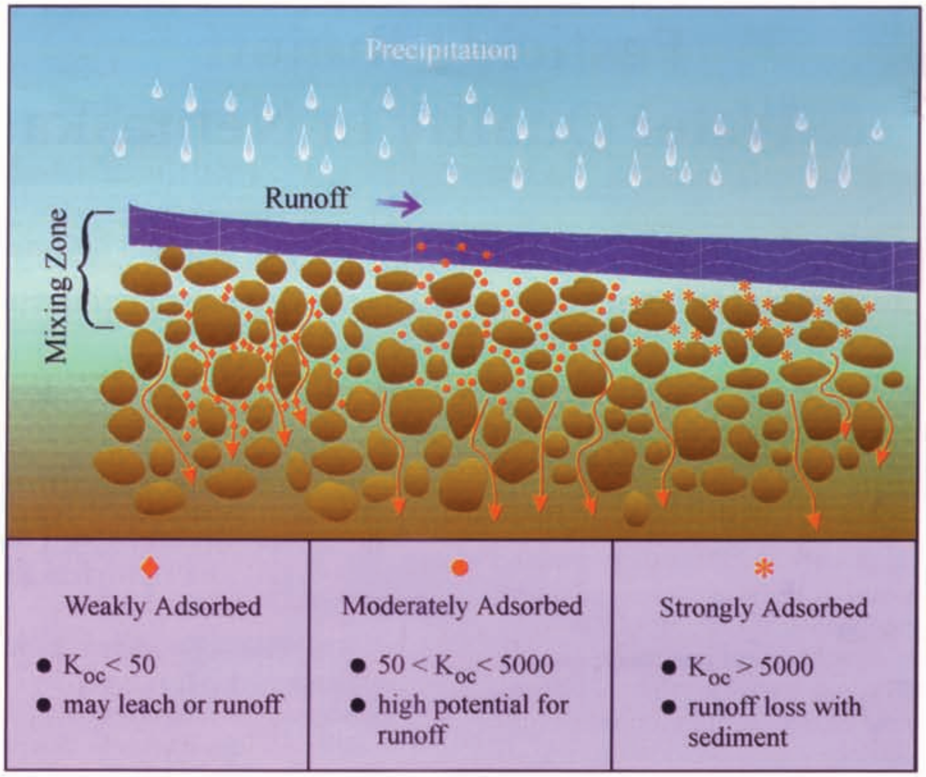

Figure 1. **Diagram illustrating mixing zone, typically the top 1/4 to 1/2 inch of soil. Pesticide K_{oc} values can potentially influence the amount of pesticide available in the mixing zone.**

tained from computer simulations that assumed standard farming operations for irrigated continuous corn production *(Table I)*. Pesticide, field and soil characteristics used in computer model predictions are provided in *Table II*.

Because soil type, field and climatic conditions are diverse in Nebraska, it is important to recognize that the actual runoff results presented may not be what is observed in your field or other locations. The examples provided are meant to show the *relative differences* in pesticide runoff when various factors such as pesticide characteristics, timing of application and rainfall, and management practices are changed. In many cases, these relative differences would occur for other soil types and field conditions found in Nebraska.

Factors Influencing Pesticide Runoff

After water from rainfall or irrigation contacts soil, it can follow several routes. The ***precipitation*** or irrigation falling on the soil may:

- leave the field by surface runoff to streams and lakes;
- ***infiltrate*** the soil and eventually return to surface water through tiles drains, subsurface flow, seepage;
- infiltrate the soil and continue to migrate downward through the soil profile and recharge underground water sources (***aquifer***, ***groundwater***); or
- leave the field through ***evaporation*** or plant uptake and ***transpiration***.

Runoff begins when precipitation exceeds the rate at which water can enter the soil (infiltration rate) and overcomes the surface storage capacity from residue cover. As runoff water leaves the field, it can carry soil particles and dissolved chemicals including fertilizers and pesticides. Research has shown that the first runoff event after pesticide application generally contains the highest pesticide concentration and accounts for most pesticide loss. Annual pesticide loss in runoff is usually less than 5 percent of the total amount applied. Although total annual losses from runoff may seem small, it is important to recognize that surface runoff losses usually far exceed leaching losses (which typically range between 0.01 to 0.5 percent). Also, when small percentages of pesticide applications are lost in runoff from large acreages (i.e. watershed), considerable amounts of pesticide may accumulate in surface water. Therefore, reducing total annual pesticide runoff losses from your fields by even one percent or less can help to improve surface water quality.

The timing, frequency and amount of precipitation after pesticide application can have a major influence on the concentration of pesticides in runoff water and the total amount lost. Studies have shown that rainfall interacts with the top 1/4 to 1/2 inch of soil. This thin surface layer is called the ***mixing zone*** *(Figure 1)* and pesticides that are in this mixing zone are potentially available to be carried away in runoff water.

Factors that influence how much of a pesticide will be present in the mixing zone and lost during a runoff event include:

- Pesticide characteristics
- Pesticide management practices
- Timing, frequency and amount of rainfall/irrigation

Pesticide Characteristics

To a large extent, the chemical characteristics of pesticides determine how they behave in the environment. Three of the most important pesticide characteristics influencing runoff are **solubility**, **adsorption**, and persistence as indicated by **half-life**.

Solubility and Adsorption

The extent to which a chemical will dissolve in a liquid is referred to as solubility. Solubility is often numerically expressed in units of "parts per million" (ppm), that is, *one part* (ounce, pound, cup) pesticide in *one million parts* water. The EPA considers compounds with solubilities greater than 30 ppm as having a high tendency to leach through soil or move with surface runoff.

Although solubility is usually a good indicator of pesticide mobility, it is not necessarily the best criterion for predicting runoff. What determines the extent to which a pesticide will leach downward or leave a field in runoff water is the pesticide's relative tendency to adhere (adsorb) to soil particles.

Generally, pesticide solubility and adsorption are inversely related; as solubility increases, adsorption generally decreases. Notable exceptions to this rule include the compounds paraquat, diquat, and glyphosate (Roundup). Although these compounds are quite soluble, their chemical structure makes them adhere tightly to soils.

Most pesticides are adsorbed by the organic matter fraction of soils. Organic matter is a complex mixture made up largely of decayed plant material that coats soil particles in the surface layers (horizons) of a soil profile and tends to act as an oil-like film. Adsorption of most pesticides can be viewed as a process in which relatively less water-soluble pesticides attempt to escape the water of the soil solution and enter the oil-like environment of organic matter. This action is relatively nonspecific and is analogous to oil and water separating out after mixing. The degree to which this process occurs depends on the amount of organic matter present. The more organic matter in the soil, the more likely the less-soluble pesticides will be adsorbed and the less likely they will leave the field with runoff water. It is also important to recognize that organic matter contributes to the **cation exchange capacity** of soils, a characteristic that is important for the retention of **basic and cationic pesticides**.

