Weeds reduce crop yields by competing for water, nutrients and light. Some weeds release toxins that inhibit crop growth, and others may harbor insects, diseases or nematodes that attack crops. Weeds often interfere with harvesting operations, and at times contamination with weed seeds or other plant parts may render a crop unfit for market. Profitable crop production depends on effective weed control.

Effective weed control in field crops requires the use of a combination of management techniques, including cultural methods and herbicides. Growing the same crop year after year and using the same weed control techniques encourage the development of problem weeds. Rotation of crops, herbicides and tillage methods help reduce this problem.

Cultural Control of Weeds

Crop competition is a very useful method of weed control. Maintaining production practices that optimize crop growth means the crop plants can compete more effectively with weeds. Several crop management practices can improve the competitive ability of the crop. These practices include crop and variety selection, planting date, population, soil fertility, drainage, etc. Recommended crop production practices are also beneficial weed control practices.

Crop and herbicide rotation may also be helpful in maintaining adequate weed control. Many weeds cannot tolerate crop rotation. Using the same herbicide program each year allows weeds tolerant of the herbicides to expand. Rotate herbicide programs to prevent this problem and to reduce the likelihood of herbicide-resistant weeds (e.g., triazine-resistant weeds) becoming a problem.

Cultivation

Timely, shallow cultivation may be necessary following herbicide application. Be sure to cultivate as shallowly as possible to prevent bringing new weed seeds from below the herbicide layer to the soil surface.

Do not cultivate most preemergence herbicides for at least 2 weeks after application unless weeds appear. If dry weather persists for 7-10 days after herbicide application, rotary hoe or cultivate shallowly. Delay cultivation after postemergence herbicide applications for at least 7-10 days to allow the chemical to move into weed stems and roots.

Chemical Control of Weeds

The first step for successful weed control with herbicides is to identify the weed species present. Note that some weed species are resistant to all of the present selective herbicides.

Annual weeds are easier to kill when they are small seedlings and when conditions favor rapid growth. However, crop plants are also easily injured under these conditions. Selective herbicides should control the weeds with little or no injury to the crop.

Timing and rate of application are very important with chemical weed control. Spraying at the wrong time often results in poor weed control and crop injury. No crop plant is completely resistant to injury from herbicides. Too much chemical can damage the crop.

Types of Herbicides

Chemical control of weeds can be obtained with either preplant incorporated, preemergence or postemergence herbicide applications. Many herbicides can be applied by more than one of these methods.

Preplant incorporated herbicides are compounds incorporated into the soil prior to planting. Incorporation of some of these herbicides is necessary to prevent losses of volatile active ingredients (e.g., EPTC) or to overcome photo-decomposition losses if the mater-ials (e.g., trifluralin) are left on the soil surface. Preplant incorporated herbicides have increased activity in the absence of rainfall that is required to move the herbicide into the weed-seed germination zone. This concept is often referred to as herbicide "activation."

Advantages of preplant incorporated herbicides:

(1) No weed competition to the crop with early control of weeds.

(2) Weeds are already controlled when wet weather causes delays in cultivation or spraying.

(3) Less reliance on rainfall to position the herbicides in the weed seed germination zone of the soil.

(4) Much more effective control of some perennial weeds (nutsedge) than with preemergence herbicide applications.

Disadvantages of preplant incorporated herbicides:

(1) Incorporation operation represents added cost and fuel usage in herbicide application.

(2) Soil compaction is increased by the incorporation operation.

(3) Herbicide may be diluted by improper incorporation (too deep), resulting in reduced weed control.

(4) "Streaking" pattern of good and poor weed control can result from incomplete incorporation. Two-pass incorporation helps prevent this problem.

(5) Planting operations may be slowed somewhat because of the added incorporation operation.

Preemergence herbicides are compounds applied to the soil surface after the crop has been planted but before the crop seedlings emerge through the soil.

Advantages of preemergence herbicides:

(1) No weed competition to the crop with early control of weeds.

(2) Weeds are already controlled when wet weather delays cultivation or spraying.

(3) Planting and herbicide application may be one operation.

(4) In the case of corn, herbicides can be used which may be a hazard to nearby 2,4-D- or dicamba-sensitive crops and plants if applied later in the season.

Disadvantages of preemergence herbicides:

(1) Preemergence applications are generally ineffective under dry soil conditions. Some preemergence herbicides are ineffective if dry conditions persist for only a few days; other herbicides may give weed control after as much as 10 days to 2 weeks of dry weather.

(2) On sandy soil, heavy rains may leach the herbicide down to the germinating crop seed and cause injury.

(3) Perennial weeds usually are not controlled by preemergence herbicide applications.

Postemergence herbicides are compounds applied to the foliage of weeds. They may burn off the aboveground parts of weeds (contact herbicides) or they may be translocated throughout the plants and kill the growing points (systemic herbicides).

Advantages of postemergence herbicides:

(1) They are not applied until the weeds are present in the field.

(2) Can be used on any soil type, and soil moisture conditions are usually not a problem.

(3) Are usually more effective (though more injurious to the crop) at high temperatures.

Disadvantages of postemergence herbicides:

(1) Should not be applied to weeds when the foliage is wet with dew or rain.

(2) There is a risk of crop injury for certain crops.

(3) With many postemergence herbicides, timing of application is critical for effective control.

(4) Rain may prevent application at the proper time.

Temperature greatly influences the effectiveness and volatility of many postemergence herbicides. Ideally, herbicides should be applied when temperatures range between 65° and 80°F. Low temperatures (below 60°F.) can result in reduced weed control; temperatures above 80°F. can result in crop injury. Late afternoon herbicide applications are less likely to result in injury than are early morning applications. Early morning application predisposes the crop plant to danger periods of high temperatures, which increase the potential for herbicide injury.

Volatile herbicides, such as dicamba (*Banvel/Clarity/DiFlexx/DiFlexx DUO/Status*) or ester formulations of 2,4-D, may vaporize at temperatures as low as 70°F. Wind may then move sufficient vapors to areas with sensitive crops to cause crop injury. Amine formulations of 2,4-D may eliminate some of the danger of vapor drift; however, spray drift (droplets) may still occur. Extreme caution is required when applying herbicides near sensitive crops.

Herbicide Formulations and Additives

Herbicides are available in a variety of formulations; granular and those mixed in water are most common. Usually, equal weed control can be expected from granular and those mixed in water. In some cases, granules have given less control. Generally, this has been due to (1) use of equipment giving non-uniform distribution of the granules or (2) formulations with too high a concentration, resulting in inadequate volume for uniform distribution.

The use of granular formulations does not eliminate the need for calibration. Various materials will “feed” differently because of variations in carrier and particle size. Therefore, granular applicators, like sprayers, should be accurately calibrated.

