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EC94-135 Understanding Pesticides and Water Quality in Nebraska

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Nebraska Cooperative Extension EC 94-135

Understanding Pesticides and Water Quality in Nebraska

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Department of Agronomy
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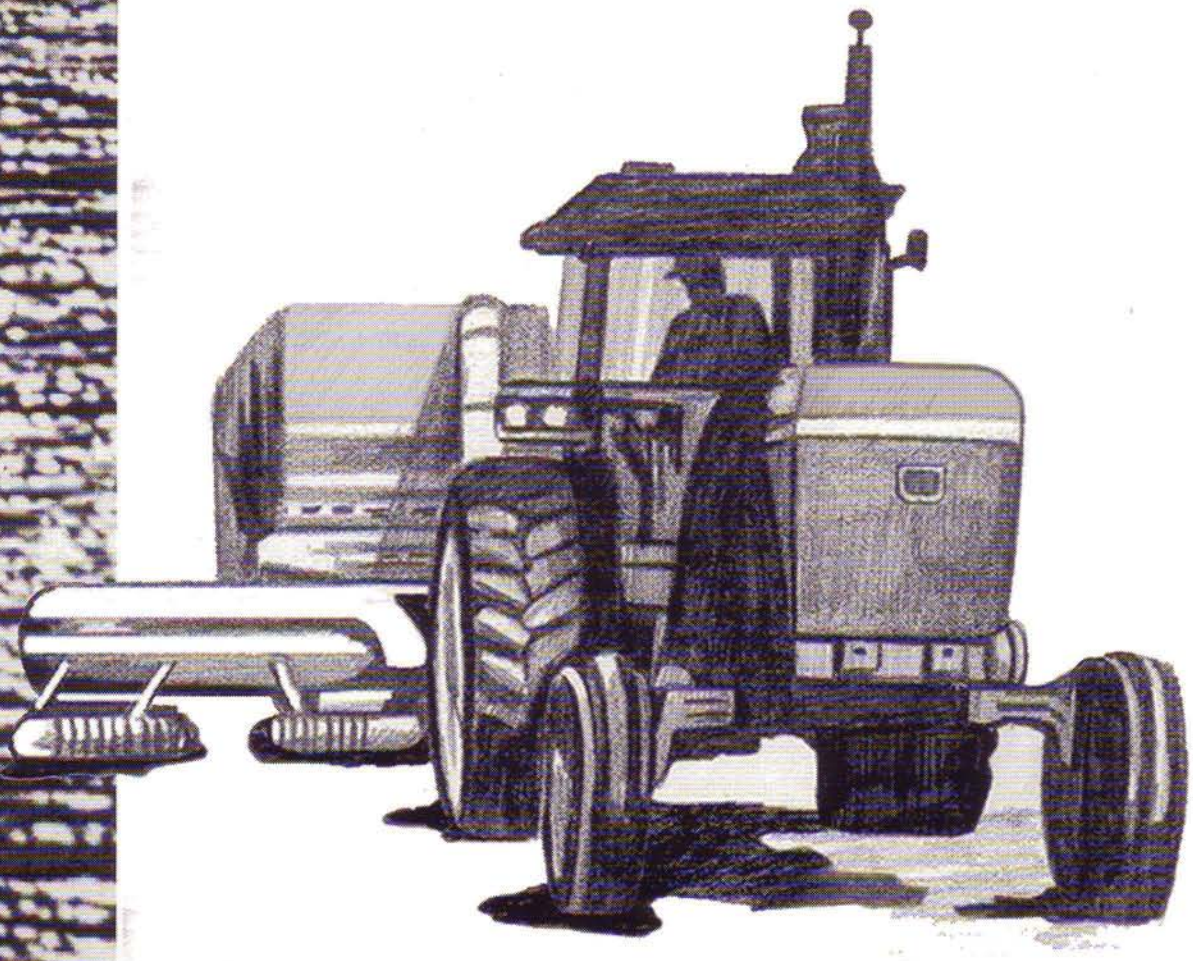

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Understanding Pesticides and Water Quality in Nebraska

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INTRODUCTION

Groundwater is Nebraska's most important natural resource. The principal source of groundwater in Nebraska is the High Plains Aquifer System. This system underlies approximately 85 percent of the state and supplies 95 percent of all groundwater used in Nebraska. The majority of groundwater in Nebraska is used by agriculture (94 percent) but domestic and commercial uses are also important. Eighty-two percent of Nebraskans use groundwater as their major source of drinking water, and nearly all of the state's farm homes rely on groundwater for their domestic needs.

Protecting ground and surface water from chemical pollutants is a state and national initiative. The Environmental Protection Agency (EPA) estimates that 1.2 billion pounds of pesticides are sold annually in the United States with about 70 percent being used in agricultural production. In Nebraska, an estimated 33 million pounds of pesticides are annually applied. This intense usage creates potential for contamination, and environmental monitoring programs are routinely initiated to identify which agrichemicals are present in ground and surface waters. Improvements in analytical technologies have resulted in the ability to detect lower levels of contamination. To date, over 70 pesticides have been found in groundwaters throughout the United States. A recent survey of over 2,000 groundwater samples identified 15 pesticides present in Nebraska's groundwaters with 13.5 percent of the wells containing atrazine. Increased public concern regarding agrichemicals has caused farmers, extension personnel, and agricultural researchers to reexamine management practices in order to minimize potential ground and surface water contamination.

One of the goals of soil chemistry is to predict the fate of pesticides in the environment so that adverse impacts can be avoided. To accomplish this, one must understand the basic processes driving pesticide dissipation and how environmental factors affect these processes. With this understanding, more judicious use and management practices can be implemented.

What is a Pesticide?

Most state and federal laws define a pesticide as any substance used for controlling, preventing, destroying, repelling, or mitigating a pest. In most instances, the pest is an unwanted weed, insect, fungus, nematode, or rodent. The term pesticide is generic. Pesticides are further subdivided into specific groups to signify the particular type of pest the chemical is intended to control. Examples include: herbicides, insecticides, fungicides, nematocides, and rodenticides, (i.e. nematocides control nematodes).

Why is there Concern over Pesticides and Water Quality?

The Environmental Protection Agency (EPA) sets drinking water standards to ensure a safe drinking water supply. Since individuals vary in weight and amount of water consumed, standards are set for a hypothetical person who weighs 154 pounds and drinks two quarts of water per day for 70 years. In toxicity tests, the EPA determines a level of contamination at which no effects from the pesticide are expected. Additional safety factors are then applied (usually a 100-fold safety factor) and the result is called a "Maximum Contaminant Level" or MCL. MCL's are federally enforceable standards for finished water provided by Public Water Supply Systems and are determined as an annual average concentration. These standards are often used as reference points for the protection and remediation of water resources under several EPA programs.

The MCL's for a number of pesticides are listed in Table I. One of the biggest concerns for Nebraska is the potential for ground and surface water contamination from atrazine. Approximately 15 million pounds of atrazine are applied yearly in Nebraska, resulting in some ground and surface water sources exceeding atrazine's MCL. This has created concern among residents in both rural and urban areas. To alleviate these concerns, efforts are needed to utilize the best management practices available to ensure a high quality of water in Nebraska.

Support for this work was provided in part by the University of Nebraska Water Center. Mention of trade names does not constitute recommendation or endorsement by the University of Nebraska.

What Processes Influence the Fate of Pesticides in Soils ?

A number of processes influence the fate of pesticides in soils (Figure 1). In general, these processes can be broken down into six categories:

1. Solubilization by water which leads to leaching and runoff.
2. Pesticide sorption by soil mineral and organic constituents.
3. Degradation by soil microorganisms.
4. Chemical degradation and photodecomposition.
5. Volatilization and evaporation.
6. Plant uptake.

The relative importance of each process is controlled by the pesticide's chemistry and environmental variables such as temperature, water content, and soil type.