Soil organic matter content can vary considerably among soil types, locations and with depth. Since organic matter content greatly influences pesticide adsorption, the amount of adsorption that occurs for a particular pesticide can vary considerably from soil to soil. To reduce some of this variability and provide a method for comparing pesticide adsorption, pesticide adsorption is often expressed as **organic carbon partition coefficients (K_{oc})**. Pesticide K_{oc} values reflect how tightly pesticides will adsorb to the *organic matter* in soils and provide a universal index for comparing adsorption. Pesticides with higher K_{oc} values have a greater tendency to be adsorbed to the organic matter in soil and are less likely to be lost with runoff water. (For more information on Pesticide K_{oc} values see Extension Circular EC94-135, *Understanding Pesticides and Water Quality in Nebraska*).

Pesticide loss in runoff can occur by two processes: (1) Pesticides can be dissolved in the soil solution and carried away with the runoff water; and/or (2) pesticides can be adsorbed to eroding soil particles that are transported off the field with the runoff water. Pesticide K_{oc} values are extremely important in predicting the amount and manner in which pesticides will be lost with runoff. *Figure 2* illustrates the relationship between pesticide K_{oc} values and the percentage of pesticide lost in runoff water. A general rule of thumb is that pesticides with K_{oc} values less than 5,000 will not be tightly adsorbed to soil and will be largely lost with runoff water. Pesticides with K_{oc} values greater than 5,000 are likely to be strongly adsorbed to soils and primarily lost with sediment. Sediment is the term used to describe the soil that has left the field with the runoff water. It is important to remember that not all soil particles transported by runoff water may leave the field, some soil (containing adsorbed pesticides) may be redeposited within the same field.

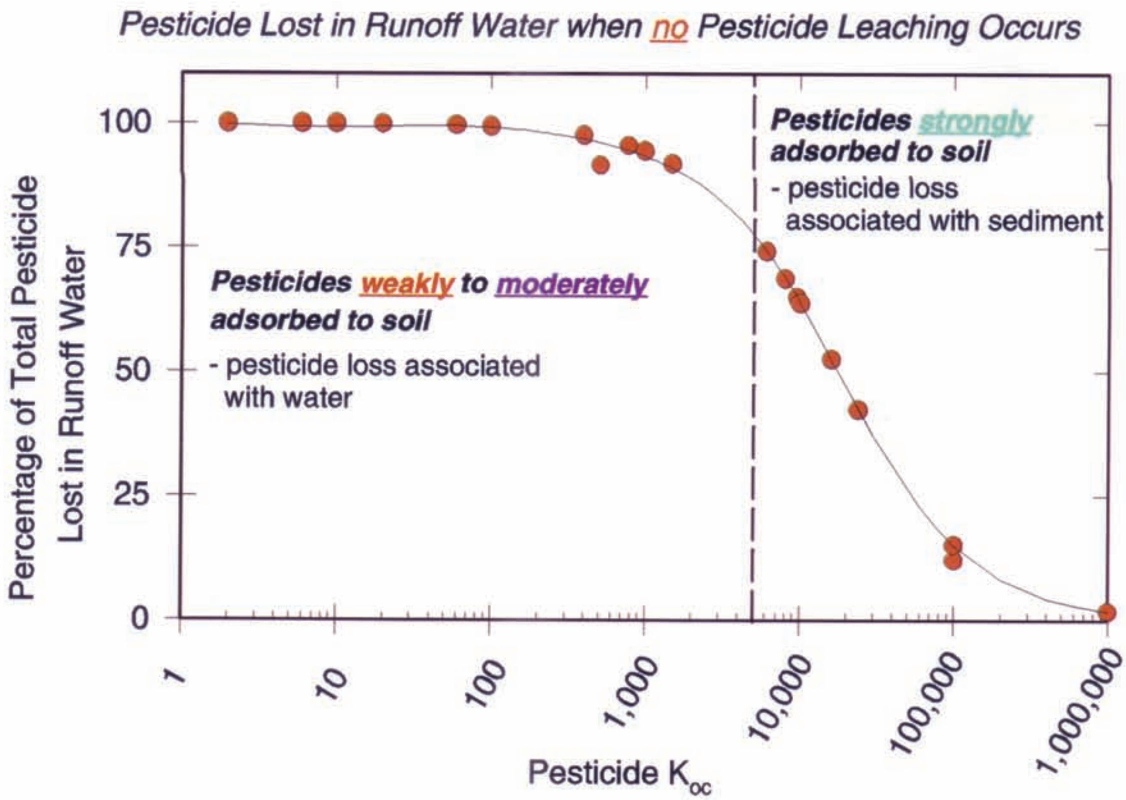

Figure 2. Relationship between pesticide K_{oc} values and percentage of pesticide runoff lost with runoff water. *Figure illustrates results from simulation where no pesticide leaching occurs and only runoff losses are significant.* In this graph, all pesticides are assumed to have a half-life of 60 days.

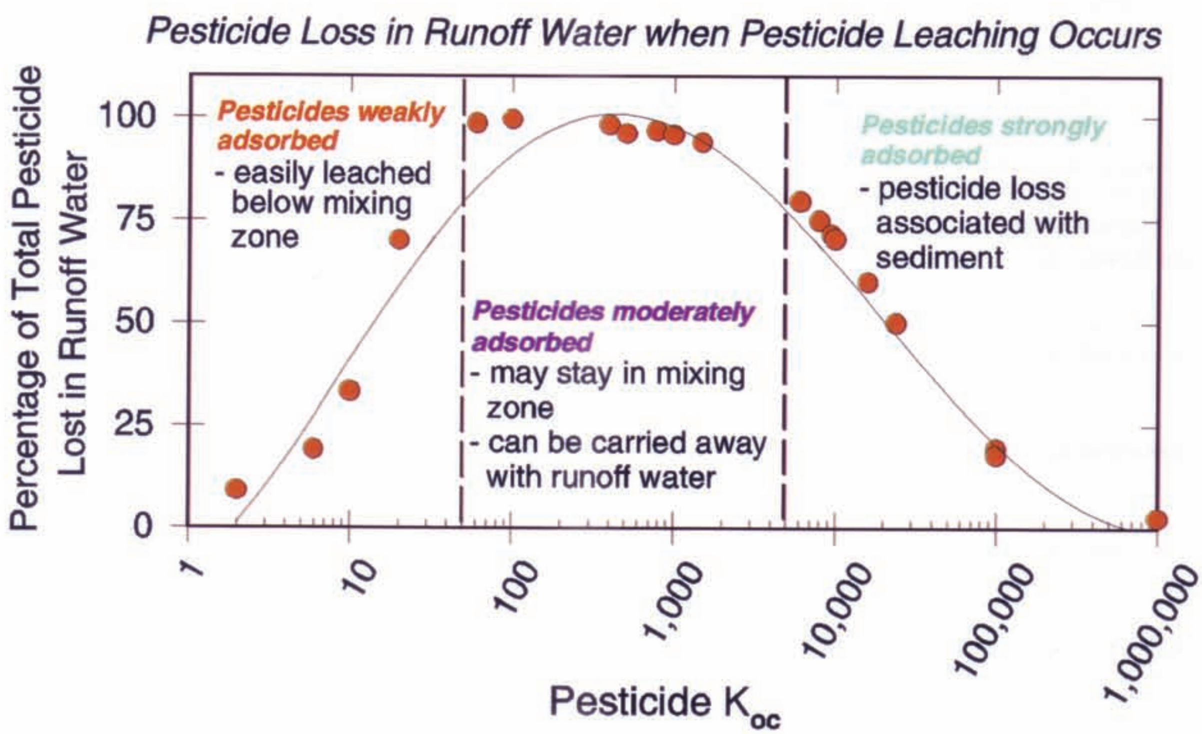

Figure 3. Relationship between pesticide K_{oc} values and percentage of pesticide runoff lost with runoff water. *Figure illustrates results from simulation where both runoff and leaching losses occur.* In this graph, all pesticides are assumed to have a half-life of 60 days.