Herbicide Formulations

AS — *Aqueous capsule suspension*
CS — *Capsule suspension*
DC — *Dry concentrate*
DF — *Dry flowable*
DG — *Dispersible granule*
DS — *Dry soluble granule*
EC — *Emulsifiable concentrate*
EW — *Emulsion*
F — *Flowable*
G — *Granule*
L — *Liquid*
SC — *Suspension concentrate*
SG — *Soluble granule*
SL — *Soluble concentrate*
SP — *Soluble powder*
WG — *Water dispersible granules*
WP — *Wettable powder*
ZC — *Zeon concentrate*

Combinations of Herbicides

Two or more herbicides are usually applied as a tank mix rather than separate applications. Combinations are used to give more consistent or broader spectrum weed control, to decrease herbicide residue (for example, atrazine carryover) or to obtain adequate season-long weed control. Growers and commercial applicators are responsible for poor weed control, crop injury and/or unwanted herbicide residue from herbicides labeled for single application but misused in combinations.

Compatibility of Pesticide-Fertilizer Combinations

Combinations of herbicides, insecticides and/or fungicides applied in either water or liquid fertilizer carriers decrease trips over the field and application costs; however, compatibility is critical. Always test the compatibility of each mixture to be applied even though the product labels allow mixing. Follow the label instructions closely during any mixing operation after you have tested for compatibility.

A single compatibility test requires only a glass quart jar and the pesticides and liquid fertilizer to be mixed. Place 1 pint of liquid fertilizer in the quart jar and add 2 teaspoons of the liquid pesticide. If the pesticide is a wettable powder, add 2 teaspoons of powder in sufficient water to form a slurry and add the slurry to the fertilizer. Cover the jar, shake well, and observe the mixture for 30 seconds. Check the mixture again after 30 minutes. If the mixture does not separate, it is compatible; however, check each batch of liquid fertilizer — they may vary in mixing properties. Also, check compatibility if the water source changes — water pH and mineral content influence compatibility.

If more than one pesticide is to be mixed with liquid fertilizer or water, the pesticides should be premixed in liquid fertilizer or water and tested for compatibility by mixing appropriate proportions of all components. The combination should be thoroughly agitated before each additional pesticide is added, and a specific mixing order should be followed.

Generally, unless label directions state otherwise, add the pesticides being tested in the following order:

1. Water conditioners (e.g., AMS) and drift reducing agents (DRAs)
2. Wettable powders or dispersible granules.
3. Flowables or aqueous liquids.
4. Emulsifiable concentrates.
5. Crop oil concentrates or surfactants.

Spray tanks should be at least half filled with the carrier before the pesticide premixes are added. If the mixture foams excessively, separates or becomes syrupy, do not apply the mixture. Compatibility agents are available that may be added to improve mixing ability.

Even if all components appear compatible, the field tank mixture will require constant, vigorous agitation to prevent separation or improper pesticide distribution in the tank. Be sure the entire tank is agitated and mixed before spraying. Do not store pesticide mixtures overnight unless they are constantly agitated. Best results are obtained by applying the entire mixture in one day.

Additives for Herbicides—Some Definitions

(1) Adjuvant — any substance that enhances the herbicide's effectiveness, an "added ingredient."
(2) Surfactant — a surface active material that can facilitate emulsifying, dispersing, spreading, wetting, sticking or other surface-modifying characteristics of herbicide solutions.
(3) Crop oil concentrates — contain a mixture of emulsifiers and surfactants. A common ratio is 80% oil and 20% surfactant.
(4) Emulsifier — an agent that promotes the dispersion of one liquid in another.
(5) Wetting agent (spreader) — reduces water surface tension, causing better contact between spray solution and treated surfaces.
(6) Soap — sodium or potassium salts of fatty acids. Can form insoluble materials in hard water. *Detergents* are synthetic materials used for cleaning.
(7) Sticker — Deposit builder. Increases herbicide adhesion to plant surfaces.
(8) Defoaming agent — self-explanatory.
(9) Compatibility agent or cosolvent — may aid in dispersion of otherwise incompatible mixtures.

During the development of a herbicide, the chemical company attempts to formulate the active ingredient to optimize performance, mixing and handling under diverse conditions. Every commercially available herbicide formulation contains its own particular set of additives to accomplish this. Sometimes additional additives are required for specific applications or when compatibility or mixing problems occur. The herbicide label will describe the need and use of these additives. The indiscriminate use of additives should be avoided because they may not improve herbicide performance and may actually reduce weed control or cause crop injury.

Additives can be referred to as "adjuvants." This term merely denotes an added ingredient. Surface active additives are called surfactants. Therefore, all surfactants are also additives or adjuvants.

Compatibility Problems

Compatibility problems in tank mixing herbicides usually occur when mixing directions are not followed. Some common causes of compatibility problems: mixing two herbicides in concentrated form, adding an EC to the spray tank before suspending the wettable powder, insufficient agitation, excessive agitation and air leaks. Problems are much more likely when mixing herbicides with liquid fertilizers. The fertilizer solution is already loaded to near capacity with nutrients. Adding a herbicide to the already loaded solution may cause problems. Also, the fertilizer may interfere with the herbicide formulation additives. Fertilizers may vary greatly from batch to batch, so the only safe procedure is to test for compatibility in a small container before mixing a large quantity. If compatibility problems are encountered, the addition of *compatibility agents* may help.

Foaming is usually due to excessive agitation or a bypass line that empties above the spray solution level in the spray tank. When foaming is a problem, addition of a *defoamer* can help.

Herbicide Application Equipment

Sprayer Implements — A good weed control sprayer should be made of non-corrosive materials, be easy to clean and have the following features:

(1) A *tank* with a volume of 100 to 300 gallons to reduce filling and mixing operations.
(2) A *pump* with a capacity of at least 4 gallons per minute and pressure up to 100 pounds per square inch (PSI).
(3) An *agitation system* — The bypass from the pressure control is a good source of agitation. Direct the bypass line into the bottom of the tank.
(4) *Screens* — There should be 50-mesh screens in the intake line and at each nozzle.
(5) *Pressure gauge* — The pressure gauge should accurately measure pressures up to 100 PSI.
(6) *Adjustable spray boom* — The boom should be adjustable from 16 to 36 inches above the ground.

(7) *Nozzles* — Drift reduction flat fan nozzles of 110° angle are best suited for most weed control applications. Commonly used nozzle volumes can vary from 0.1 to 0.8 gallons per minute, depending on the application. Good general-use nozzles are 11004 or 11006. These nozzles permit the boom to be carried closer to the ground and thus reduce spray drift.

Herbicide Incorporation

Disks, especially large tandem disks, are poor tools for incorporation. Depth and ridging are difficult to control and non-uniform distribution of the herbicide in the soil is likely.

If a disk is used, it should be set at a depth of 4 to 5 inches and a speed of 4 to 6 mph. Incorporation must be done in two directions.