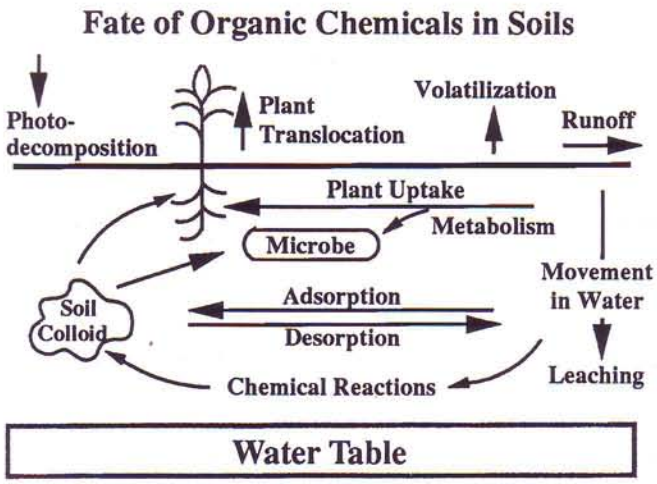

Figure 1. Processes Affecting the Fate of Pesticides in Soils.

Solubility

The extent to which a chemical will dissolve in a liquid is referred to as solubility. Water solubility is often numerically expressed in units of "parts per million" (ppm), ie. one part pesticide in one million parts water. The Environmental Protection Agency (EPA) has indicated that compounds with aqueous solubilities greater than 30 ppm have a high tendency to leach. The solubilities of some pesticides commonly used in Nebraska are listed in Table IIb. For example, the aqueous solubility of aldicarb (trade name Temik) is 6,000 ppm. This means 6,000 lbs. of aldicarb can be dissolved in a million pounds of water (approximately 120,000 gallons) compared to 33 pounds of atrazine or 6.2 pounds of simazine. In practical terms, an acre inch of rain would add enough water to dissolve approximately 1,400 lbs. of aldicarb. By comparison, an acre inch of rain will dissolve approximately 1.4 lbs. of simazine. Solubility is particularly influenced by temperature and pH. Increased temperature increases the ability of a pesticide to dissolve while pH changes may either increase or decrease a pesticide's solubility and is chemical specific.

Although water solubility is usually a good indicator of soil mobility, it is not necessarily the best criterion. As indicated above, most pesticides are applied to fields at application rates far below their solubility limit. This means that there is usually enough water in the soil to cause pesticides to dissolve and allow them to move with water. What determines the extent to which a pesticide will leach downward or run off a field is the pesticide's affinity to adhere to soils (sorption).

Generally, pesticide solubility and sorption are inversely related; as water solubility increases (ie. aqueous solubility ppm values increase), the affinity for a pesticide to adsorb to soil generally decreases. Notable exceptions to this rule include the compounds paraquat, diquat, and glyphosate. Although these compounds are quite soluble, their chemical structure makes them behave differently than most pesticides in soils. Paraquat and diquat are cationic (strong basic pesticides that carry a positive charge). Basic and acidic pesticides are held to soil constituents by electrical or static charges (positive and negative attractions) and behave differently than electrically neutral compounds. Glyphosate has both basic and acidic properties that give it **chelating**[1] properties in soils.

Sorption

The tendency of a pesticide to leach or run off is strongly dependent upon the interaction of the pesticide with the soil's solids. The word sorption is a "catchall" term that includes the processes of **adsorption** and **absorption**. Adsorption refers to the binding of a pesticide to the surface of a soil particle; absorption implies a penetration of the pesticide *into* the soil matrix. This distinction can be important because pesticides may become increasingly absorbed with time (months to years) and desorption (or release) of the absorbed pesticide may be reduced with time. This unavailable or undetachable pesticide is often referred to as "bound residue" and is generally unavailable for microbial degradation or pest control. Therefore, the formation of bound residue with time decreases the chances for leaching or runoff. Conversely, the time for greatest concern for leaching or runoff is immediately after application.

Factors that contribute to sorption of pesticides on soil or aquifer (groundwater) materials include: chemical and physical characteristics of the pesticide;

[1](Words in bold letters are defined in Glossary of Terms).

composition of the soil; and nature of the soil solution. By gaining an understanding of these factors, logical conclusions can be drawn about the impact of the sorption process on the transport of the pesticide.

Soil and aquifer material are primarily composed of sand, silt, clay, water and a highly variable amount of organic material. In general, sandy soils and aquifer constituents offer little in the way of sorptive surfaces. Soils with high silt, clay and organic matter contents provide a rich sorptive environment for pesticides.

How are pesticide sorption characteristics determined?

Pesticide adsorption is determined experimentally by combining a known mass of soil with a pesticide solution. The soil mixture is shaken for 12 to 24 hours and then the pesticide concentration remaining in solution is measured. By knowing the concentration of pesticide added and the amount remaining in solution, the mass of pesticide adsorbed to the soil can be calculated. The ratio of pesticide adsorbed to that remaining in solution after **equilibration** (after shaking) is called the **adsorption partition coefficient** and is denoted by the symbols $\mathbf{K_d}$ or $\mathbf{K_p}$.

$$K_d = \frac{\text{mass of pesticide adsorbed per mass of soil}}{\text{pesticide concentration remaining in solution}}$$

Most pesticides are adsorbed by the organic matter fraction of soils. Organic matter is a complex mixture predominated by carbon, hydrogen, oxygen, and nitrogen compounds. Organic matter coats the surface of soil particles in the top horizons of a soil profile and tends to act like a **nonpolar** (oil-like) film. Sorption of most electrically neutral pesticides can be viewed as a process in which nonpolar chemicals attempt to escape the **polar** environment of the soil solution and enter the less polar environment of soil 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 is dependent upon the amount of organic matter present. The more organic matter present, the more likely the less-soluble pesticide will be adsorbed. The percentage of soil organic matter can vary considerably among soils and with depth or geographical location. Consequently, $\mathbf{K_d}$ values for pesticides are soil specific and the $\mathbf{K_d}$ of one pesticide can vary considerably from soil to soil or with depth in a soil profile. To achieve a more universal index for comparing pesticides sorption characteristics in a manner that is relatively independent of soils, $\mathbf{K_d}$ values are divided by the percent organic carbon in the soil. This conversion is referred to as the **organic carbon partition coefficient** or $\mathbf{K_{oc}}$.

$$K_{oc} = \frac{K_d}{\text{percent soil organic C}} \times 100$$

The soil organic *carbon* content of soils is not always readily available. Soil organic *matter* content, however, is often reported by soil testing laboratories or found in soil surveys. One can estimate the percent soil organic carbon content for your soil by dividing the percent organic matter content by 1.724.

The Environmental Protection Agency has set a threshold value for pesticide $\mathbf{K_{oc}}$ at 300 to 500 L/Kg. Pesticides with $\mathbf{K_{oc}}$ less than this threshold value are the ones most likely to leach or run off. A number of $\mathbf{K_{oc}}$ values are listed in Table IIIb. $\mathbf{K_{oc}}$ assumes an **equilibrium** between the soil and pesticide has been established. Certain climatic conditions, such as high rainfall, or management practices, such as furrow irrigation, can cause water to percolate quickly through a soil profile. Pesticides that are carried with this fast moving water may never be in contact with soil surfaces long enough to allow maximum pesticide adsorption to occur. In this situation, pesticides may move farther than one might predict from their $\mathbf{K_{oc}}$ values. Conversely, if pesticides are in contact with soil surfaces for long periods of time (weeks to months), $\mathbf{K_{oc}}$ values may increase with time due to the formation of bound residue and result in less movement than predicted. For these reasons $\mathbf{K_{oc}}$ values should be compared on a *relative* basis.

The strength of adsorption is inversely related to pesticides solubility in water and directly related to its partition coefficient. This is particularly true within a given class of compounds. Chlorinated hydrocarbons like dieldrin (no longer available) are strongly adsorbed, while phenoxy herbicides like 2,4-D are much more weakly adsorbed. This relationship holds for electrically neutral compounds but not for positively charged compounds because they can be strongly adsorbed on negatively charged soil surfaces (**cation exchange**).