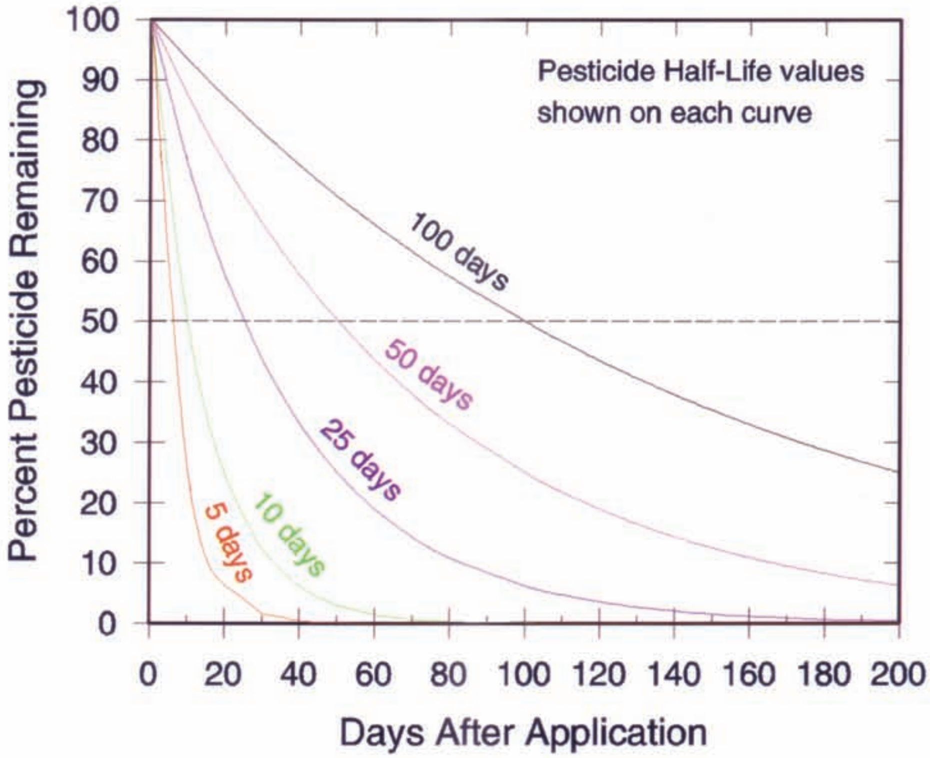

Figure 4. Relationship between percent pesticide remaining and days after application for various pesticide half-life values.

*Does this mean that **all** pesticides with K_{oc} values less than 5,000 will be carried away with runoff water?*

Not necessarily. *Figure 2* illustrates the relationship between pesticide K_{oc} values and percentage of pesticide in the water phase. In the field, dissolved pesticides can either leach or runoff. *Figure 3* illustrates a situation where both pesticide leaching and runoff are considered. This graph illustrates that pesticide loss in runoff water is relatively low when K_{oc} values are less than 50 or above 5,000 and high between 50 and 5,000. The reason for this bell-shaped curve is that pesticides with very low K_{oc}'s are highly leachable and can readily move downward out of the mixing zone *(Figure 1)* with the initial rainfall or irrigation. Pesticides with moderate K_{oc} values (50 to 5,000) will not leach as readily from the soil surface and may be present in the mixing zone when runoff begins. Consequently, under normal situations where some infiltration and leaching is likely to occur, pesticides with moderate K_{oc} values are more likely to be present in runoff than those which are readily leached below the mixing zone *(Figure 1)*. Pesticides with high K_{oc} values (greater than 5,000 L/kg) will adhere tightly to soils and will largely be associated with runoff events that involve substantial sediment loss. Although sediment loss can be significant during some runoff events, the volume of runoff water is usually much greater than sediment loss. Therefore pesticides dissolved in water (such as weakly- to moderately-adsorbed pesticides) generally account for the majority of pesticide lost in runoff.

Table III lists some pesticides that are commonly used in Nebraska and ranks them according to their K_{oc} values. Pesticides have been grouped into three classes: weakly adsorbed, moderately adsorbed and strongly adsorbed. These groupings are also used in *Figures 1-3* and should be viewed as guidelines when planning pesticide management strategies (see Pesticide Management Practices on page 6).

Pesticide Persistence

When a pesticide is applied to soil, interactions with soil microbes, sunlight, and other chemicals can cause pesticides to degrade or break down. Pesticides are not broken down all at once, but are degraded in a series of steps that eventually lead to the production of CO_2 (carbon dioxide), H_2O (water) and some inorganic products (primarily nitrogen, phosphorus, or sulfur). Degradation can occur by microbial action or by chemical reactions. A primary process for pesticide loss in soil and water is through microbial degradation.

Pesticide persistence is often expressed as the time required for 50 percent of the original pesticide to be degraded to other products. This length of time is termed ***half-life***. For example, a pesticide with a

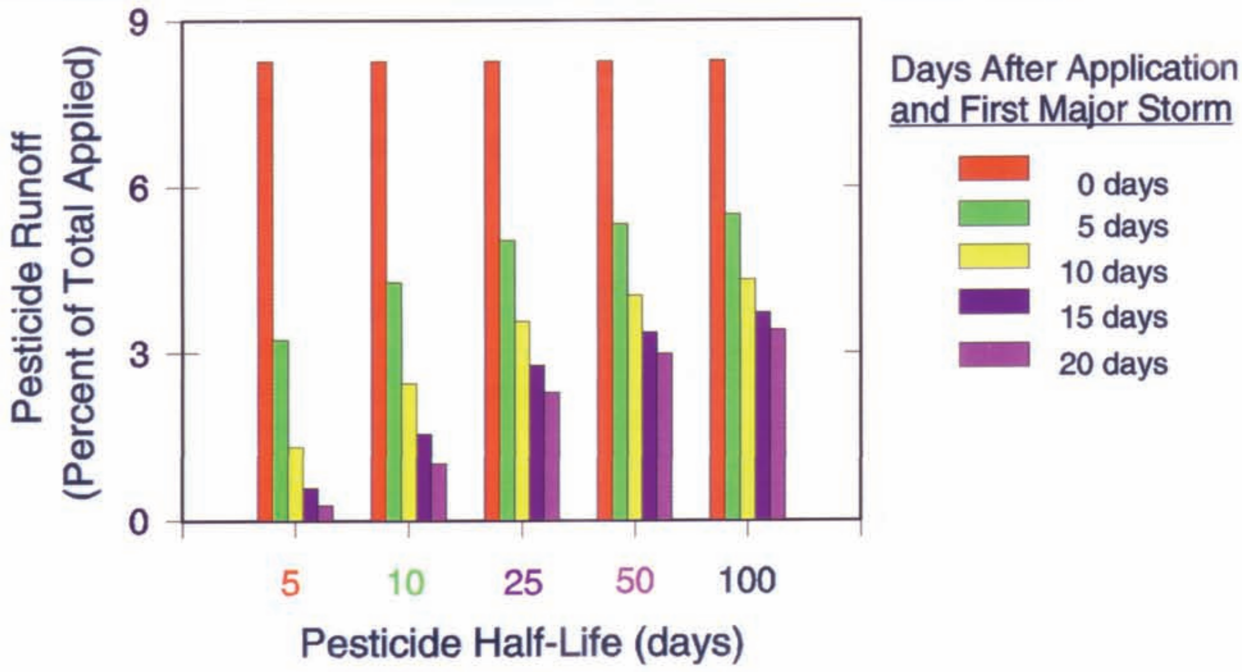

Figure 5. **Relationship between pesticide half-life values and pesticide runoff. Figure illustrates percentage of pesticide loss in runoff from an initial single 2.4 inch storm that occurs at various days after application. All pesticides are assumed to have a K_{oc} of 500 L/kg.**