A field cultivator can give acceptable one-pass incorporation of herbicides if special care is taken in setup and operation. Wide sweeps give better incorporation than points. Shanks should be close enough to allow for this, and three sets of sweeps are also required. It is important to follow with a leveling tool, such as a flex-tine drag or spring-tooth harrow, to smooth out ridges behind the cultivator.

The speed of the cultivator should be at least 6 mph, at a depth of 3 to 4 inches. Actual incorporation will occur at one-half the tool depth. Caution must be taken not to run the back portion of the cultivator lower than the front. If the back of the tool is lower, untreated soil can be brought to the surface, burying the herbicide.

Danish-type harrows equipped with "S" tines and rolling baskets can do a good job of one-pass incorporation. Rolling baskets outperform other trailing operations.

Operation considerations are similar to those with the field cultivator. Good soil tilth is a prerequisite for one-pass incorporation.

PTO-driven tools do a good job of one-pass incorporation. However, their application in Michigan may be limited. These tools are operated at lower speeds and are not as wide as other implements.

The most consistent incorporation (no streaking), especially when using a disk or field cultivator alone, is achieved with two passes at an angle to each other. However, new tillage implements have made one-pass incorporation of herbicides a possibility. Although a majority of the questions concerning incorporation concern the best implement to use for one-way incorporation, soil condition influences the success of incorporation more than the tool used. The reliability of one-pass incorporation will also be influenced by the tillage system used.

In clean tillage (low crop residue) situations, preemergence applications made on wet soil will likely perform as well or better than two-pass incorporated treatments. One-pass incorporation is not a good approach with less than optimum soil tilth.

High crop residue levels (corn stalks disked or chisel plowed with one or two secondary tillage operations) make one-pass incorporation difficult. If the residue level is great enough to clog the incorporation tool, two-pass incorporation is advisable. The soil should also have good tilth, as outlined above.

Where ridges are left from fall plowing or use of a chisel plow in the spring, it is advisable to level the ground before herbicide application. Streaking is favored by application of the herbicide to rough or uneven ground.

Soil Types

Soil texture (sand, silt, clay) and organic matter influence the effectiveness of soil-applied herbicides. In general, lower rates of herbicides are used on sandy (coarse- textured) soils than on clays or soils high in organic matter (fine-textured) to obtain the same level of control. **Herbicide rate recommendations in this bulletin are given for medium-textured soils with greater than 3% organic matter.** Clay and organic matter adsorb herbicides, making them less available to kill weeds. Soils with high clay and organic matter content require higher herbicide rates for adequate weed control. Sandy soils with low organic matter content require careful herbicide rate selection to avoid crop injury.

Soil pH can influence the activity of soil-applied herbicides. Some herbicides are more persistent at higher soil pH, and crop rotation must be considered before applying a herbicide. Some herbicides are more available at higher soil pH. Rates must be reduced to avoid crop injury. Knowledge of the soil pH in a field is critical — soil pH may vary greatly within a field.

Organic matter analysis is available through MSU County Extension offices or directly through the MSU Soil and Plant Nutrient Lab (www.css.msu.edu/SPNL/). Organic matter analysis may be determined on soil samples submitted for N-P-K analysis for an additional charge. Organic matter levels change slowly and may need to be checked every four years.

Soil sample analyses are only as accurate or representative as the soil sample, so each field should be checked individually. See the Soil and Plant Nutrient Lab website: **www.spnl.msu.edu** or Extension bulletin E-498, "Sampling Soils," for proper soil sampling procedures.

Remember, follow herbicide label recommendations, always know the soil pH, and adjust herbicide rates for soil texture and organic matter as specified on the label.

Accurate Calibration

Accurate applicator calibration is essential for effective chemical weed control without crop injury. Calibrate a new sprayer before use and routinely recalibrate the sprayer during the growing season.

Use the following steps as a guide to calibrate a ground sprayer for broadcast application.

(1) Determine the desired application volume of carrier (usually water) in gallons per acre (GPA). For most weed control applications, 5-30 GPA at 30 to 40 PSI is sufficient.

(2) Adjust the boom height so that spray overlap is about 100% at the spray target. This would be a minimum of 18 inches on a 20-inch nozzle spacing and 24 inches on

a 30-inch nozzle spacing for 110° nozzles. Boom height is important in maintaining spray overlap for uniform distribution. Check each nozzle at the recommended pressure for output. Replace any defective nozzles and screens. All nozzles should deliver within 10% of one another.

(3) Fill the spray tank and system with water.

(4) Spray a measurable area in the field, at a fixed speed and at the desired pressure. Spray at least 20% of the total tank volume and at least 2 acres of area.

(5) Measure the volume of water (in gallons) needed to refill the tank.

(6) Determine the area (in acres) that was test sprayed, using the following formula: length of area sprayed (in feet) X boom width (in feet) ÷ 43,560 = acres sprayed.

(7) Divide the volume sprayed by the area sprayed to obtain the actual output of the sprayer in gallons per acre.

(8) Make adjustments to tractor speed, pressure or nozzle size and repeat steps 3–7 to change application rate to the recommended values.

(9) Calculate the amount of formulated pesticide needed to treat the desired area.

The following procedures can be used to calibrate a ground sprayer for either banded or broadcast applications.

(1) Determine the desired application volume in GPA.

(2) Check each nozzle at the recommended pressure for output. Replace any defective nozzles and screens. All nozzles should deliver within 10% of one another.

(3) For band application, accurately determine the width, in inches, of the band sprayed. For broadcast application, measure the distance, in inches, between adjacent nozzles.

(4) Locate this width in the table below and read off the corresponding course distance.

WIDTH (inches)	COURSE DISTANCE (feet)
10	408
15	272
20	204
30	136

(5) In the field to be sprayed, mark off the course of the proper distance.

(6) Fill the tank completely with water only.

(7) Tie a quart container (graduated in ounces) to one nozzle on the sprayer to catch all of that nozzle's spray.

(8) Start a distance back from the beginning of the course to get up to operating speed, and turn the sprayer ON at the beginning of the course and OFF at the end.

(9) Remove the quart container, and read the volume collected IN OUNCES.

(10) OUNCES collected = GPA.

Pesticide Use Precautions

Herbicides, like all pesticides, should be handled with extreme caution and respect. There are three important reasons for using pesticides safely and wisely:

- To protect yourself and others from exposure.
- To avoid harming and polluting the environment.
- To avoid crop injury.

These three points cannot be emphasized enough.

Each herbicide label contains specific information on **personal protective equipment (PPE) and restricted entry interval (REI)**. Refer to **Table 16** for the **Restricted Entry Intervals** for an individual herbicide. This information is prominantly displayed under the heading of **Agricultural Use Requirements**.

Using more herbicide than is recommended on any label is illegal and can result in crop injury, herbicide carryover or other problems.