Microbial Degradation

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 (i.e. nitrogen, phosphorus, sulfur). Degradation can occur by microbial action or by chemical reactions. A predominant pathway for pesticide loss in soils and water is through microbial degradation. Microbial degradation may be either direct or indirect. Some pesticides may be directly utilized as substrates (food sources) for growth and maintenance by microorganisms. In most cases however, microbial degradation of pesticides is believed to be indirect, where the pesticide is passively degraded or consumed along with other substrates found in the soil. Regardless, microbial degradation is a biological transformation whereby microorganisms transform the original compound into one or more different compounds. The intermediate products formed by the degradation process

may (and usually do) have chemical and physical properties different from those of the parent pesticide, and consequently behave differently in the environment. A primary degradation product of dicamba is dichlorosalicylic acid (DCSA). Dicamba is a highly mobile compound whereas DCSA is relatively immobile and has only about 10 percent of dicamba's weed control effectiveness. Most of atrazine's degradates lose their herbicide effectiveness; however, deethylatrazine (one of atrazine's degradates), is similar to atrazine in weed control.

The rate or **kinetics** of degradation varies with pesticide structure. Degradation rates are also influenced by such factors as: pesticide concentration, temperature, soil water content, pH, oxygen status, prior pesticide use, soil fertility, and microbial populations. The most important factors which influence microbial degradation change dramatically with soil profile depth (Figure 2). Soil horizons located deeper in the profile are cooler, generally contain much less organic matter and are relatively less fertile. These changes greatly reduce microbial populations and degradation rates. Therefore, as pesticides migrate below the soil surface (by even 6 to 12 inches), not only do the chances for pesticide retention decrease due to less organic matter, the chances for microbial degradation also decrease.

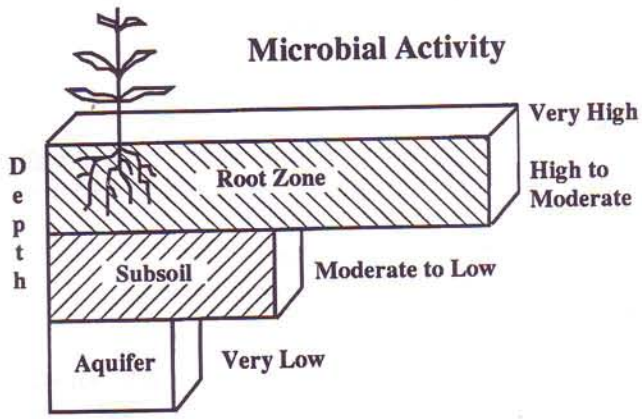

Figure 2. Changes in Microbial Activity with Depth.

Pesticide persistence is expressed as the time required for 50 percent of the original pesticide to decompose to other products. This length of time is termed **half-life**. For example, a pesticide with a half-life of three months will degrade to one-half of its original amount in three months. It will take another three months to degrade half of the remaining half (leaving one-fourth of the original amount) and so on.

Half-life measurements are commonly made in the laboratory under uniform conditions. In the field, soil temperature, organic carbon, and moisture content change constantly, and these factors dramatically influence the rate of degradation. Consequently, half-life values, as with most pesticide fate indices, should be considered as *guidelines* rather than absolute values. The Environmental Protection Agency's threshold value for half-life is three weeks, which indicates that pesticides with half-lives greater than three weeks are considered persistent and potentially threatening to water resources.

Chemical Degradation

Chemical degradation is similar to microbial degradation except that transformation of the original compound into other compounds is not microbially mediated. For both microbial and chemical degradation, the major chemical reactions are often the same and include hydrolysis, oxidation, and reduction. Photochemical or light-catalyzed degradation is another breakdown process that can influence the fate of pesticides. Chemical, biological, and photochemical processes may all work simultaneously to reduce the amount of pesticide residues in the environment.

Hydrolysis. Hydrolysis is a chemical transformation process in which the pesticide reacts with water, resulting in the splitting of the water molecule. Compounds that undergo hydrolysis contain certain functional groups (elements or groups of atoms) in their structure that can react with water. In soils, water is generally abundant enough to make this one of the most important chemical reactions influencing pesticide fate. Hydrolysis reactions may occur in **acidic** (pH values less than 7) or **alkaline** (pH greater than 7) soil environments and are pesticide specific. Atrazine is highly sensitive to acid hydrolysis and is less persistent at lower soil pH. Chlorpyrifos is sensitive to alkaline hydrolysis and is less persistent at higher soil pH. Diazinon is sensitive to hydrolysis reactions in both acidic and alkaline pH ranges. In Nebraska, soil pH generally increases with depth. This could result in an increase in atrazine persistence and decrease in chlorpyrifos persistence in the subsurface soil horizons. Hydrolysis reactions for two pesticides are shown in Figure 3.

Pesticides most subject to hydrolysis reactions include 2,4-D esters, carbamates, amines, and organophosphate insecticides. Examples of relative half-lives for a few pesticides based on rates of hydrolysis alone, and not including microbial degradation, are given in Table V. The values in Table V were estimated from data measured in aqueous solutions. Soils can profoundly influence the hydrolysis half-lives of some pesticides. This effect is attributed to adsorption of the pesticide and the pH at the surfaces of soil particles. The pH at soil surfaces can be considerably lower than the bulk soil solution and increase acid hydrolysis. In the field, half-lives due to hydrolysis may be shorter since adsorption of pesticides to soils can catalyze (increase) hydrolysis reaction rates. In one study, the

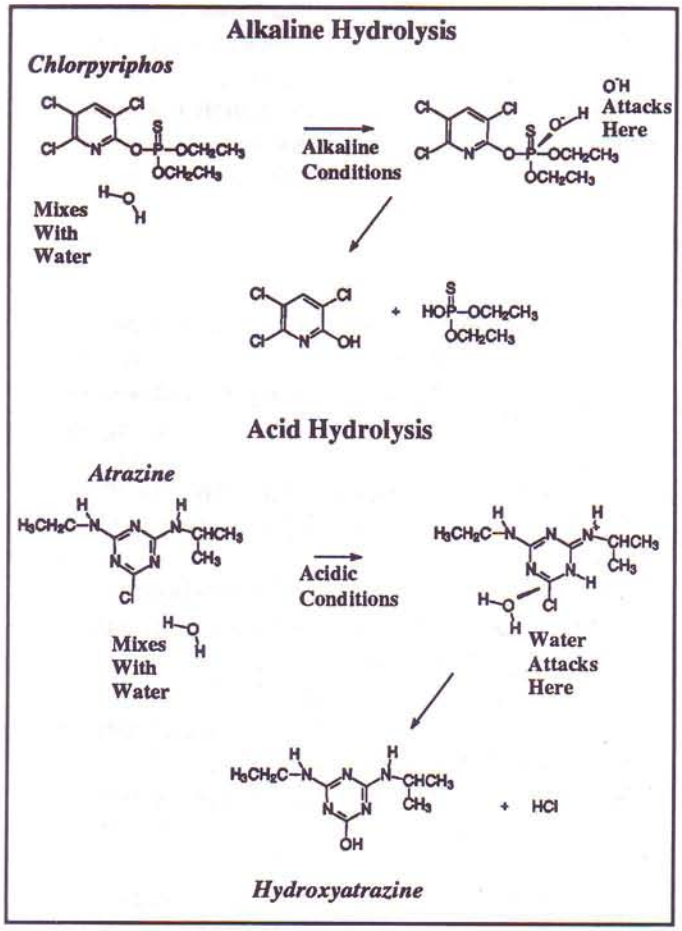

Figure 3. Examples of Hydrolysis Reactions.