half-life of two months will degrade to one-half of its original amount in two months. It will take another two months to degrade half of the remaining half (leaving 1/4 of the original amount) and so on. *Figure 4* illustrates how the percent pesticide remaining at various days after application changes with pesticide half-life values. Note that a shorter pesticide half-life means less time is required to degrade the pesticide.

Pesticide persistence can influence the amount of pesticide lost in runoff. *Figure 5* illustrates how the potential for pesticide runoff can be influenced by pesticide half-life. In this example, we chose pesticides with half-lives of 5, 10, 25, 50, and 100 days. We then simulated a situation where a 2.4-inch rainstorm occurred at different days after application. Note that when the rainstorm occurred on the day of application (0 days), the amount of pesticide runoff was the same for all pesticides, regardless of pesticide half-life. However, when that same rainstorm occurred at later dates (5, 10, 15 or 20 days after application), less pesticide runoff occurred for pesticides with shorter half-lives *(Figure 5)*.

Half-life measurements are commonly made in the laboratory under controlled environmental conditions. In the field, soil temperature, soil water and organic matter content can vary greatly and these factors dramatically influence degradation rates. Consequently, half-life values should be viewed as *guidelines* rather than absolute values. A listing of pesticide half-life values in given in *Table IV*.

Pesticide Management Practices

Based on the half-life and K_{oc} of the pesticide you are applying, different management options should be considered. The EPA's threshold value for pesticide half-life is three weeks. Pesticides with half-lives greater than three weeks (21 days) are considered persistent and potentially threatening to water resources. Consequently, selecting a pesticide with a short half-life may reduce the time the pesticide is vulnerable to runoff losses.

Pesticide K_{oc} values can also be used to guide management options. Pesticides that are weakly adsorbed to soils (K_{oc} less than 50) are more likely to leach and move to groundwater. However, these pesticides can also be easily lost with runoff water. If soil conditions or management practices result in minimal infiltration and leaching (such as in highly compacted soils or following pesticide application to wet fields), weakly adsorbed pesticides can easily be involved in pesticide runoff (as illustrated in *Figure 2*). To effectively manage weakly adsorbed pesticides, the following steps should be taken:

- Use optimum application rates (avoid high rates)
- Minimize applications to highly sloped or erodible land.
- If groundwater contamination is a concern, select non-leaching forms of products such as ester formulations rather than salts.

Moderately adsorbed pesticides have a high potential to stay in the mixing zone and are likely to be involved in surface water runoff. In addition to determining optimum application rates and proper timing of application, Best Management Practices (BMP's) for these pesticides should control runoff and reduce the amount of pesticide in the mixing zone. Mechanical incorporation can reduce pesticide runoff provided soil erosion is controlled. Banding and use of postemergence pesticides are two practices that reduce the amount of pesticide applied to the field during potential high runoff periods and can reduce pesticide runoff.

Strongly adsorbed pesticides are attached to soil and therefore most chemical loss occurs when soil is carried off the field with runoff water. Best Management Practices for these chemicals include methods to control erosion and prevent sediment transport into surface waters. Conservation tillage, no-till, contouring, sediment basins, and grass buffer strips can help reduce sediment loss.

Intensity and Frequency of Rainfall

Rainfall intensity, amount, frequency, and timing in relation to chemical application all affect pesticide runoff losses. While rainfall is beyond human control, it may be possible to adjust irrigation schedules or avoid chemical applications at peak rainfall times. Unless indicated, the following examples show how rainfall intensity and frequency influences atrazine runoff.

When is pesticide runoff most likely to occur?

Researchers at the University of Nebraska and elsewhere have shown that the first runoff event after application generally contains the highest pesticide concentration and accounts for the greatest losses. Results from a 50-year simulation showed that 72 percent of the total annual atrazine runoff occurred within the first 30 days of application. Further analysis of atrazine runoff losses indicated that 42 percent of the total annual runoff occurred with the first runoff event. Although 42 percent was the average, the range over 50-years was between 0 and 95 percent. This wide range is because the amount lost during the first runoff event depends on the timing of runoff in relation to application, as illustrated by *Figure 6.*

In general, pesticide loss is greatest when runoff occurs immediately after application. With time, pesticide runoff from the first post-application storm will

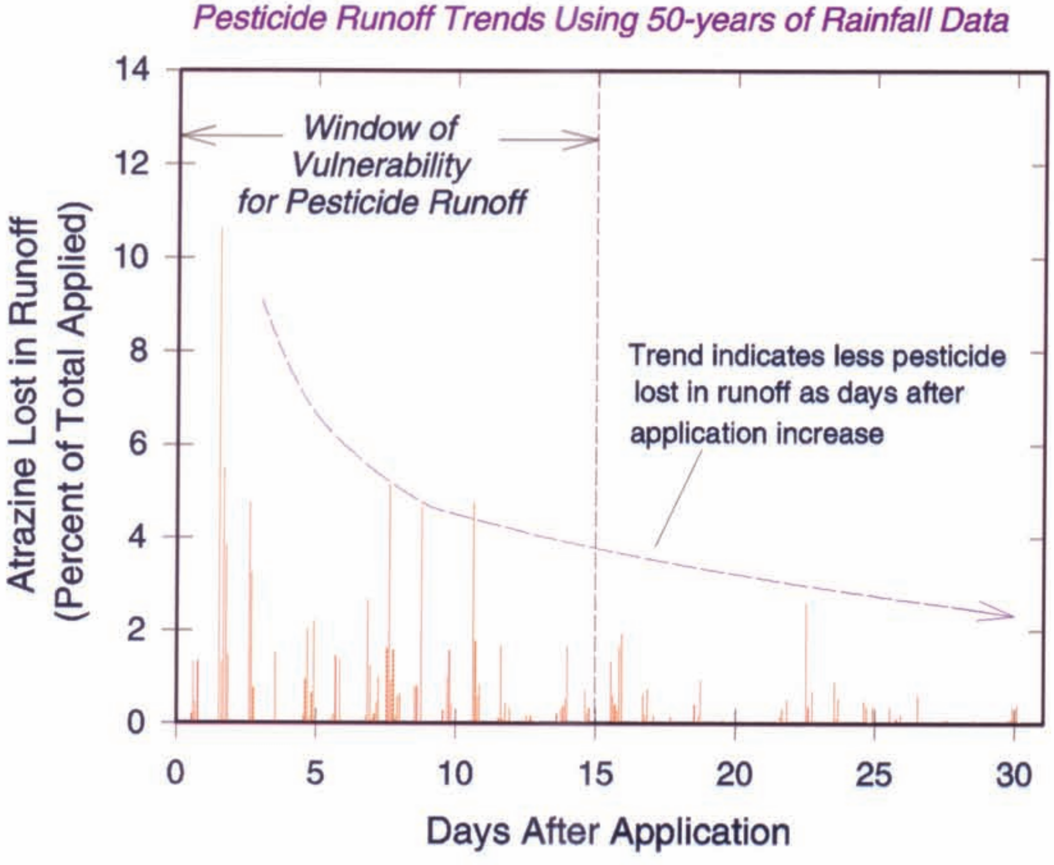

Figure 6. **Percentage of atrazine lost in first runoff event for 50 different years. Trend indicates greatest losses generally result when first runoff event occurs within 10 to 15 days after pesticide application.**