The ability of a herbicide to kill weeds without harming crop plants (selectivity) may be partially lost under unfavorable weather conditions. Herbicide drift to non-target crops often results in crop injury. Do not spray under windy conditions.

Herbicide Application

Herbicide Spray Volumes and Rates

The volume of water to use will vary with the herbicide, although generally 10 to 40 gal per acre and a spraying pressure of 30 to 40 PSI are recommended. With wettable powders, use nozzles that deliver at least 15 GPA.

Some contact-type postemergence herbicides (e.g., *Basagran, Ultra Blazer*) require a minimum of 20 GPA spray volume and 40 PSI spray pressure to ensure adequate coverage. Drift-reducing flat fan nozzles are effective for herbicide applications. Hollow cone nozzles can also give good results, especially for postemergence applications at higher pressures. If higher pressures are used, be sure the nozzles are designed to be operated at the increased pressure. Operating nozzles beyond the specified pressure range will result in a poor spray pattern, insufficient coverage and lack of weed control.

Band Application

In cultivated crops, spraying narrow bands of herbicide over the rows will take less material per acre, reducing the cost per acre for the chemical. Where chemical costs are high, band spraying may be justified. Timely cultivation of weeds in the unsprayed area between rows is necessary.

In seasons when the soil is too wet to cultivate, overall spraying has the advantage of controlling weeds between the rows.

When band spraying, be very careful to maintain the proper rate of application on the area sprayed. (If you lower the spray boom to narrow the area covered by a given nozzle, remember that each nozzle is still delivering the same amount of spray mixture as it did on the wider area.) Use nozzles designed for banding — the spray volume with these nozzles is the same across the entire band.

Cleaning Pesticide Sprayers

It is important to clean pesticide sprayers after each use, especially if they are used for more than one crop and for the application of insecticides and fungicides. The need for extensive cleaning can be minimized if one sprayer is dedicated to herbicide application only.

Do not use a sprayer to apply insecticides or fungicides if the sprayer has been used to apply 2,4-D-type herbicides.

In general, rinse the entire sprayer, inside and out, including the boom, hoses and nozzles. Partially fill the spray tank with water and keep the pump running so that the water is circulated throughout the entire system. Spray the water rinsate out through the nozzles. This process should be repeated when changing soil-applied herbicides and at the end of each day. Money can be saved and the environment protected if the water rinsing is done in the field using a water-filled nurse tank and if the water rinsate is applied to the crop according to label rates. Many herbicide labels have specific instructions for cleaning the spray system. Always read and follow these directions carefully.

Unless otherwise specified, thoroughly wash the entire spray system after all postemergence applications. Use 1 gallon of household ammonia in 100 gallons of water as a cleaning agent or commercially available tank cleaners.

Run the pump so that the cleaning solution is circulated throughout the entire system for at least 2 hours, and then pump it out through the nozzles. Do not dump this cleaning solution, and do not apply it to any crop or cropland. Discard the cleaning solution in an appropriate pesticide rinsate degradation pit. Rinse the entire system with water after all the cleaning solution has drained from the sprayer. Do not leave pesticide solutions or cleaning solutions in the tank overnight.

Corrosion and mechanical damage to pumps, tanks, nozzles, etc., may result from leaving water in the spray system over the winter. To prepare the spray equipment for storage, disconnect all the hoses and allow all water to drain out. Coat all bare metal parts with oil or a rust inhibitor. Disassemble metal nozzles and store them in oil. Prepare the spray pump for storage following the manufacturer's recommendations.

Pesticides and the Environment

Many people who live in rural Michigan get their drinking water from wells. Well water is groundwater, so it is easy to see why you should be concerned about keeping herbicides out of groundwater. Several processes determine the fate of herbicides and whether they will end up in your drinking supply. Sometimes these processes are beneficial and enhance weed control. For example, the leaching of a root-absorbed herbicide into the root zone can enhance weed control. The degradation of pesticides can remove non-essential pesticide residues from the environment. Often, however, these processes are detrimental. Runoff can move a herbicide away from target weeds. As a result, chemical is wasted, weed control is reduced and there is an increased chance of damage to non-target plants, hazard to human health, and pollution of nearby soil and water.

In this section we will examine the fate of pesticides and the various processes that affect their stability and persistence following an application, disposal, or spill.

Adsorption is the binding of chemicals to soil particles. (This term is sometimes confused with absorption, the process by which plants intake chemicals.) The amount and persistence of pesticide adsorption vary with pesticide properties, soil moisture content, soil pH and soil texture. Soils high in organic matter or clay are the most adsorptive; coarse, sandy soils that lack organic matter or clay are much less adsorptive.

A soil-adsorbed herbicide is less likely to volatilize, leach or be degraded by microorganisms. When herbicides are tightly held by soil particles, they are less available for absorption by plants. Therefore, certain herbicides used on highly adsorptive soils may require higher rates or more frequent applications to compensate for the portion of the herbicide that binds to the soil particles and is unavailable for plant uptake.

Volatilization occurs when a solid or a liquid turns into a gas. Volatilization of pesticides increases with higher air temperature and air movement, higher temperature at the treated surface (soil, plant, etc.), low relative humidity and decreasing size of spray droplets. Pesticides also volatilize more readily from coarse-textured soils and from medium- to fine-textured soils with high moisture content.

A pesticide in a gaseous state can be carried away from the treated area by air currents. The movement of pesticide vapors in the atmosphere is called vapor drift. Unlike the drift of sprays and dusts that can sometimes be seen during an application, **vapor drift** is invisible.

Avoid applying volatile herbicides such as dicamba, 2,4-D ester, or EPTC (*Eptam*) when conditions favor volatilization. The vapor pressure rating of the herbicide may help indicate the volatility of the material. The higher the vapor pressure rating, the more volatile the pesticide. Herbicide labels usually mention the potential for volatility of the herbicides. Volatilization can sometimes be reduced through the use of low volatile formulations or soil incorporation of the herbicide (e.g., EPTC [*Eptam*]).

Photodegradation is the breakdown of herbicides, such as trifluralin, by the action of sunlight. Herbicides applied to foliage, the soil surface or structures vary considerably in their stability when exposed to natural light. Like other degradation processes, photodegradation reduces the amount of chemical present, which can subsequently reduce the level of weed control. Soil incorporation by mechanical means during or after application, or by irrigation water or rainfall following application, can reduce herbicide exposure to sunlight.

Microbial degradation occurs when microorganisms such as fungi and bacteria use a herbicide as a food source. Microbial degradation can be rapid and thorough under soil conditions favoring microbial growth. These conditions include warm temperatures, favorable pH levels, and adequate soil moisture, aeration (oxygen) and fertility. The amount of adsorption also influences microbial degradation. Adsorbed herbicides are more slowly degraded because they are less available to some microorganisms.