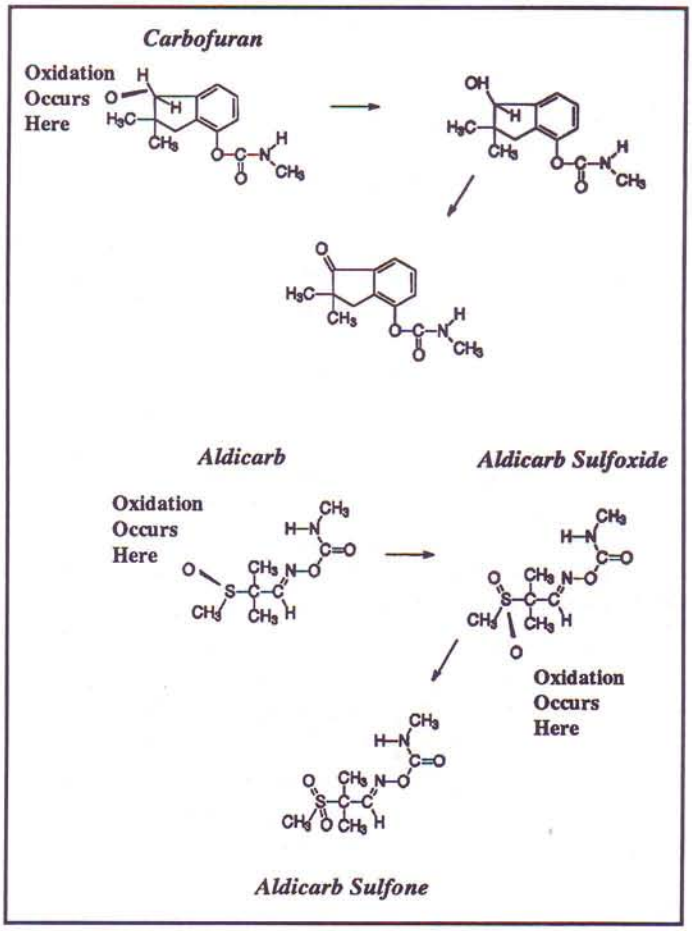

Figure 4. Examples of Oxidation Reactions.

half-life for atrazine in an aqueous solution (pH=3.9) was 209 days but in the presence of sterilized soil (thus removing the microbial degradation component) the half-life was only 22 days.

Oxidation. Oxidation is a chemical reaction that results in either addition of a oxygen atom, a loss of **electrons**, or an increase in the oxidation state of the pesticide. The oxidation of carbofuran is illustrated in Figure 4, which shows the addition of an oxygen atom. The degradate formed can be further oxidized by losing a hydrogen (H) atom and forming a ketone (an oxygen atom attached to a carbon atom with a double bond between). An increase in the number of bonds to nitrogen, carbon, sulfur or other atoms indicates oxidation of a pesticide. Initially it may not appear that oxidation reactions result in the breakdown of pesticides. In the carbofuran example, the degradate formed actually has a higher molecular weight than the parent compound. However, a more oxidized form of the molecule may be necessary for further microbial or chemical degradation in the environment. Mineralization end products H_2O and CO_2 (the final end products in pesticide degradation) are rich in oxygen.

Reduction. An organic chemical is considered to be reduced if its hydrogen content increases or its oxygen content decreases. As with oxidation reactions, reductions do not always involve changes in a chemical's hydrogen or oxygen content. A chemical is said to be reduced if it experiences a net gain in electrons or reduction in oxidation state. Reduction reactions generally occur under conditions where oxygen is limiting (anaerobic environments). This is generally not the case in surface soils but reduction can be an important reaction for pesticides in groundwater. Reductions reactions may increase if a soil becomes flooded.

Photodecomposition. Photochemical reactions are probably the least important of the processes that affect pesticides after they have migrated into soil because soils adsorb radiant energy. However, in air and water, or on soil and plant surfaces, photochemical reactions can be important. Pesticides which migrate to streams and lakes could be subject to degradation by photochemical reactions. It is difficult to predict from molecular structure the extent to which pesticides will be degraded by photochemical reactions. Direct photochemical reactions can be ruled out for those compounds that have no or extremely low absorbance of light at terrestrial surface solar radiations. However, pesticide photodegradation may occur indirectly as a result of reactions with other chemicals that readily

absorb light. Some pesticides which are known to be subject to photochemical breakdown include: carbaryl, 2,4-D, MCPA, malathion, methyl parathion, parathion, and trifluralin.

Volatilization and Evaporation

Volatilization is the process by which chemicals transform from a solid or liquid into a gas. Volatility is a measure of the escaping tendency of a chemical to transform into a gas and is usually numerically expressed in units of vapor pressure. Vapor pressure is the pressure exerted by the chemical in its gaseous state when in **equilibrium** with its solid or liquid state. Consider an example where water is placed in a sealed glass container and the air above the water is evacuated. In this example, some of the water in the glass will evaporate and the space above the water will contain water vapor or gaseous water. Depending on the temperature of the container, the water vapor in the space will increase until equilibrium is reached. At this point, as many water molecules escape the water as enter it (ie. the rates of evaporation and condensation are equal). If we were to measure the pressure inside the sealed glass we would find the vapor pressure of water at 25°C is 24 mm of mercury (Hg). By comparison, the vapor pressure of benzene (a highly flammable liquid) at the same temperature is 92 mm Hg.

The vapor pressures of pesticides used in Nebraska are listed in Table VIb. Pesticide volatilization increases as the vapor pressure increases. Vapor pressure can be useful for estimating the lifetime of foliar and soil application deposits. Pesticides that are formulated as salts are listed with a vapor pressure of zero since their present formulation are initially considered nonvolatile. With time however, transformations of the pesticide **salt** formulations can lead to volatile products. Therefore, one should not assume that no vapor losses can occur from pesticides formulated as salts.

Volatilization losses are usually less for pesticides that have low vapor pressures (such as atrazine) than those with high vapor pressures (such as trifluralin or phorate). Although the vapor pressures of triflurlin and phorate are much lower than water, they are classified as high for pesticides (Tables VIa, VIb). Pesticides that are volatile and have a low aqueous solubility are the ones most susceptible to volatilization.

On the basis of vapor pressures alone, one would expect little volatilization of pesticides. Volatilization and evaporation rates, however, can be influenced by surface area. In the case of pesticides, chemicals are spread over a large surface area and conditions are ideal for volatilization or evaporation. For example, a gallon of water in an open bucket may evaporate slowly, but when spread over an acre will evaporate quite readily. Evaporation or volatilization losses may have two outcomes. The first is loss of herbicide activity since the chemical may not persist long enough to give desired weed control. This is why soil incorporation is recommended for herbicides such as trifluralin. By incorporating the chemical, volatilization losses are greatly reduced because vapors must diffuse to the soil surface before escaping into the atmosphere. Another consequence of volatilization is drift of vapor onto nearby sensitive or non-target crops. This problem most often occurs with growth-regulating chemicals such as 2,4-D or dicamba on sensitive crops such as grapes and tomatoes.

It is important to remember that vapor pressure values are influenced by temperature. As temperature increases so does vapor pressure and the chance for volatilization loss. Volatilization losses are generally less following early spring application than later in the season when soil temperatures are higher. Volatilization will also increase with air movement and can be greater from an unprotected smooth surface than from fields with rough surfaces or wind breaks. Soil incorporation or immediate irrigation is usually recommended for highly volatile pesticides to reduce loss and damage to sensitive plants.

Plant Uptake

In order to be effective, herbicides must be absorbed by seeds or plants. Aside from directly absorbing and perhaps metabolizing pesticides, plant growth can also influence pesticide fate by altering the flow of water in the root zone. Crops that have high rates of **transpiration** can reduce the leaching of water soluble pesticides. Consequently, pesticides applied in early spring, when crop root systems are not well developed are more likely to migrate deeper into the soil profile with percolating water than in summer months when irrigation and precipitation are better utilized by the actively growing crop. Cover crops, which can utilize available nutrients (such as soluble nitrates) and water, can prevent erosion and also reduce deep percolation of pesticides and nutrients.