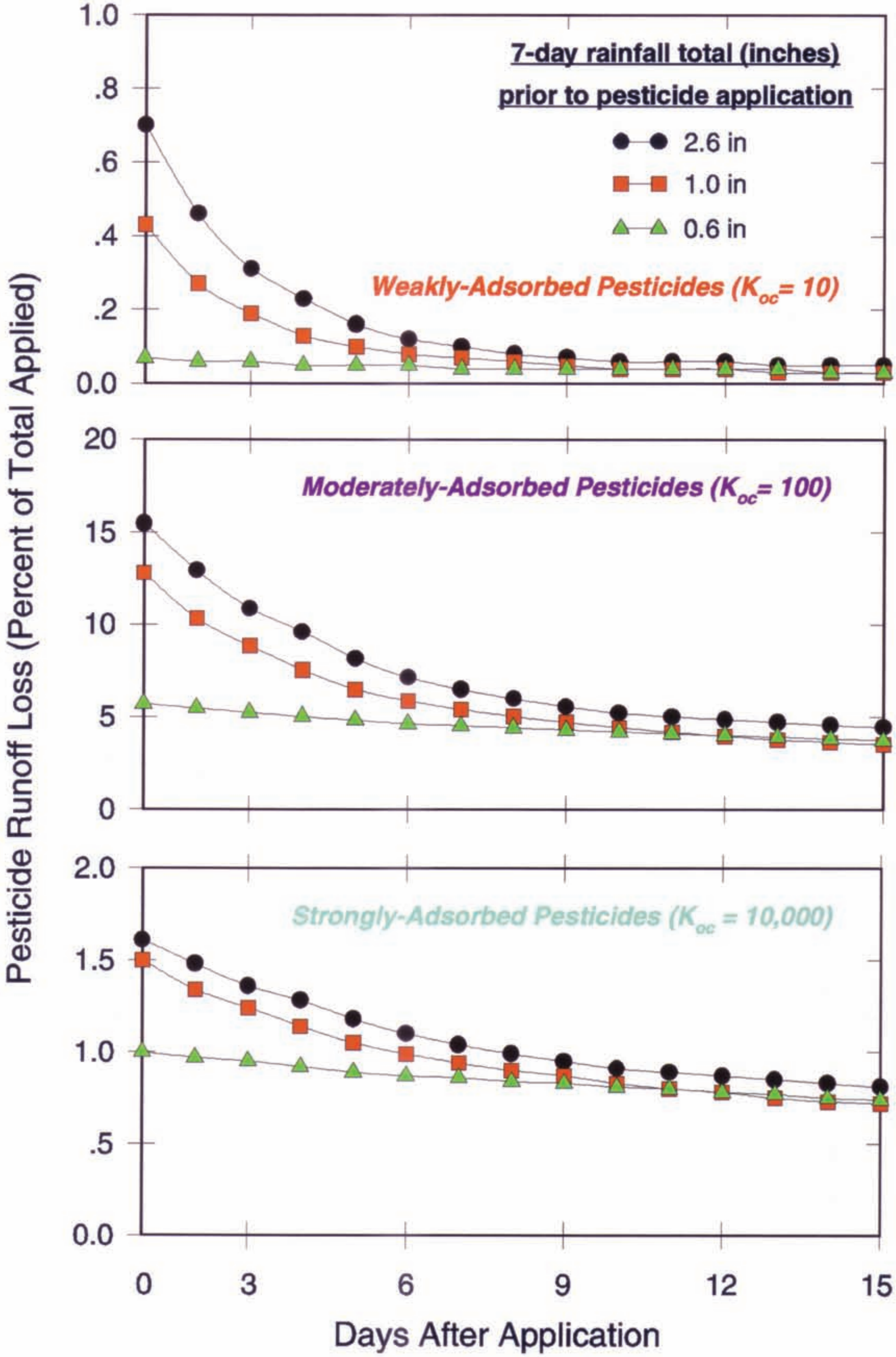

Figure 7. The relationship between timing of pesticide application and first post-application storm on pesticide runoff for weakly, moderately, and strongly adsorbed pesticides. Pesticide runoff values (symbols) represent 24-hour loss from a single 2.4-inch storm event for various days after application. Individual curves (lines) show runoff losses from fields receiving different 7-day rainfall totals *prior* to pesticide application. Soil type and field characteristics are given in Table II.

decrease. The time frame between pesticide application and first runoff event has been termed the "***window of vulnerability***." The importance of this time frame is illustrated in *Figure 6*.

In this figure, we show the amount of atrazine lost in the first runoff event for 50 different years. Since each year's precipitation pattern was different, the timing of the first significant runoff event also differed. Years in which the first runoff event occurred shortly after application generally resulted in more atrazine runoff. Years in which the first major runoff event occurred later, resulted in less atrazine runoff. These results indicate that the time frame that pesticides are most vulnerable to runoff (window of vulnerability) is generally within 10 to 15 days after application. While timing of rainfall is beyond the control of the pesticide user, there is generally some flexibility in scheduling applications and irrigations. A Best Management Practice (BMP) for irrigated lands would be to delay major irrigations after application and assure that runoff is minimized during the first post-application irrigation. Provided runoff avoided, another possible BMP for pivot irrigated land would be to apply a light irrigation shortly after application as a means of incorporating the pesticide below the mixing zone.

Although the last example illustrated a general trend that less pesticide runoff occurs with increased days after application *(Figure 5)*, considerable variability in atrazine runoff was still observed for the various days after application. This is likely due to the amounts of rainfall and runoff occurring for the various years and relative wetness of the soil prior to pesticide application. An important factor that influences how much pesticide will be lost during the *window of vulnerability* is ***antecedent soil water***.

The antecedent soil water is the water content of the soil prior to additional irrigation or precipitation. Antecedent soil water can also give an indication of how much additional water a soil profile can hold before runoff occurs. For a given soil profile, a wet soil will have less capacity to hold additional water than a dry soil; therefore, applying a pesticide shortly after a rainstorm increases the chances that more runoff will occur from the first post-application rainfall. This is especially true during the *window of vulnerability*.