Chemical degradation is the breakdown of a herbicide by soil processes not involving a living organism. The adsorption of herbicides to the soil, soil pH levels, soil temperature and moisture all influence the rate and types of chemical reactions that occur. Some herbicides are persistent at high soil pH while others are more persistent at low soil pH.

Absorption is the process by which plants and microorganisms take up chemicals. It is another process that can transfer herbicides in the environment. Once absorbed, most herbicides are degraded within plants. Residues may persist inside the plant or be released back into the environment as the plant tissues decay.

Crop removal is another herbicide transfer process. When treated crops are harvested, the herbicide residues are removed with them and transferred to a new location. After harvest, many agricultural commodities are washed or processed to remove or degrade much of the remaining residue.

Runoff moves herbicides in water. Runoff occurs as water moves over a sloping surface, carrying herbicides either mixed in the water or bound to eroding soil. The amount of herbicide runoff depends on the grade or slope of the field, the erodibility and texture of the soil, the soil moisture content, the amount and timing of irrigation or rainfall (especially in relation to the time of herbicide application), and properties of the herbicide. For example, a herbicide application made to a heavy clay soil already saturated with water is highly susceptible to runoff. Established vegetation or plant residues also influence runoff because of their ability to retain soil and moisture.

Herbicide losses from runoff are greatest when heavy rainfall occurs shortly after a herbicide application. If heavy rainfall is expected, delay applying pesticides. Some no-tillage and minimum-tillage cropping systems have been found to reduce herbicide runoff, as do soil incorporation application methods. Finally, surface grading, drainage ditches and dikes, and the use of border vegetation can help reduce the amount and control the movement of runoff waters.

Leaching is another process that moves herbicides in water. In contrast to runoff, which occurs as water moves on the surface of the soil, leaching occurs as water moves through the soil. Several factors influence the leaching of herbicides. These include the water solubility of the herbicide.

A herbicide dissolved in water can move readily with the water as it seeps through the soil. Soil structure and texture influence soil permeability (how fast the water moves through soil), as well as the amount and persistence of herbicide adsorption to soil particles. Adsorption is probably the most important factor influencing leaching of herbicides. If a herbicide is strongly adsorbed to soil particles, it is less likely to leach, regardless of its solubility, unless the soil particles themselves move with the water flow.

Groundwater and Surface Water Contamination

Groundwater is the water beneath the earth's surface occupying the saturated zone (the area where all the pores in the rock or soil are filled with water). It is stored in water-bearing geological formations known as **aquifers**. Groundwater moves through aquifers and can be obtained at points of natural discharge such as springs or streams, or by drilling a well into the aquifer.

The upper level of the saturated zone in the ground is called the **water table**. The water table depth below the soil surface fluctuates throughout the year, depending on the amount of water removed from the ground and the amount of water added by recharge and connected surface waters. **Recharge** is water that seeps through the soil from rain, melting snow or irrigation. **Surface waters** are visible bodies of water such as lakes, rivers and oceans.

Both surface water and groundwater are subject to contamination by **point-source and non-point-source pollution**. The key to preventing pesticides in groundwater and surface waters is identification of the source and its route to the water. Point-source contamination refers to situations where movement of a pesticide into water can be traced to a specific site. Non-point sources occur over a wide area. Most pesticides detected in groundwater and surface water can be traced to nonpoint sources. This type of pollution generally results from land runoff, precipitation, acid rain or percolation rather than from a discharge at a specific, single location, such as a single pipe or wellhead.

The potential for the pollution of groundwater and surface water from improper waste disposal is a major concern. Problems result from domestic waste (e.g., septic systems, landfills, waste treatment plants), industrial waste (e.g., landfills, brine and mine wastes, deep well disposal), and government-generated waste (e.g., radioactive wastes).

Improper agricultural practices are another concern. Inadequate handling of livestock waste storage facilities and improper application of manures and fertilizers can cause unacceptable levels of nitrate in groundwater. Pesticides in groundwater and surface water are receiving considerable national attention. Evidence suggests that, in certain areas, agriculture's relative contribution to groundwater and surface water contamination may be significant.

Herbicides in Groundwater

There are several herbicide breakdown processes that occur in the environment. These processes help determine whether herbicides reach groundwater or are degraded before reaching these underground waters. Geological characteristics, such as the depth of the water table and the presence of sinkholes, are also critical. If the water table is close to the soil surface, fewer opportunities may exist for adsorption and degradation to occur.

On the soil surface and within the first few inches of soil, herbicides can be volatilized, adsorbed to soil particles, taken up by plants, broken down by sunlight, or degraded by soil microorganisms and chemical reactions. The extent of herbicide leaching is affected by both pesticide and soil properties. Weather conditions and management practices also affect leaching of herbicides through the soil. Too much rain or irrigation water can leach herbicides beyond the zone where weeds are controlled. A herbicide that is not volatilized, absorbed by plants, bound to soil or degraded can potentially move through the soil to groundwater.

After herbicides reach groundwater, they may continue to break down but at a much slower rate because of less available light, heat and oxygen. The movement of groundwater is often slow and difficult to predict. Substances that enter the groundwater in one location can turn up years later in other locations. A major difficulty in dealing with groundwater contaminants is that the sources of pollution are not easily recognizable. The problem is occurring underground, out of sight.

Herbicides in Surface Water

Non-point-source contamination of surface water can occur in several ways. Pesticides can reach surface water through drift or volatilization or by wind erosion of dust particles carrying pesticides into the atmosphere followed by rainfall deposition in the water; from groundwater discharging into surface water; and in surface water runoff.

Pesticides have been detected in rainfall in many states in the Midwest, including Iowa, Indiana, Wisconsin and Ohio. The greatest number of detections and the highest concentrations were observed in May. When detected, most pesticide concentrations are below 1 part per billion (ppb).

The majority of pesticides detected in surface water are from surface runoff events. Either the pesticides are attached to the soil particles that are being transported in the runoff water or the pesticides are dissolved in the runoff water. The degree of pesticide loss to surface water is dependent on the degree of surface water runoff in the field. This is dependent on the slope of the field, the vegetative and/or residue cover on the field site, the soil texture and the soil moisture content at the time of the rainfall that produces the runoff event. Pesticide application methods have a strong influence on the potential for the pesticide to be carried in surface water runoff. Preemergence herbicide applications have a greater potential for surface loss than applications in which the herbicide is incorporated and applications in which the herbicide is applied postemergence. The pesticide application rate is important too. The higher the pesticide application rate, the greater the potential amount of pesticide that could be lost in runoff.

Once a pesticide reaches surface water it may or may not degrade. Some pesticides degrade by hydrolysis or by direct or indirect photodegradation. Our knowledge of which pesticides are degraded in surface waters is quite limited.

Keeping Herbicides Out of Groundwater and Surface Water

It is very difficult to purify or clean contaminated groundwater or surface water. Treatment is complicated, time consuming, expensive and often not feasible. The best solution to groundwater and surface water contamination is to prevent the problem in the first place. Management practices can be implemented to effectively reduce pesticide runoff and leaching and protect groundwater and surface water.