Possible Trouble Spots in Nebraska

Nebraska's topography, groundwater depths, and soil types are diverse and the specific site can have a dramatic impact on pesticide fate. A number of different attempts have been made to identify potential locations vulnerable to groundwater contamination. Included in this attempt is the formation of the DRASTIC model.

DRASTIC — A Groundwater Vulnerability Model

The DRASTIC model was developed for systematically evaluating groundwater pollution potential. The

Groundwater Vulnerability to Contamination in Nebraska Using the DRASTIC Method

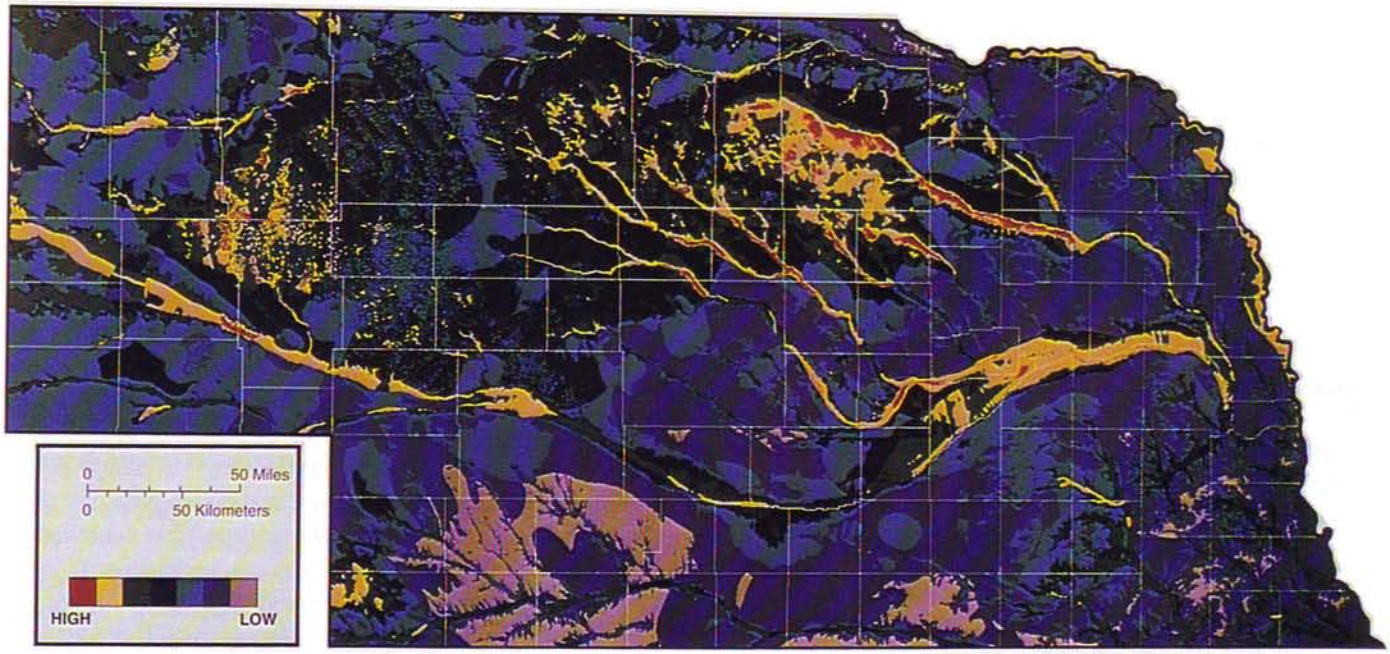

Figure 5. Nebraska Map of Potential Groundwater Vulnerability to Chemical Leaching (This map was produced by the Center for Advanced Land Management Information Technologies, Conservation and Survey Division, Institute of Agriculture and Natural Resources, UNL, under contract to the Nebraska Department of Environmental Control).

model computes an index that gives a measure of the groundwater vulnerability to pollution. The index is best used as a screening tool to determine if an area is generally sensitive or vulnerable to groundwater contamination. To determine this, DRASTIC considers seven factors: **D**epth to groundwater; **R**echarge of the aquifer, **A**quifer media, **S**oil media, **T**opography (slope), **I**nfluence of vadoze zone, and **C**onductivity (hydraulic).

In assessing areas that are most sensitive to groundwater contamination, the DRASTIC model makes four major assumptions. The DRASTIC model assumes the contaminant is: introduced at the ground surface, leached into the soil by precipitation, has the mobility of water ($K_{oc} = 0$) and that the area evaluated is 100 acres or larger.

A statewide map of Nebraska using the DRASTIC model is shown in Figure 5. Areas of greatest concern are indicated by a red color followed by yellow, light green, dark green, light blue, dark blue, and grey. It is apparent from the figure that areas along the major waterways and tributaries are susceptible to groundwater contamination. Examples of soil series or soil series associations found in these potentially vulnerable areas include Valentine, Gothenburg, Platte, Elsmore, Page, Hord, Gibbon, Cozad, Boel, Loup, Wildhorse, and Lawet. This listing is not inclusive but merely gives examples of some soil types present in these vulnerable areas.

About 70 percent of the atrazine contamination in Nebraska has been documented to occur in areas that are also subject to nitrate leaching. These areas are characterized as irrigated corn growing on excessively well- to well-drained soils with short distances to groundwater. These area can be typically found along the Central Platte River Valley. If you suspect that you may be applying pesticides in counties that have sensitive areas, you should consider the depth to groundwater for the specific site, as well as the soil and pesticide properties.

Protecting our Water Resources.

Having defined the major mechanism and processes responsible for determining the fate of pesticides in the

Water Quality Risk Factors

Chemical	*Soil*
■ High Solubility ■ Low Soil Adsorption Coefficient ■ Long Half-Life ■ Low Volatility	■ Porous Soil ■ Low Organic Matter
Site	*Management*
■ Shallow Water Table ■ Irrigated/Sloping Land ■ Near Surface Water ■ Sink Holes/Abandon Wells	■ Incomplete Planning ■ Misapplication ■ Over Irrigation

More Conditions Present = Greater Risks

Figure 6. Factors Contributing to Greater Risk for Ground and Surface Water Contamination.

environment, this information can now be used to guide responsible management decisions. Figure 6 summarizes the four factors which could lead to potential ground 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.

A primary concern when applying pesticides is to determine if the application site is vulnerable to ground or surface water contamination. In most cases, if the field is level and not close to surface waters (rivers, lakes, or wetlands) the chances for pesticide run off will be minimal. If the depth to groundwater is greater than 50 feet on fine-textured, nonirrigated soils, the chances for deep percolation are also reduced. Sandy soils, low in organic matter, should be particularly scrutinized when pesticide applications are needed.

If the field is susceptible to rapid leaching or runoff, the next consideration would be the characteristics of the pesticide that influence mobility and persistence. These characteristics and classifications can be obtained from Tables III and IV. When several pesticide options exist for the pest and site to be treated, the data presented in the tables should help users select the pesticide that presents the least potential for ground or surface water contamination.

RIPS — A Water Quality Decision Aid

One way to determine if the pesticide-site combination chosen poses a risk to groundwater contamination is to use a decision aid developed by University of Nebraska scientists. This decision aid is available in a booklet or computer program format. The computer program is easy to use and well suited for many agricultural practitioners. The program asks four main questions: (1) depth to groundwater; (2) what soil series will be receiving the pesticide; (3) which pesticide is intended to be applied; and (4) whether the pesticide will be surface broadcast or soil incorporated. A list of 16 soil series found in Nebraska are included in the program. If the soil series of interest is not listed, you may choose one that closely resembles your soil or you may type in the soil series name along with the soil's pH, organic matter content, hydraulic conductivity, and cation exchange capacity. This information is usually available from your county soil survey or Soil Conservation Service. Having entered this information, the computer program calculates a pesticide-soil score and a groundwater contamination score. Scores range from 2 to 100 and are grouped into five categories with the higher values representing a higher potential for pesticide leaching and groundwater contamination. By comparing your score with the five pesticide-soil or groundwater contamination categories, you can ascertain whether your particular soil-pesticide combination poses a threat to groundwater contamination. If you identify a potential contamination concern, you may wish to consult with extension personnel who may assist you in choosing alternative pesticides or management strategies that would reduce the potential for groundwater contamination.

