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 resistant weeds (e.g., triazine-resistant weeds) becoming a problem.

Cultivation

Timely, shallow cultivation may be necessary following herbicide treatment. 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 2 weeks after herbicide application, rotary hoe or cultivate shallowly. Delay cultivation after postemergence herbicide applications for at least 7 to 10 days to allow the chemical to move into weed stems and roots.

Chemical Control of Weeds

No one chemical used as a herbicide will kill all species 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 herbicides. 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 compounds is necessary to prevent losses of volatile active ingredients (ex., *Treflan, Eptam*) or to overcome photodecomposition losses if the materials are left on the soil surface. Preplant incorporated herbicides have increased activity in the absence of rainfall required to move the herbicide into the weed-seed germination zone. This concept is often referred to as herbicide “activation.” Incorporation is also often required to obtain perennial weed suppression from soil-applied herbicides.

Advantages of preplant incorporated herbicides:

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

(2) Weeds already controlled where wet weather later delays cultivation or spraying;

(3) Less reliance on rainfall to position the herbicides in the soil. Generally more reliable weed control than preemergence sprays;

(4) Much more effective control on some perennial weeds (nutsedge) than with preemergence sprays.

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 due to herbicide application and incorporation operation.

Preemergence herbicides are compounds that are 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 already controlled where 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 will not present a hazard to nearby 2,4-D- or *Banvel*-sensitive crops and plants.

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 above-ground parts of weeds (contact herbicides) or they may be translocated throughout the plants and kill the growing points (translocated or systemic herbicides).

Advantages of postemergence herbicides:

(1) Can be used in an emergency, since 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 greater risk of crop injury for certain crops;

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

(4) There is a risk that 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, while 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),* 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 and 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

ACS— *Aqueous Capsule Suspension*
DC— *Dry Concentrate*
DF — *Dry Flowable Granule*
DG — *Dispersible Granule*
DS — *Dry Soluble Granule*
EC — *Emulsifiable Concentrate*
EW — *Emulsifiable Concentrate*
F — *Flowable*
G — *Granule*
L — *Liquid*
S — *Soluble Powder*
SC — *Suspension Concentrate*
SL — *Soluble Liquid*
SP — *Soluble Powder*
WDG — *Water-dispersible Granules*
WP — *Wettable Powder*

Registration of Herbicides

Recommendations in this bulletin are based on field trials conducted in Michigan and other North Central states over a period of several years. Herbicides must be registered with the U.S. Environmental Protection Agency and the Michigan Department of Agriculture before they can be legally used in Michigan. The pesticide label is the legal document on pesticide use. The label must be read carefully and all the instructions followed closely. Use of a herbicide in a manner not consistent with the label can lead

to civil fines and/or condemnation of the crop. Do not mix and apply any pesticides and fertilizers if forbidden on either label.

Combinations of Herbicides

Two or more herbicides are usually applied as a tank mix versus 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 one pint of liquid fertilizer in the quart jar and add two teaspoons of the liquid pesticide. If the pesticide is a wettable powder, add two 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, as they may vary in mixing properties. Also, check compatibility if water source changes, as 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 pre-mixed 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. wettable powders or dispersible granules,
2. flowables or aqueous liquids,
3. emulsifiable concentrates,
4. crop oil concentrates.

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 which 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. (See Extension Bulletin E-1858, “Using Spray Additives with Herbicides.”)

Additives for Herbicides— Some Definitions

(1) Adjuvant — any substance which enhances the herbicide effectiveness, an “added ingredient.”

(2) Surfactant — a surface active material which can facilitate emulsifying, dispersing, spreading, wetting, sticking, or other surface-modifying characteristics of herbicide solutions.

(3) Emulsifier — an agent that promotes the dispersion of one liquid in another.

(4) Wetting agent spreader) — reduces water surface tension, causing better contact between spray solution and treated surfaces.

(5) Soap — sodium or potassium salts of fatty acids. Can form insoluble materials in hard water. *Detergents* are synthetic materials used for cleaning.

(6) Sticker — Deposit builder, increases herbicide adhesion to plant surfaces.

(7) Defoaming agent — self-explanatory.