- **Use integrated pest management programs**—Minimize herbicide use by combining chemical control with other pest management practices such as tillage, cultivation, crop rotation and pest scouting.
- **Reduce compaction**—Surface water runoff increases when soils are compacted.
- **Rotate crops**—Crop rotation improves water infiltration, which reduces runoff. Crop rotations also may provide more surface crop residue and may reduce the application of specific pesticides repeatedly to a given field site.
- **Utilize conservation practices that reduce erosion and surface runoff**—These practices include but are not limited to no-till and other forms of conservation tillage, increasing crop residues or planting cover crops, planting grass waterways to retard soil and water runoff, and keeping buffer strips to protect surface water boundaries.
- **Consider the geology of your area**—When planning herbicide applications, be aware of the water table depth and the permeability of the geological layers between the surface soil and groundwater.
- **Consider soil and field characteristics**—The susceptibility of the soil or field site to leaching or runoff should be determined. Soil texture and organic matter content, in particular, influence chemical movement into groundwater; the slope of the field influences surface runoff.
- **Select herbicides carefully**—Remember, herbicides that are highly soluble, relatively stable and not readily adsorbed to soil tend to be the most likely to leach. Choose herbicides with the least potential for leaching into groundwater or for runoff into surface water. Read labels carefully and consult a specialist from MSU Extension or your pesticide dealer, if necessary.

Refer to **Table 16** for a complete listing of herbicides that contain **Groundwater Advisory** statements. Consult the herbicide label for individual instructions on how to protect groundwater and surface water from herbicide contamination.

Herbicides containing atrazine may not be mixed or loaded within 50 feet of perennial or intermittent streams and rivers, lakes or reservoirs. These herbicides may not be mixed or loaded within 50 feet of any well unless conducted on an impervious pad designed and maintained to contain any product spills, leaks or rinse water.

These herbicides cannot be applied within 66 feet of the points where field surface water runoff enters perennial or intermittent streams and rivers or within 200 feet of lakes or reservoirs.

These herbicides can be applied to HEL (highly erodible land) acres only if the 66-foot buffer or setback from runoff points is planted to a crop or seeded with grass.

- **Follow label directions**—The label carries crucial information about the proper rate, timing and placement of the herbicide.
- **Reduce herbicide application rates**—Use the lowest rate of the pesticide that provides adequate pest control. Band applications of preemergence herbicides reduce the potential of herbicides to leach or run off by 50% or more.
- **Incorporate pesticides**—On fields not considered highly erodible, incorporation of pesticides can be used to reduce runoff by moving some of the pesticide below the soil surface away from overland water flow. Incorporation of herbicides will not be compatible with surface residue requirements in some fields.
- **Calibrate accurately**—Equipment should be calibrated carefully and often. During calibration, check the equipment for leaks and malfunctions.
- **Measure accurately**—Concentrates need to be carefully measured before they are placed into the spray tank. Do not “add a little extra” to ensure the herbicide will do a better job. Such practices only increase the likelihood of injury to the treated crop, the cost of pest control, and the chance of groundwater and surface water contamination.
- **Avoid back-siphoning**—The end of the fill hose should remain above the water level in the spray tank at all times to prevent back-siphoning of chemical into the water supply. Use an anti-backflow device when siphoning water directly from a well, pond or stream. These practices also reduce the likelihood of the hose becoming contaminated with herbicides.
- **Consider weather and irrigation**—If you suspect heavy or sustained rain, delay applying herbicides. Control the quantity of irrigation to minimize the potential for herbicide leaching and runoff.
- **Avoid spray drift and volatilization**—Preemergence herbicide applications have the greatest potential for volatilization and runoff.
- **Clean up spills**—Avoid spills. When they do occur, contain and clean them up quickly with an absorbent material such as cat litter. Chemicals spilled near wells and sinkholes can move directly and rapidly into groundwater. Chemicals spilled near ditches, streams or lakes can move rapidly into surface water.
- **Change the location of mixing areas**—Mix and load pesticides on an impervious pad, if possible. If mixing is done in the field, change the location of the mixing area regularly. Do not mix herbicides adjacent to the water source, and do not let the water run inadvertently on the soil near the mixing area. This will increase herbicide leaching and/or runoff.
- **Dispose of wastes properly**— All herbicide wastes must be disposed of in accordance with local, state and federal laws. Triple-rinse containers. Pour the rinsewater into the spray tank for use in treating the site or the crop. Do not pour rinsate on the soil, particularly repeatedly in the same location. This will saturate the soil and increase the potential for herbicide leaching.
- **Store herbicides away from water sources**—Herbicide storage facilities should be situated away from wells, cisterns, springs and other water sources.

Michigan’s water resources currently provide a vast supply of clean water for agriculture, homes and industry. They can ensure high water quality for future needs only if they are protected now. Be sure to understand how your activities, including herbicide usage, can affect them.

Storing Pesticides

Pesticides must be stored in a facility that will protect them from temperature extremes, high humidity and direct sunlight. The storage facility should be heated, dry and well ventilated. It should be designed for easy containment and cleanup of pesticide spills and made of materials that will not absorb any pesticide material that leaks out of a container. Store only pesticides in such a facility, and always store them in their original containers.

Do not store any feed, seed, food or fertilizer with pesticides. Do not store any protective clothing or equipment in the pesticide storage facility. Store herbicides separately from insecticides and fungicides to avoid contamination of one material by another and accidental misuse.

Keep the facility locked at all times when not in use to prevent animals, children and irresponsible adults from entering and becoming poisoned. Post the facility as a Pesticide Storage Facility to warn others that the area is off-limits. Maintain an accurate inventory of the pesticides stored in the facility at all times in case of emergency.

Always read and follow the Storage and Disposal section of pesticide labels for specific storage and handling instructions.

Handling and Mixing Pesticides

Always wear the personal protective equipment (PPE) required by the label, when handling, mixing and applying pesticides, and during cleanup of application equipment.

Mix pesticides downwind and below eye level. Avoid excessive splashing and sloshing. If pesticides are spilled on you, wash them off immediately with lots of water and change clothing. Resume spraying only after cleaning up any spills. Try to use closed handling/mixing systems when appropriate.

Mix only what is required for the area to be sprayed according to label directions. Avoid mixing excessive amounts. To do otherwise will create a hazardous waste that is difficult and expensive to dispose of. Keep unauthorized persons out of the area in which you handle pesticides.

Handling and Disposing of Pesticide Containers

Pesticide containers are considered hazardous waste until they are cleaned or disposed of properly. When possible, reduce the number of pesticide containers by using bulk or returnable containers. Buy pesticides in larger volume containers, in containers that may be recycled, or in water-soluble bags to avoid disposal problems.