For further information on how to obtain a copy of RIPS, write to the Department of Agronomy (Weed Science), 362 Plant Science, University of Nebraska, Lincoln, NE 68583-0915.

Individual Efforts Can Make a Difference

Nebraska has one of the largest underground water supplies in the nation. It is our obligation to protect this valuable resource. Researchers at the University of Nebraska and elsewhere continue to search for best management practices (BMP's) to protect our water resources. The most important thing a user can do when using pesticides is to read and follow the label directions. From planning and preparation to storage and disposal, following the label directions will significantly reduce the risks of contaminating our water resources. When possible, select a pesticide that poses the least threat to rapid leaching or runoff and is relatively nonpersistent. This will help maintain the high quality of water we enjoy in Nebraska. By acting now, we can assure future generations of Nebraskans the chance to enjoy the water quality we are blessed with today.

Glossary of Terms

Absorption — The process by which a chemical passes from one system *into* another such as from the soil solution into a plant root or into the matrix of a soil particle.

Acidic Pesticide — A pesticide whose neutral (molecular) form becomes negatively charged as pH is increased. Example: dicamba.

Adsorption — Retention of a chemical onto the surface of a soil particle.

Aqueous Solubility — The maximum amount of chemical that can be dissolved in water.

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.

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

Chelate — An association between an organic compound and an inorganic (metallic) cation in which the cation is held by bonding to parts of the organic compound. Example: glyphosate can form a chelate with calcium or magnesium.

Degradation — The chemical or biological transformation of the original (parent) compound into one or more different compounds (degradates, intermediates, metabolites).

Desorption — The detachment of a pesticide from a soil particle.

Electron — The negatively charged component of atoms; they exist in roughly spherical clouds around the center of atoms.

Equilibrium — A state of dynamic balance, where forward and reverse reactions or forces are equal and the system does not change with time. Example: the relative humidity of air is a measurement of how much water a body of air holds relative to its capacity at a given temperature and is in balance or "equilibrium" between evaporation and condensation forces.

Groundwater — Water which saturates cracks, caverns, 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, intermediate, or metabolite).

Hydrolysis — A chemical degradation process resulting from the reaction of an organic molecule (pesticide) with water under acidic or alkaline conditions.

Humus — The more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed. Usually dark colored. See also, soil organic matter.

K_d — See Soil Partition Coefficient.

Kinetic — A study of time dependent processes. The kinetics of pesticide adsorption indicates the rate at which pesticides are adsorbed by soil particles.

K_{oc} — See Organic Carbon Partition Coefficient.

Leaching — The downward movement by water of dissolved or suspended minerals, fertilizers, agrichemicals and other substances through soil.

MCL (Maximum Contaminant Level) — an enforceable, regulatory standard for maximum permissible concentrations as an annual average of contaminants in water. MCL's are established under the federal Safe Drinking Water Act, which assures Americans of a safe and wholesome water supply. The MCL standards of purity are applied to water distribution systems after the water has been treated, regardless of a surface or ground water source. They are health-based numbers which by law must be set as close to the "no-risk" level as feasible.

Microorganism — A biotic organism, microscopic in size, found in soils and important in the degradation of most pesticides.

Mineralization — The complete transformation or degradation of a pesticide into carbon dioxide (CO_2), water (H_2O) and other inorganic products.

Nonpoint Sources of Contaminants — Water contaminants coming from nonspecific sources, for example, from agriculture and municipal runoff.

Nonpolar — A term used to describe a molecule (pesticide) whose electrical charge distribution is evenly distributed (no regions of positive or negative charge). Nonpolar compounds are characterized as being hydrophobic (water-hating) and not very soluble in water but readily bound to (or soluble in) organic matter.

Organic Carbon Partition Coefficient — A universal constant used to describe the tendency of a pesticide to sorb to the soil organic fraction component of a soil. Often abbreviated as K_{oc}.

Oxidation — A chemical reaction involving the addition of an oxygen atom or a net loss in electrons.

Percolation — The downward movement of water through soil.

pH — A numerical measure of acidity used to distinguish alkaline, neutral and acidic solutions. The scale is from 1 to 14; neutral is pH 7.0, values below 7 are acidic, and above 7 are alkaline.

ppb (parts per billion) — An abbreviation indicating the parts or mass of a pesticide in a billion parts of water or soil.

ppm (parts per million) — An abbreviation indicating the parts or mass of a pesticide in a million parts of water or soil.

Point Sources of Contaminants — Water contaminants from specific sources such as leaking underground gasoline storage tank, run-off from a cattle feed lot, back-siphoning of an agrichemical into a well or spillage of a chemical near a water supply.

Polar — A term used to describe a molecule (such as a pesticide) whose electrical charge distribution results in positively and negatively charged regions on the molecule. Polar compounds are characterized as being hydrophilic (water-loving) and readily soluble in water but not strongly bound to organic matter.

Salt — A solid ionic compound (pesticide) made up from a cation other than H^+ and an anion other than OH^- or O^{2-}. Example: acifluorfen sodium salt.

Soil Organic Matter — The organic fraction of soil: includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. See also, Humus.

Soil Partition Coefficient — A "soil specific" unit of measure used to describe the sorption tendency of a pesticide to a soil. Often abbreviated as $\mathbf{K_d}$ or $\mathbf{K_p}$.

Sorption — A catch-all term referring to the processes of absorption, adsorption or both.

Transpiration — Most of the water lost by plants evaporates from leaf surfaces by the processes of transpiration. Transpiration is essentially the evaporation of water from cell surfaces and its loss through the anatomical structures of the plant.

Vapor Pressure — A numerical unit of measure used to indicate the tendency of a compound (liquid or solid) to volatilize or become a gas. A commonly used unit of measurement for pesticide vapor pressure is millimeters of mercury (abbreviated: mm Hg).

Volatilization — The process by which chemicals go from a solid or liquid state into a gaseous state.

Water Table — The top of an unpressurized aquifer, below which the pore spaces generally are saturated with water. The aquifer is held in place by an underlying layer of relatively impermeable rock. The water table depth fluctuates with climatic conditions on the land surface above, and the rate of discharge and recharge of the aquifer.

Table I. Maximum Contaminant Levels (MCL) of Pesticides in Drinking Water.

Common Name	Trade Name	MCL (ppb)
Alachlor	Lasso	2
Aldicarb	Temik	3
Aldicarb sulfone	Degradate of Temik	2
Aldicarb sulfoxide	Degradate of Temik	4
Atrazine	Aatrex	3
Carbofuran	Furadan	40
2,4-D	Weedone, 2,4-D, etc.	70
Dalapon	Dalapon	200
Dinoseb	Dinoseb	7
Diquat	Diquat	20
Endothall	Endothal	100
Glyphosate	Roundup	700
Oxamyl (Vydate)		200
Picloram	Tordon	500
Simazine	Princep	4

Table IIa. Water Solubility Classes of Pesticides.

Solubility	Class Description
ppm (mg/L)	
greater than 3,000	very high
3,000 to 300	high
300 to 30	moderate
30 to 3	low
less than 3	very low

Table IIb. Water Solubilities of Commonly used Pesticides in Nebraska.