To illustrate this, we tabulated the amount of pesticide runoff occurring from a single 2.4-inch storm that occurred at various days between 0 and 15 days after application (see *Figure 7*). Fields received 0.6, 1.0, or 2.6 inches of rainfall prior to application of a weakly, moderately, and strongly adsorbed pesticide. Results indicate that a field receiving between 1.0 and 2.6 inches of rainfall within 7 days prior to pesticide application had much higher pesticide runoff losses from the first post-application storm than fields which received 0.6 inches of rainfall. In other words, the greatest loss of pesticide during the *window of vulnerability* occurs in years with higher rainfall prior to application. Consequently, avoiding pesticide applications to wet fields is one way of minimizing the chances for runoff from the first post-application rainfall event. Although this trend was noted for the various pesticides tested, it is important to note that there were considerable differences in the amount of pesticide lost in runoff among the weakly, moderately, and strongly adsorbed pesticides *(Figure 7)*. Pesticide runoff losses were roughly 10 times higher for the moderately adsorbed pesticide than for the weakly or strongly adsorbed pesticides (Note: compare y-axes in *Figure 7*).

Can Pesticide Application Dates Influence Runoff?

Rainfall patterns have a major influence on the amount of pesticides lost in runoff. While it is difficult to predict the weather, precipitation patterns over many years can be examined. By examining the long-term (1961-1990) average rainfall patterns during April and May for various cities across Nebraska *(Table V)*, it is evident that, *on average*, more rain occurs in May than April. Considering this, we compared the amount of atrazine runoff occurring after a April 1 versus May 1 application date for 30 days following application. Computer simulations were run using 50 years of rainfall data for York, Neb. As expected, the 30-day loss varied from year to year, but on average more atrazine runoff occurred following a May 1 application than an April 1 application *(Figure 8)*. This indicates that when climatic conditions allow for an early pesticide application (early April), the odds are in favor of less rainfall occurring within the window of vulnerability and consequently, on average, less pesticide runoff should occur.

What is the relationship among pesticide application rate, method of application, and amount of pesticide runoff?

The amount of pesticide applied and method of application can dramatically influence the amount of pesticide runoff observed. Computer simulations were performed to determine how rate, timing, and method of application affects the amount of atrazine lost in runoff. Simulations represent a single-year atrazine application. Runoff losses were compared from atrazine application treatments that assumed either: (1) a pre-emergence application; (2) a pre-plant band application (application rates to half-row width); (3) a pre-plant incorporation (no reduction in residue cover); or (4) a post-emergence application. Application rates varied between 0.5 and 2.0 lbs of active ingredient (a.i.) per acre. Results indicated that a reduction in application rate reduced the total amount

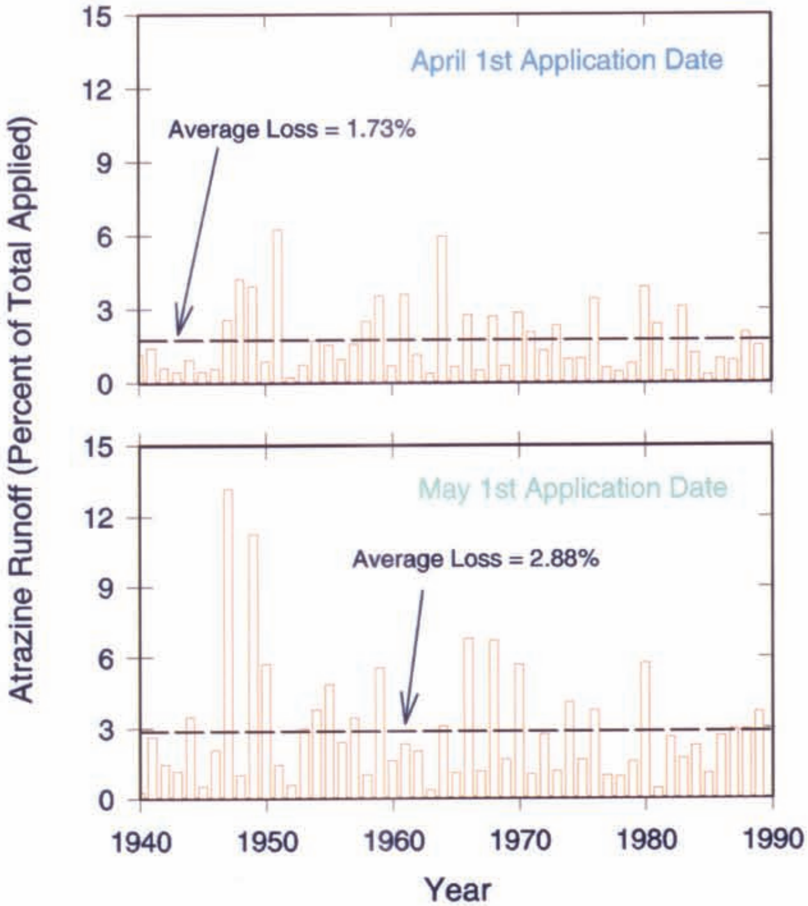

Figure 8. Comparison of percentage of atrazine lost in runoff from an April 1st versus May 1st pesticide application date. Simulations used 50 years of rainfall data for York, NE.

of atrazine lost *(Figure 9)* but not the percentage of total atrazine applied. Incorporation and banding greatly reduced atrazine runoff. Post emergence applications (at a reduced rate) also resulted in less total atrazine loss. These results illustrate how the management practices of timing and application rate can influence pesticide runoff losses.

Summary and Suggestions for Best Management Practices

- The *window of vulnerability* for pesticide runoff is typically within 10 to 15 days after application.
- Antecedent soil water can drastically affect the amount of pesticide runoff. When possible, avoid pesticide application to wet soil.
- Select pesticides with shorter half-lives and/or high K_{oc} values (strongly adsorbed) to reduce pesticide runoff.
- Examine pesticide K_{oc} values and determine if the pesticide is *weakly*, *moderately*, or *strongly* adsorbed to soil. Use Best Management Practices appropriate for each classification.
- Applying pesticides in early April may result in less pesticide runoff than May applications.
- Use the appropriate application rate as directed by the pesticide label.
- Manage soils to increase organic matter content in topsoil. This will increase pesticide adsorption to soil and reduce pesticide runoff.
- Where appropriate, incorporate pesticides to reduce pesticide runoff losses.
- Use band application instead of broadcasting. Banding reduces runoff losses because less total pesticide is applied to the field.
- Apply pesticide directly to the crop or pest rather than soil. Foliar-applied (postemergence) herbicides may pose less risk for surface and groundwater contamination because less total pesticide is applied to the field.
- Practice crop rotation to help control weeds, insects, diseases, and other pests.
- When possible, use alternative controls such as resistant varieties and crop competition.