All pesticide containers can be rendered non-hazardous waste by triple rinsing (or equivalent). The rinsate should be added to the spray tank. After triple rinsing, perforate both ends so the container cannot be reused.

All metal and plastic triple-rinsed containers should be recycled, if possible. If this option is not available, dispose of them in a state-licensed sanitary landfill. Dispose of all paper containers in a sanitary landfill or a municipal waste incinerator. Do not bury or burn any pesticide containers. Do not reuse any empty pesticide containers for any purpose.

Protect Non-target Organisms

Applying pesticides carelessly can harm non-target organisms that are beneficial to agriculture and our environment. The best way to avoid injury of beneficial insects and microorganisms is to minimize pesticide use. Selective pesticides should be used whenever possible and applied only when necessary as part of a total pest management program.

Bees and other pollinating insects are essential for successful production of many crops, such as deciduous tree fruits, small fruits, most seed crops and certain vegetables. Many pesticides, particularly insecticides, are highly toxic to pollinating honeybees and wild bees. Check herbicide labels to identify those that are toxic to bees. *Gramoxone Inteon* (paraquat), for example, is a herbicide toxic to bees. Be aware of how bee poisonings can occur and how to prevent them.

The following precautions reduce the chance of bee poisoning:

• Do not apply herbicides (such as *Gramoxone Inteon*) that are toxic to bees during bloom. Even shade trees and weeds should not be sprayed during bloom. Mow cover crops and weeds to remove blooms before spraying.

• Reduce drift during application. Aerial applications usually are more hazardous to bees than ground applications.

• Time pesticide applications carefully. Evening applications are less hazardous than early morning ones; both are safer than midday application.

• Do not treat near hives. Bees may need to be moved or covered before you use insecticides near colonies.

Pesticides can be harmful to all kinds of vertebrates such as **fish and wildlife**. Most recognizable are the direct effects from acute poisoning. Fish kills often result from water pollution by a pesticide (usually insecticides). Pesticides can enter water via drift, surface runoff, soil erosion and leaching.

Bird kills from pesticides can occur when birds ingest the toxicant in granules, baits or treated seed; are exposed directly to the spray; consume a treated crop or drink and use contaminated water; or feed on pesticide-contaminated prey.

Worker Protection Standard

Federal rules for farm worker protection, issued in 1992, require farmers to provide additional training and notification to farm workers to prevent accidental or occupational exposure to pesticides. Farmers should contact Extension agents to learn the details of this standard and availability of training materials for education of workers and handlers.

Read and follow the label instructions on **restricted entry intervals (REI) (Table 16)** for every pesticide used. Some pesticide labels require both oral warning and posted signs to notify workers of pesticide applications. If the label doesn't require *both* forms of notification, notify workers *either* orally *or* by posting warning signs at entrances to treated areas. (Greenhouses *must* post warning signs for every application.) When using posted signs, post 24 hours or less before the pesticide application and remove signs within three days after the end of the restricted entry interval. Keep workers out during the entire time the signs are posted (except for early-entry workers wearing the proper personal protective equipment).

Record Keeping

The federal pesticide recordkeeping regulations and the federal worker protection standards require that all applicators who apply restricted-use pesticides (RUP) keep records and maintain them for at least three years, and preferably five years. Records to be kept include:

- Brand name or product name and the EPA registration number. Active ingredients Restricted-entry interval (REI)
- Total amount of the product used.
- Size of the area treated.
- Crop, commodity, stored product or site to which the pesticide was applied.
- Location of the application.
- Month, day, year, and time of the application.

- Name and certification number of the applicator or applicator's supervisor.

Any record form is acceptable as long as the required data are included. Penalties are costly and are increased for subsequent violations. Provisions for protecting the identity of the individual producers are included in the law. Commercial applicators must furnish a copy of the required records to the customer of the RUP application.

Restricted Use Pesticides

Several herbicides are currently classifed as restricted use pesticides and, as such, can be purchased and applied only by certified commercial or private pesticide applicators. Certification of pesticide applicators is administered by the Michigan Department of Agriculture and Rural Development. **Restricted use pesticides** are identified in **Table 16** of this guide.

Herbicide Resistance in Weeds

Herbicide-resistant weeds have become a major challenge in weed management systems in Michigan and throughout the Midwest. Herbicide resistance can be defined as the *inherent ability of a plant to survive and reproduce following exposure to a dose of herbicide(s) normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis*. In more simple terms, a herbicide-resistant weed is a weed that was once controlled by a certain herbicide and is no longer controlled by that herbicide. For example, atrazine is a very effective herbicide in controlling common lambsquarters; however with repeated use of atrazine or other triazine herbicides (atrazine, metribuzin, or *Princep*) common lambsquarters can no longer be controlled with or is resistant to triazine herbicides in several fields throughout Michigan. Herbicide resistance develops by using the same herbicide or herbicides with the same site of action year after year to control a particular weed species without other effective control measures. Repeated use of the herbicide allows for control of all of the susceptible plants of a population and allows for plants of that population that may be naturally resistant to survive and produce resistant offspring. In the case of triazine-resistant common lambsquarters, several resistant populations developed in fields where corn was grown continuously and atrazine was the primary herbicide used to control common lambsquarters.

While triazine-resistant common lambsquarters is the most widespread resistant weed in Michigan, there are currently 17 different weed species resistant to five different herbicide sites of action in Michigan. Common lambsquarters, common ragweed, common groundsel, common purslane, Powell amaranth, redroot pigweed, ladysthumb, horseweed, spreading orach, velvetleaf, late flowering goosefoot, and eastern black nightshade are all weeds where triazine-resistant biotypes have been identified in Michigan. Similar to triazine herbicides, herbicides belonging to the phenylurea chemical family disrupt photosynthesis in the plant. Biotypes of common purslane, Powell amaranth, redroot pigweed, and horseweed are all weeds that have developed resistance to herbicides in this family (*Linex, Lorox,* and *Karmex*). Resistance to the ALS-inhibiting herbicides is also common in Michigan. Biotypes of common ragweed, tall waterhemp, common lambsquarters, smooth pigweed, horseweed, kochia, eastern black nightshade and giant foxtail have been identified resistant to imidazolinone, sulfonylurea, and sulfonamide herbicides (ALS-inhibitors).

In the past, growers have dealt with herbicide-resistant weeds by incorporating other control measures for the resistant weed into their weed management program. Most of the time this has included using a herbicide with a different site of action. In recent years, the use of glyphosate in Roundup Ready crops has been the control measure of choice. While in many cases glyphosate has provided effective control of resistant weeds, there is a growing concern about the development of glyphosate-resistant weeds. In fact, glyphosate-resistant weeds are becoming a serious problem in several states in the United States, including Michigan. Glyphosate-resistant horseweed, common ragweed, giant ragweed, common waterhemp and Palmer amaranth have been identified in Michigan. In fact, some of these populations have been identified as resistant to both glyphosate and ALS-inhibiting herbicides. In order to limit the development of herbicide resistance, including glyphosate resistance, an understanding of the practices that lead to herbicide resistance is important.