Common Name	Trade Name	Water Solubility (mg/L)
Acifluorfen sodium salt (H)	Blazer	250,000
Alachlor (H)	Lasso	240
Aldicarb (I)	Temik	6,000
Atrazine (H)	Aatrex	33
Benefin (H)	Balan	2,300,000
Bentazon sodium salt (H)	Basagran	0.1
Bromoxynil butyrac ester (H)	Buctril	27
Butylate (H)	Sutan +	44
Carbaryl (I)	Sevin	120
Carbofuran (I)	Furadan	351
Chlorimuron ethyl (H)	Classic	1,200
Chlorpyrifos (I)	Lorsban, Dursban	0.4
Chlorsulfuron (H)	Glean	7,000
Clomazone (H)	Command	1,100
Clopyralid (salt) (H)	Stinger	300,000
Cyanazine (H)	Bladex	170
Cycloate (H)	Ro-neet	95
Desmedipham (H)	Betanex	8
Diazinon (I)	DZN, Diazinon	60
Dicamba salt (H)	Banvel	400,000
Diclofop-methyl (H)	Hoelon	0.8
Diquat (salt) (H)	Diquat	718,000
2,4-D ester (H)	Weedone, etc.	100
2,4-D amine (H)	2,4-D amine	796,000
2,4-DB salt (H)	Butyrac	709,000
EPTC (H)	Eradicane	344
Ethofumesate (H)	NortonSC	50
Fenoxaprop-ethyl (H)	Bugle, (Opt II)	0.8
Fluazifop-p-butyl (H)	Fusilade-2000	2
Fomesafen (H)	Reflex	700,000
Glyphosate isopropylamine salt (H)	Roundup	900,000
Imazamethabenz-methyl (m-isomer) (H)	Assert	1,370
Imazamethabenz-methyl (p-isomer) (H)	Assert	857
Imazapyr acid (H)	Arsenal	11,000
Imazaquin salt (H)	Scepter	160,000
Imazethapyr (H)	Pursuit	200,000
Lactofen (H)	Cobra	0.1
Linuron (H)	Lorox	75
Malathion (I)	Cygon	130
MCPA (salt) (H)	Rhomene	866,000

Table IIb. Water Solubilities of Commonly used Pesticides in Nebraska (continued).

Common Name	Trade Name	Water Solubility (mg/L)
MCPA (ester) (H)	various	5
MCPP (H)	2 + 2 (MCPP+2,4-D)	660,000
Methyl parathion (I)	Mocap	60
Metolachlor (H)	Dual	530
Metribuzin (H)	Sencor, Lexone	1,220
Metsulfuron-methyl (H)	Ally	9,500
Nicosulfuron (H)	Accent	70 (at pH 7)
Oxyfluorfen (H)	Goal	0.1
Paraquat (H)	Gramoxone Extra	620,000
Pendimethalin (H)	Prowl	0.275
Permethrin (I)	Ambush, Pounce	0.006
Phorate (I)	Thimet	22
Picloram (H)	Tordon	200,000
Primisulfuron (H)	Beacon	12,200 (at pH 7)
Propachlor (H)	Ramrod	613
Pyrazon (H)	Pyramin	400
Quizalofop-ethyl (H)	Assure II	0.31
Sethoxydim (H)	Poast Plus	4,390
Simazine (H)	Princep	6.2
Tebuthiuron (H)	Spike	2,500
Terbufos (I)	Counter	5
Thifensulfuron-methyl (H)	Pinnacle	2,400
Triclopyr ester (H)	Crossbow	23
Trifluralin (H)	Treflan	0.3

(H) - Herbicide, (I) Insecticide.

Table IIIa. Mobility Classes of Pesticides based on Organic Carbon Partition Coefficients.

Organic C Partition Coefficient (K_{oc})	Class Description
greater than 2,000	immobile
2,000 to 500	low mobility
500 to 150	intermediate mobility
150 to 50	mobile
less than 50	very mobile

Table IIIb. Organic Carbon Partition Coefficients (K_{oc}) for Pesticides Commonly used in Nebraska.

Common Name	Trade Name	K_{oc} (L/Kg)
Acifluorfen sodium salt (H)	Blazer	113
Alachlor (H)	Lasso	170
Aldicarb (I)	Temik	30
Atrazine (H)	Aatrex	100
Benefin (H)	Balan	34
Bentazon sodium salt (H)	Basagran	9,000
Bromoxynil butyrac ester (H)	Buctril	1,079
Butylate (H)	Sutan +	400
Carbaryl (I)	Sevin	300
Carbofuran (I)	Furadan	22
Chlorimuron ethyl (H)	Classic	110
Chlorpyrifos (I)	Lorsban, Dursban	6,070
Chlorsulfuron (H)	Glean	40
Clomazone (H)	Command	300
Clopyralid (salt) (H)	Stinger	6
Cyanazine (H)	Bladex	190
Cycloate (H)	Ro-neet	430
Desmedipham (H)	Betanex	1,500
Diazinon (I)	DZN, Diazinon	1,000
Dicamba salt (H)	Banvel	2
Diclofop-methyl (H)	Hoelon	16,000
Diquat (salt) (H)	Diquat	1,000,000
2,4-D ester (H)	Weedone, etc.	100
2,4-D amine (H)	2,4-D amine	20
2,4-DB salt (H)	Butyrac	20
EPTC (H)	Eradicane	200
Ethofumesate (H)	NortonSC	340
Fenoxaprop-ethyl (H)	Bugle, (Opt II)	9,490
Fluazifop-p-butyl (H)	Fusilade-2000	5,700
Fomesafen (H)	Reflex	60
Glyphosate isopropylamine salt (H)	Roundup	24,000
Imazamethabenz-methyl (m-isomer) (H)	Assert	66
Imazamethabenz-methyl (p-isomer) (H)	Assert	35
Imazapyr acid (H)	Arsenal	100
Imazaquin salt (H)	Scepter	20
Imazethapyr (H)	Pursuit	10
Lactofen (H)	Cobra	10,000
Linuron (H)	Lorox	400
Malathion (I)	Cygon	1,800
MCPA (salt) (H)	Rhomene	20
MCPA (ester) (H)	various	1,000
MCPP (H)	2 + 2 (MCPP+2,4-D)	20
Methyl parathion (I)	Mocap	5,100
Metolachlor (H)	Dual	200
Metribuzin (H)	Sencor, Lexone	60
Metsulfuron-methyl (H)	Ally	35
Nicosulfuron (H)	Accent	100 (E)
Oxyfluorfen (H)	Goal	100,000
Paraquat (H)	Gramoxone Extra	1,000,000
Pendimethalin (H)	Prowl	5,000
Permethrin (I)	Ambush, Pounce	100,000
Phorate (I)	Thimet	1,000
Picloram (H)	Tordon	16
Primisulfuron (H)	Beacon	95
Propachlor (H)	Ramrod	80
Pyrazon (H)	Pyramin	120
Quizalofop-ethyl (H)	Assure II	510
Sethoxydim (H)	Poast Plus	100
Simazine (H)	Princep	130
Tebuthiuron (H)	Spike	80
Terbufos (I)	Counter	500
Thifensulfuron-methyl (H)	Pinnacle	45
Triclopyr ester (H)	Crossbow	780
Trifluralin (H)	Treflan	8,000

(H) - Herbicide, (I) Insecticide (E) Estimated value.

Table IVa. Persistence Classes of Pesticides based on Soil Half-life values.

Soil Half - Life	Class Description
days	
greater than 100	High Persistent
100 to 30	Moderately Persistent
30 to 15	Moderately Short-Lived
15 to 5	Short-Lived
less than 5	Very Short-Lived

Table IVb. Half-lives of Pesticides Commonly used in Nebraska.