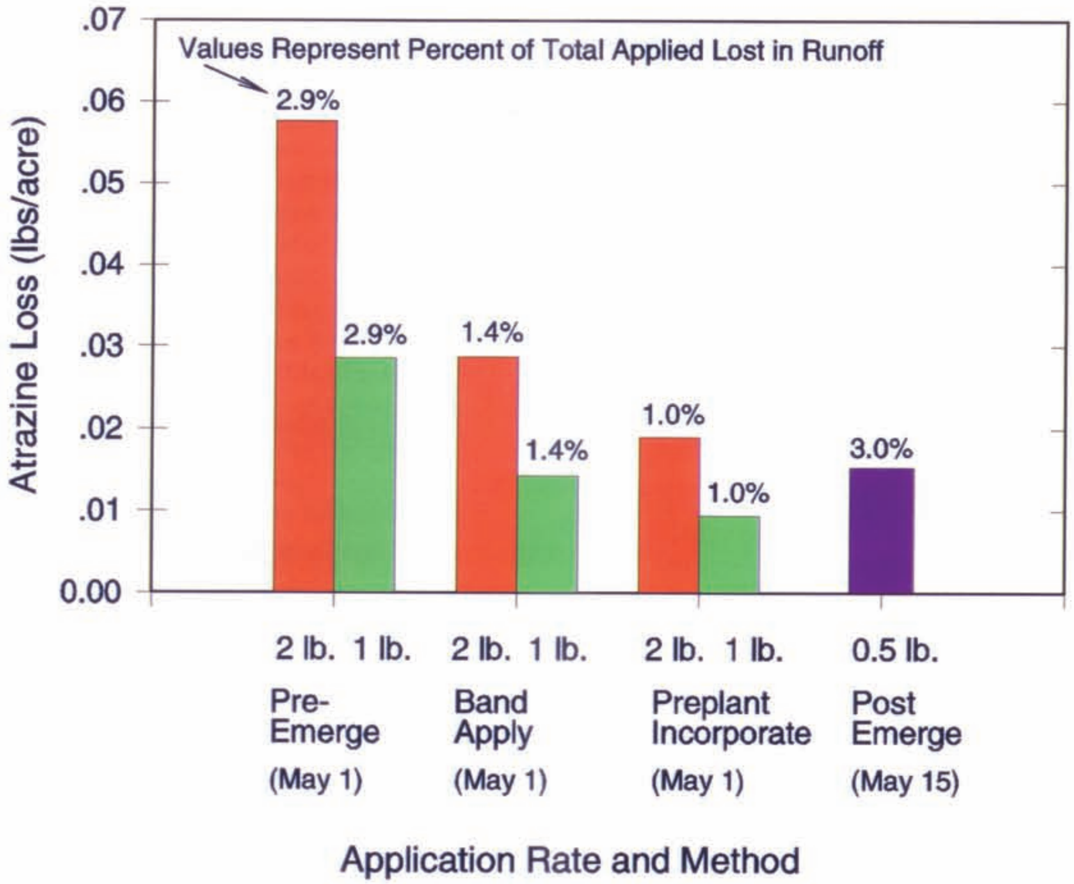

Figure 9. Comparison among timing, method, and rate of application on atrazine runoff losses. Simulations are for a single year in York, NE.

Glossary of Terms

Adsorption - Retention of a chemical onto the surface of a soil particle.**Antecedent soil water** - The relative wetness of the soil prior to precipitation or rainfall.

Aquifer - A water-containing layer of rock, sand or gravel that will yield useable supplies of water.

Basic pesticide - A pesticide whose neutral (molecular) form becomes positively charged as pH is lowered. Example: atrazine.

Cation Exchange Capacity - The sum total of exchangeable cations (positively charged ions or molecules) that a soil can adsorb.

Cationic Pesticide - A very strong, basic pesticide whose positive charge is independent of pH. Example: paraquat

Evaporation - The conversion of soil water or liquid to vapor and loss to the atmosphere.

GLEAMS - An abbreviation for the name of a computer pesticide fate model. GLEAMS is derived from "*G*roundwater *L*oading *E*ffects of *A*gricultural *M*anagement *S*ystems."

Groundwater - Water which saturates cracks, sand, gravel and other porous subsurface rock formations. "Aquifers" are the zones in which readily-extractable water saturates the pores of the formation.

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

Infiltrate, Infiltration - The process of water (from precipitation or irrigation) penetrating into or entering the surface of the soil profile

Maximum Contaminant Level (MCL) - An enforceable, regulatory standard for maximum permissible concentrations of a pesticide or contaminant in drinking water. MCL's are established under the federal Safe Drinking Water Act. The MCL standards of purity are applied to water distribution systems after the water has been treated, regardless of a surface or groundwater source. They are health-based numbers which by law must be set as close to the "no-risk" level as feasible.

Mixing zone - The top 1/4 to 1/2 inch of a soil profile where runoff water penetrates, mixes, and carries away dissolved pesticides.

Organic Carbon Partition Coefficient (K_{oc}) - 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 K_{oc}.

Precipitation - The depositing of moisture from the atmosphere upon the surface of the earth. Generally refers to snow and rain.

Solubility - The maximum amount of chemical that can be dissolved in a solution; often used in place of *aqueous solubility*, the maximum amount of chemical that can be dissolved in water.

Transpiration - The loss of water from cell surfaces and through the anatomical structures of the plant. Most of the water lost by plants evaporates from leaf surfaces by the process of transpiration.

Window of vulnerability - A time-frame when pesticide runoff is most susceptible to post-application precipitation events; typically the window of vulnerability is 10 to 15 days following pesticide application.

For More Information

The University of Nebraska has several NebGuides and extension circulars related to water quality. These publications are available from your county extension educators or contact the Institute of Agricultural and Natural Resources (IANR) Communications and Information Technology at (402) 472-3023. A sampling of some of the extension materials available on water quality include:

Understanding Pesticides and Water Quality in Nebraska, Extension Circular EC94-135.

Effects of Agricultural Runoff on Nebraska Water Quality, NebGuide G82-586.

Management Practices to Reduce Atrazine Runoff to Surface Water. Nebraska Cooperative Extension.

Pesticides and Groundwater: An Applicator's Map and Guide to Prevent Groundwater Contamination. Land Use Map No. 33. Conservation and Survey Division.

Water Runoff Control Practices for Sprinkler Irrigation Systems, Nebraska G91-1043.

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Appendix

Table I. Farming operations for irrigated continuous corn near York, NE. These operations were used in GLEAMS model for predicting pesticide runoff.

Operation	*Date*
Spring Disking	March 21
Pesticide Application and Planting - atrazine broadcast at 2 lbs a.i./acre	May 1
Harvest	October 15
Shredding Stalks	November 1
Fall Disking	November 10
Anhydrous Ammonia Application	November 15

Table II. Pesticide, soil and site characteristics of field used in GLEAMS modeling simulations.

Pesticide, Soil and Site Characteristic	*Unit*	*Value*
Pesticide K_{oc}†	L/kg	100
Pesticide Half-life†	days	60
Soil Texture		Silt loam
Percent Organic Matter	%	1.9
Residue Cover at Planting	%	30.0
Slope	%	2.5
Runoff Type		Overland flow

† Pesticide K_{oc} and half-life values are those of atrazine and used in examples presented in *Figures 6, 8,* and *9.*

Table III. Ranking of pesticides by K_{oc} values: less than 50, 50 to 5,000, and greater than 5,000 L/kg.