Farmers should include weed control practices that delay or prevent the development of herbicide resistance. The following is a list of practices to reduce risk of herbicide resistant weeds. Some practices may be impractical in certain situations. No single practice is likely to be successful alone.

Practices to Reduce Risk of Herbicide Resistant Weeds

(1) Rotate herbicides using herbicides of differing sites of action. Do not make more than two consecutive applications of herbicides with the same site of action against the same weed unless other effective control practices are also included in the management system.

(2) Apply herbicides in tank-mixed, prepackaged or sequential mixtures that include multiple sites of action. Combining herbicides with different sites of action and similar persistence in soil will help prevent herbicide resistance.

(3) Scout fields regularly and identify weeds present.

(4) Rotate crops, particularly those with different life cycles.

(5) Combine mechanical control practices such as rotary hoeing and cultivation with herbicide treatments.

(6) Clean tillage and harvest equipment before moving from fields infested with resistant weeds to those that are not infested.

Herbicide Sites of Action

Herbicide site of action refers to the method by which the herbicide kills plants. An understanding of herbicide site of action is useful in developing herbicide programs that limit the development of herbicide-resistant weeds. The following list categorizes herbicides by general sites of action.

In fact, most herbicide labels now include a standardized system to inform users of the product's site of action (SOA). A box labeled 'Herbicide Group' is present near the top of the label. The number in the box is the SOA of the active ingredient of the herbicide. Individual herbicide families and herbicide examples are listed within each site of action. In addition, the site of action is listed for each herbicide on the weed response tables for each crop.

Herbicide Sites of Action

Site of Action	Herbicide Group Number	Chemical Family	Herbicide
ACCase inhibitors	1	Cyclohexanediones	Sethoxydim (*Poast, Poast Plus*) Clethodim (*Select, Select Max, Arrow*)
		Aryloxyphenoxypropionates	Fluazifop (*Fusilade DX*, component in *Fusion*) Fenoxaprop (component in *Fusion*) Quizalofop (*Assure II, Targa*)
		Phenylpyrazolins	Pinoxaden (*Axial XL*)
ALS inhibitors	2	Imidazolinones	Imazethapyr (*Pursuit*) Imazamox (*Raptor*)
		Sulfonylureas	Chlorimuron (*Classic*) Halosulfuron (*Permit, Sandea*) Iodosulfuron (component in *Autumn Super*) Mesosulfuron (*Osprey*) Nicosulfuron (*Accent Q*) Primisulfuron (*Beacon*) Prosulfuron (*Peak*) Rimsulfuron (*Matrix, Resolve*) Thifensulfuron (*Harmony*) Tribenuron (*Express*) Triflusulfuron (*UpBeet*)
		Triazolopyrimidine	Flumetsulam (*Python*) Cloransulam-methyl (*FirstRate*) Pyroxsulam (*PowerFlex HL*) Florasulam (component in *Quelex*)
		Sulfonylaminocarbonyltriazolinones	Propoxycarbazone (*Olympus*) Thiencarbazone-methyl (component in *Capreno*)
Microtubule inhibitors (root inhibitors)	3	Dinitroanilines	Trifluralin (many names) Ethalfluralin (*Sonalan*) Pendimethalin (*Prowl/Prowl H_20*)
		Benzamide	Pronamide (*Kerb*)
Synthetic auxins	4	Arylpicolinate	Halauxifen (*Elevore*, component in *Quelex*)
		Phenoxy acetic acids	2,4-D (*Enlist One*, others) 2,4-DB (*Butyrac 200, Butoxone 200*) MCPA
		Benzoic acids	Dicamba (*Banvel, Clarity, DiFlexx, Engenia, XtendiMax*; component in *Status*)
		Pyridines	Clopyralid (*Stinger*) Fluroxypyr (*Starane Ultra*)
Photosystem II inhibitors	5	Triazines	Atrazine Simazine (*Princep, Sim-Trol*)
		Triazinone	Metribuzin (*Metribuzin*, others) Hexazinone (*Velpar*)
		Phenyl-carbamates	Desmedipham (*Betenex*) Phenmedipham (component in *Betamix*)
		Uracils	Terbacil (*Sinbar*)
	6	Benzothiadiazoles	Bentazon (*Basagran*, others)
		Nitriles	Bromoxynil (*Buctril, Moxy*, others)
	7	Phenylureas	Linuron (*Lorox, Linex*)

(Continued on next page)

Herbicide Sites of Action *(continued)*

Site of Action	Herbicide Group Number	Chemical Family	Herbicide
Lipid synthesis inhibitor	8	Thiocarbamates	EPTC (*Eptam*)
EPSPS inhibitor	9	Organophosphorus	Glyphosate (See Table 10)
Glutamine synthetase inhibitor	10	Organophosphorus	Glufosinate (*Liberty, Rely*)
Diterpene biosynthesis inhibitor (bleaching)	13	Isoxazolidinone	Clomazone (*Command*)
Protoporphyrinogen oxidase inhibitors (PPO)	14	Diphenylether	Acifluorfen (*Ultra Blazer*) Fomesafen (*Flexstar, Reflex*) Lactofen (*Cobra, Phoenix*)
		N-phenylphthalimide	Flumiclorac (*Resource*) Flumioxazin (*Valor, Valor EZ*)
		Aryl triazolinone	Sulfentrazone (*Authority, Spartan*) Carfentrazone (*Aim*) Fluthiacet-methyl (*Cadet*)
		Pyrazoles	Pyraflufen-ethyl (*Vida*)
		Pyrimidinedione	Saflufenacil (*Sharpen*)
Long-chain fatty acid inhibitors	15	Acetamides	Acetochlor (*Harness, Surpass NXT, Breakfree NXT, Warrant*) Dimethenamid-P (*Outlook*) Metolachlor (*Parallel,* others) Pyroxasulfone (*Zidua, Zidua SC*) s-metolachlor (*Dual Magnum, Dual II Magnum, Cinch*) Flufenacet (*Define*)
Specific site unknown	16	Benzofuranes	Ethofumesate (*Nortron*)
Auxin transport inhibitor	19	Semicarbazone	diflufenzopyr (component in *Status*)
Photosystem I inhibitors	22	Bipyridiliums	Paraquat (*Gramoxone, Parazone*) Diquat (*Reglone*)
4–HPPD inhibitors (bleaching)	27	Isoxazole Pyrazole Pyrazolone Triketone	Isoxaflutole (*Balance Flexx*) Pyrasulfotole (component in *Huskie*) Topramezone (*Armezon/Impact*) Bicyclopyrone (component in *Acuron*) Mesotrione (*Callisto*) Tembotrione (*Laudis*)