(8) 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 paticular 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 since 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. All herbicide formulations

contain surfactants. Emulsifiable concentrates contain emulsifiers, which aid in the dispersion of the formulation into the water phase. Wettable powders contain wetting agents and dispersants, which facilitate moistening the tiny particles and prevent clumping.

When to Use Additives

Herbicides may be applied either to the soil or to the foliage, so the addition of a surfactant is left to the user. Sometimes additives are only required for postemergence treatments made during adverse climatic conditions. In other cases, the nature of the herbicide may necessitate addition of the surfactant to the spray mixture rather than the formulation. The herbicide label always gives directions for such additive requirements.

Although claims have been made that additives increase the effectiveness of soil-applied herbicides, there is no independent data to support these claims. Experiments conducted by several universities failed to show any benefit from the inclusion of spray additives with soil-applied herbicides. Additives are used with postemergence applications to aid coverage of leaf surfaces and increase penetration into the leaf.

Crop Oil Concentrates

Crop oil concentrates contain a mixture of emulsifiers and surfactants. A common ratio is 80% oil and 20% surfactant. Crop oil concentrates are generally recommended at a rate of 1 quart per acre or less.

These additives are recommended with postemergence applications of several herbicides. Herbicide labels contain specific directions on the use of additives.

There is a greater risk for crop injury when using additives with postemergence atrazine applications. Injury is frequently associated with cold, wet or cloudy conditions. The injury appears as a temporary stunting plus necrosis of the leaf margins. *Banvel,* 2,4-D, or *Bladex* should not be included in a spray mix of atrazine plus crop oil concentrate or severe injury to the crop may occur.

Adjuvants, Surfactants, Wetting Agents

Many spray additives are currently available and many exaggerated claims have been made. In most cases, these materials are no better than crop oil concentrates. In fact, under poor environmental conditions for postemergence weed control, the crop oil concentrates can be slightly superior. Remember that any benefit comes only in postemergence, not preemergence, applications. Additives aid performance of the herbicide in adverse conditions but are not a way to use less herbicide.

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 fluid fertilizers. The fertilizer solution is already loaded to near capacity with nutrients. Adding an herbicide to the already loaded solution may cause problems. Also, the fertilizer may interfere with the herbicide formulation additives. Since fertilizer may vary greatly from batch to batch, 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.

Pre-slurry the powder if you have problems in getting a wettable powder to wet and become suspended in solution. Adding a wetting agent to the spray tank will sometimes correct a floating powder problem.

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 18 to 36 inches above the ground.

(7) *Nozzles* — Flat fan nozzles of 73 to 110° angle with replacement tips are best suited for most weed control work. Nozzle volume can vary from 1 to 10 gallons per minute, depending on the applications. Good general-use nozzles are 8002 or 8004. 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 riding are difficult to control and non-uniform distribution of the herbicide in the soil is likely.

A disk does have a place for special applications, such as chopping the quackgrass rhizomes, which is required for *Eradicane* activity. The disk should be used 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 rear 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. Again, 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 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 (metribuzin) 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, as soil pH may vary from 6.5 to 7.5 in areas within a field.

Organic matter analyses is available through MSU county Extension offices or directly through the MSU Soil Testing Laboratory. 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 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 re-calibrate 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 application, 5-30 GPA at 30-40 PSI is sufficient.
2. Adjust the boom height so that the spray overlaps about 30% at the ground (or other surface to be sprayed). With 80 degree nozzles, this places the nozzles about 20 inches apart on the boom; and 20 inches above the sprayed surface. Check each nozzle at the recommended pressure for output. Replace any defective nozzles and screens. All nozzles should deliver within 10% of each other.
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 of GPA.

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

(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)
8	510
10	408
12	340
14	291
16	255
18	227
20	204
22	185
24	170
26	157

(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 poisoning.
- To avoid harming and polluting the environment.
- To avoid crop injury.

These three points cannot be emphasized enough.

Pesticide accidents occur most often during mixing and tank filling operations. Although accidental ingestion of chemicals is considered the greatest health hazard, there is also great danger of poisoning when pesticides contact skin or eyes, or when the dust or vapors are inhaled. Protective clothing should be worn at all times during the handling and application of pesticides and the cleaning of spray equipment. Such equipment should include full coverage clothing, chemical-resistant rubber gloves and boots, splash-guard goggles, and a MSHA/NIOSH-approved respirator for the chemical compound being used. Care for these items as you would your implements. Heed all the precautionary statements on the product label and cover-up to protect yourself.