Trade Name	*Common Name*	*K_{oc} (L/kg)*
	Weakly-Adsorbed Pesticides (K_{oc} less than 50 L/kg)	
Orthene	Acephate	<1
Banvel, Clarity	Dicamba	2
Stinger	Clopyralid	6
Pursuit	Imazethapyr	10
Tordon	Picloram	16
2,4-D amine	2,4-D amine	20
Garlon, etc.	Triclopyr salt	20
Mecomec	Mecoprop	20
Justice, Statesman, etc.	2,4-D acid	20
Scepter	Imazaquin	20
Furadan	Carbofuran	22
Peak	Prosulfuron	25
Accent	Nicosulfuron	30
Temik	Aldicarb	30
Basagran	Bentazon	34
Assert	Imazamethabenz, p-isomer	35
Ally	Metsufuron	35
Glean	Chlorsulfuron	40
Pinnacle	Thifensulfuron	45
	Moderately-Adsorbed Pesticides (K_{oc} between 50 and 5,000 L/kg)	
Beacon	Primisulfuron	50
Sencor, Lexone	Metribuzin	60
Flexstar	Fomesafen	60
Assert	Imazamethabenz, m-isomer	66
Spike	Tebuthiuron	80
Amber	Triasulfuron	95
Aatrex	Atrazine	100
Arsenal	Imazapyr acid	100
Poast	Sethoxydim	100
2,4-D ester	2,4-D ester	100
Classic	Chlorimuron	110
MCPA	MCPA acid	110
Permit	Halosulfuron	110
Ramrod	Propachlor	112
Blazer	Acifluoren	113
Pyramin	Pyrazon	120
Lasso	Alachlor	124
Princep	Simazine	130
Frontier	Dimethenamid	140
Pramitol	Prometon	150
Bladex	Cyanazine	190
Dual	Metolachlor	200
Eradicane	ETPC	200
Harness	Acetochlor	200
Command	Clomazone	300
Sevin	Carbaryl	300
Norton SC	Ethofumesate	340

Table III. Continued.

Trade Name	*Common Name*	K_{oc} *(L/kg)*
Sutan	Butylate	400
Lorox	Linuron	400
Tough	Pyridate	e411
Counter	Terbufos	500
Assure II	Quizalofop	510
Thimet	Phorate	540
Di-Syston	Disulfoton	e600
Ro-neet	Cycloate	600
Broadstrike	Flumetsulam	700
Remedy, etc.	Triclopyr ester	780
Dyfonate	Fonofos	870
DZN, Diazinon	Diazinon	1,000
Betanex	Desmedipham	1,500
Malathion	Malathion	1,800
------------------------ *Strongly-Adsorbed Pesticides (K_{oc} greater than 5000 L/kg)* ------------------------		
Penncap	Methyl parathion	5,100
Asana	Esfenvalerate	5,300
Fusilade-DX	Fluazifop-p	5,700
Fortress	Chlorethoxyfos	e5,960
Lorsban, Dursban	Chlorpyrifos	6,070
Treflan	Trifluralin	7,000
Balan	Benefin	9,000
Bugle, Option II, etc.	Fenoxaprop-p	9,490
Cobra	Lactofen	10,000
Buctril	Bromoxynil ester	10,000
Resource	Flumiclorac	10,000
Hoelon	Diclofop	16,000
Prowl	Pendimethalin	17,200
Roundup	Glyphosate	24,000
Comite	Propargite	56,500
Goal	Oxyfluorfen	100,000
Ambush, Pounce	Permethrin	100,000
Capture	Bifenthrin	216,500
Aztec	Cyfluthrin	e384,000
Force	Tefluthrin	e400,000
Warrior	Lambda-cyhalothrin	e400,000
Diquat	Diquat	1,000,000
Gramoxone Extra, Cyclone	Paraquat	1,000,000

e = estimated value

Table IV. Degradation half-life values for pesticides commonly used in Nebraska.

Trade Name	*Common Name*	*Half-life (days)*
Aatrex	Atrazine	60
Accent	Nicosulfuron	21
Ally	Metsulfuron	30
Amber	Triasulfuron	e100
Ambush, Pounce	Permethrin	30
Arsenal	Imazapyr	90
Asana	Esfenvalerate	e90
Assert	Imazamethabenz	45
Assure II	Quizalofop-p	60
Aztec	Cyfluthrin	e30
Balan	Benefin	40
Banvel, Clarity	Dicamba	14
Basagran	Bentazon	20
Beacon	Primisulfuron	30
Betanex	Desmedipham	30
Bladex	Cyanazine	14
Blazer	Acifluoren	14
Broadstrike	Flumetsulam	60
Buctril	Bromoxynil	7
Bugle, Option II, etc	Fenoxaprop-p	9
Capture	Bifenthrin	e95
Classic	Chlorimuron	40
Cobra	Lactofen	3
Comite	Propargite	74
Command	Clomazone	24
Counter	Terbufos	5
Diquat	Diquat	1,000
Di-Syston	Disulfoton	e30
Dual	Metolachlor	30
Dyfonate	Fonofos	67
DZN, Diazinon	Diazinon	40
Eradicane	ETPC	6
Flexstar	Fomesafen	100
Force	Tefluthrin	24
Fortress	Chlorethoxyfos	e14
Frontier	Dimethenamid	20
Furadan	Carbofuran	50
Fusilade-DX	Fluazifop-p	15
Garlon, etc.	Triclopyr salt	30
Glean	Chlorsulfuron	40
Goal	Oxyfluorfen	35
Gramoxone Extra, Cyclone	Paraquat	1,000
Harness	Acetochlor	18
Hoelon	Diclofop	30
Justice, Statesman, etc.	2,4-D acid	10
Lasso	Alachlor	21
Lorox	Linuron	60
Lorsban, Dursban	Chlorpyrifos	30
Malathion	Malathion	1
MCPA	MCPA	5
Mecomec	Mecoprop	21

Table IV. Continued.

Trade Name	*Common Name*	*Half-life (days)*
Norton SC	Ethofumesate	35
Orthene	Acephate	9
Peak	Prosulfuron	e40
Penncap	Methyl parathion	5
Permit	Halosulfuron	17
Pinnacle	Thifensulfuron	12
Poast	Sethoxydim	5
Pramitol	Prometon	500
Princep	Simazine	60
Prowl	Pendimethalin	44
Pursuit	Imazethapyr	75
Pyramin	Pyrazon	21
Ramrod	Propachlor	7
Resource	Flumiclorac	4
Ro-neet	Cycloate	30
Roundup	Glyphosate	47
Sceptor	Imazaquin	60
Sencor, Lexone	Metribuzin	45
Sevin	Carbaryl	10
Spike	Tebuthiuron	360
Stinger	Clopyralid	40
Sutan	Butylate	13
Temik	Aldicarb	30
Thimet	Phorate	60
Tordon	Picloram	90
Tough	Pyridate	e21
Treflan	Trifluralin	45
2,4-D amine	2,4-D amine	10
Warrior	Lambda-cyhalothrin	56

e = estimated value

Table V. Comparison of average monthly rainfalls (1961-1990) during April and May of selected cities across Nebraska.

Location	*April*	*May*
	---------------- inches ----------------	
Alliance	1.72	3.32
Broken Bow	2.19	3.27
Fremont	2.68	4.41
Grand Island	2.50	3.82
Lincoln	2.76	3.90
Nebraska City	3.24	4.17
Norfolk	2.29	3.68
Omaha	2.66	4.52
Scottsbluff	1.58	2.77
Sioux City	2.34	3.67
Valentine	1.67	3.16