Common Name	Trade Name	Half-life (days)
Acifluorfen sodium salt (H)	Blazer	14
Alachlor (H)	Lasso	15
Aldicarb (I)	Temik	30
Atrazine (H)	Aatrex	60
Benefin (H)	Balan	20
Bentazon sodium salt (H)	Basagran	40
Bromoxynil butyrac ester (H)	Buctril	7
Butylate (H)	Sutan +	13
Carbaryl (I)	Sevin	10
Carbofuran (I)	Furadan	50
Chlorimuron ethyl (H)	Classic	40
Chlorpyrifos (I)	Lorsban, Dursban	30
Chlorsulfuron (H)	Glean	40
Clomazone (H)	Command	24
Clopyralid (salt) (H)	Stinger	40
Cyanazine (H)	Bladex	14
Cycloate (H)	Ro-neet	30
Desmedipham (H)	Betanex	30
Diazinon (I)	DZN, Diazinon	40
Dicamba salt (H)	Banvel	14
Diclofop-methyl (H)	Hoelon	30
Diquat (salt) (H)	Diquat	1,000
2,4-D ester (H)	Weedone, etc.	10
2,4-D amine (H)	2,4-D amine	10
2,4-DB salt (H)	Butyrac	10
EPTC (H)	Eradicane	6
Ethofumesate (H)	NortonSC	30
Fenoxaprop-ethyl (H)	Bugle, (Opt II)	9
Fluazifop-p-butyl (H)	Fusilade-2000	15
Fomesafen (H)	Reflex	100
Glyphosate isopropylamine salt (H)	Roundup	47
Imazamethabenz-methyl (m-isomer) (H)	Assert	45
Imazamethabenz-methyl (p-isomer) (H)	Assert	45
Imazapyr acid (H)	Arsenal	90
Imazaquin salt (H)	Scepter	60
Imazethapyr (H)	Pursuit	90
Lactofen (H)	Cobra	3
Linuron (H)	Lorox	60
Malathion (I)	Cygon	1
MCPA (salt) (H)	Rhomene	25
MCPA (ester) (H)	various	25
MCPP (H)	2 + 2 (MCPP+2,4D)	21
Methyl parathion (I)	Mocap	5
Metolachlor (H)	Dual	90
Metribuzin (H)	Sencor, Lexone	40
Metsulfuron-methyl (H)	Ally	30

Table IVb. Half-lives of Pesticides Commonly used in Nebraska (continued).

Common Name	Trade Name	Half-life (days)
Nicosulfuron (H)	Accent	40 (E)
Oxyfluorfen (H)	Goal	35
Paraquat (H)	Gramoxone Extra	1,000
Pendimethalin (H)	Prowl	90
Permethrin (I)	Ambush, Pounce	30
Phorate (I)	Thimet	60
Picloram (H)	Tordon	90
Primisulfuron (H)	Beacon	40 (E)
Propachlor (H)	Ramrod	6
Pyrazon (H)	Pyramin	21
Quizalofop-ethyl (H)	Assure II	60
Sethoxydim (H)	Poast Plus	5
Simazine (H)	Princep	60
Tebuthiuron (H)	Spike	360
Terbufos (I)	Counter	5
Thifensulfuron-methyl (H)	Pinnacle	12
Triclopyr ester (H)	Crossbow	46
Trifluralin (H)	Treflan	60

(H) - Herbicide, (I) Insecticide (E) Estimated value.

Table V. Estimated Half-lives for Pesticides Susceptible to Hydrolysis at three pH values.

Pesticide	pH		
	5	7	9
		days	
Diazinon	32	176	84.0
Carbaryl	2,359	24	0.2
Chlorpyrifos	80	73	7.3
Malathion	586	14	0.2

Table VIa. Volatility Classes of Pesticides based on Vapor Pressure Values.

Vapor Pressure	Class Description
mm Hg	
greater than 1.0×10^{-1}	Very High
1.0×10^{-1} to 1.0×10^{-4}	High
1.0×10^{-4} to 1.0×10^{-6}	Moderate
1.0×10^{-6} to 1.0×10^{-7}	Low
less than 1.0×10^{-7}	Very Low

Table VIb. Vapor Pressures of Pesticides Commonly used in Nebraska.

Common Name	Trade Name	Pressure (mm Hg)
Acifluorfen sodium salt (H)	Blazer	0
Alachlor (H)	Lasso	1.40×10^{-5}
Aldicarb (I)	Temik	3.00×10^{-5}
Atrazine (H)	Aatrex	2.89×10^{-7}
Benefin (H)	Balan	0
Bentazon sodium salt (H)	Basagran	6.60×10^{-5}
Bromoxynil butyrac ester (H)	Buctril	1.00×10^{-4}
Butylate (H)	Sutan +	1.30×10^{-2}
Carbaryl (I)	Sevin	1.20×10^{-6}
Carbofuran (I)	Furadan	6.00×10^{-7}
Chlorimuron ethyl (H)	Classic	4.00×10^{-12}
Chlorpyrifos (I)	Lorsban, Dursban	1.70×10^{-5}
Chlorsulfuron (H)	Glean	4.60×10^{-6}
Clomazone (H)	Command	1.40×10^{-4}
Clopyralid (salt) (H)	Stinger	0
Cyanazine (H)	Bladex	1.60×10^{-9}
Cycloate (H)	Ro-neet	1.60×10^{-3}
Desmedipham (H)	Betanex	3.00×10^{-9}
Diazinon (I)	DZN, Diazinon	6.00×10^{-5}
Dicamba salt (H)	Banvel	0
Diclofop-methyl (H)	Hoelon	3.5×10^{-6}
Diquat (salt) (H)	Diquat	0
2,4-D ester (H)	Weedone, etc.	
2,4-D amine (H)	2,4-D amine	0
2,4-DB salt (H)	Butyrac	0
EPTC (H)	Eradicane	3.40×10^{-2}
Ethofumesate (H)	NortonSC	4.90×10^{-6}
Fenoxaprop-ethyl (H)	Bugle, (Opt II)	3.20×10^{-8}
Fluazifop-p-butyl (H)	Fusilade-2000	2.50×10^{-7}
Fomesafen (H)	Reflex	0
Glyphosate isopropylamine salt (H)	Roundup	0
Imazamethabenz-methyl (m-isomer) (H)	Assert	1.10×10^{-8}
Imazamethabenz-methyl (p-isomer) (H)	Assert	1.10×10^{-8}
Imazapyr acid (H)	Arsenal	$<1.00 \times 10^{-8}$
Imazaquin salt (H)	Scepter	0
Imazethapyr (H)	Pursuit	
Lactofen (H)	Cobra	8.00×10^{-9}
Linuron (H)	Lorox	1.70×10^{-5}
Malathion (I)	Cygon	8.00×10^{-6}
MCPA (salt) (H)	Rhomene	0
MCPA (ester) (H)	various	1.50×10^{-6}
MCPP (H)	2 + 2 (MCPP+2,4-D)	0
Methyl parathion (I)	Mocap	1.50×10^{-5}
Metolachlor (H)	Dual	3.14×10^{-5}
Metribuzin (H)	Sencor, Lexone	$<1.00 \times 10^{-5}$
Metsulfuron-methyl (H)	Ally	2.50×10^{-12}
Nicosulfuron (H)	Accent	1.00×10^{-9}
Oxyfluorfen (H)	Goal	2.00×10^{-7}
Paraquat (H)	Gramoxone Extra	0
Pendimethalin (H)	Prowl	9.4×10^{-6}
Permethrin (I)	Ambush, Pounce	1.30×10^{-8}
Phorate (I)	Thimet	6.40×10^{-4}
Picloram (H)	Tordon	0
Primisulfuron (H)	Beacon	1.00×10^{-9}
Propachlor (H)	Ramrod	2.30×10^{-4}
Pyrazon (H)	Pyramin	5.00×10^{-2}
Quizalofop-ethyl (H)	Assure II	3.00×10^{-7}
Sethoxydim (H)	Poast Plus	1.60×10^{-7}
Simazine (H)	Princep	2.21×10^{-8}
Tebuthiuron (H)	Spike	2.00×10^{-6}
Terbufos (I)	Counter	3.20×10^{-4}
Thifensulfuron-methyl (H)	Pinnacle	1.30×10^{-10}
Triclopyr ester (H)	Crossbow	1.26×10^{-6}
Trifluralin (H)	Treflan	1.10×10^{-4}

(H) - Herbicide, (I) Insecticide.