Using more chemical than is recommended on any label is illegal and can result in the carryover of residues in the soil. Pesticides may also leach into ground and surface water. Herbicide residues can also damage sensitive crops the following year. Some long-residual herbicides last more than one year in the soil; keep this in mind when planning a crop rotation program. The herbicides recommended in this bulletin should dissipate in one growing season unless otherwise noted. Check the product labels for precautions on rotational crops.

Herbicides offer an effective and economical means of weed control. Crop plants are seldom completely resistant to herbicide injury but have some level of tolerance. 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 Residues and Bioassays

With the advent of preplant and preemergence herbicides which give season-long weed control, the accumulation of herbicides in the soil and their influence on subsequent crops in the rotation have become important in crop management. However, when used at recommended rates in seasons of normal rainfall and temperature, most recommended herbicides for field crops do not present a problem on crops planted the following season. Exceptions are listed in Table 12.

Atrazine carryover to rotation crops is a common problem. A problem with herbicide residues is more likely to occur the year following a season of limited rainfall and cool temperatures because of the slow dissipation of the herbicide.

Herbicide bioassays can indicate whether enough herbicide is present to harm the crop. Obtain soil for a bioassay late in the fall prior to freeze-up or early in the spring. The bioassay procedure is a relatively simple test, but a few basic steps should be followed.

(1) Collect soil from several locations in the field. Reliability of the assay depends on accurate sampling. Sample soil to the depth the field has been tilled. Approximately 5 lb of soil are needed for each sample. Collect an equal amount of soil from an adjacent field where no herbicide has been applied. This second sample is used as a check.

(2) Start the bioassay within one or two weeks after soil is collected to prevent the loss of herbicide under warm conditions. If the assay cannot be run immediately, store the soil in a cool place, or even allow it to freeze.

(3) If the soil is wet, allow it to dry so that it may be worked easily. If the soil is cloddy, crush the clods but do not pulverize.

(4) Partially fill two, 1-qt containers with soil, one with the soil being tested and the other with soil from the "check" field. Punch holes in the bottoms of the containers to allow drainage. Tin cans or milk cartons make satisfactory containers.

(5) Plant 15 seeds of a sensitive crop in each container and cover with 1/2 inch of soil. Wet the soil, but do not saturate. Oats are very sensitive to both triazines and dinitroanilines. Place exactly the same number of seeds in each container. Knowing the exact number of seeds planted enables seedling emergence to be measured. Do not plant too many seeds or the seedlings may compete for the herbicide and decrease the injurious effects.

(6) Place containers in a warm place (70 to 75°F), preferably in a window to receive as much sunlight as possible. Additional artificial light should also be supplied to obtain approximately a 15-hour day length. Water plants sparingly, but do not let the soil dry out.

(7) Determine plant emergence, and monitor plant growth for at least three weeks after planting. Compare "check" plants with those in the soil being tested.

(8) Atrazine injury may cause yellowing of the oat leaves, with the plant becoming droopy and finally dying; if carryover is marginal, stunting may occur. Stunting can be determined by a comparison with "check" plants. Dinitroaniline injury may result in a decrease in seedling emergence and/or stunting of the seedlings.

(9) If any evidence of herbicide carryover is observed, it is advisable to plant a resistant crop.

Soil can also be analyzed in a laboratory for the amount of herbicide remaining in the soil. Most herbicides can be detected with a chemical soil analysis. This procedure is more expensive than a plant bioassay. Consult your MSU county Extension agent for a listing of commercial laboratories.

Herbicide Application

Herbicide Spray Volumes and Rates

Tables 1-8 list chemicals which will give satisfactory weed control without injury to crops, except as noted under "Remarks." 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 is recommended. With wettable powders use nozzles that deliver at least 15 gal per acre. Use 30 to 40 gal of water per acre when spraying quackgrass with atrazine. Use 10 gal of water per acre or less when spraying quackgrass or annual grasses with *Poast.*

Some contact-type postemergence herbicides (*Basagran, Ultra Blazer*) require a minimum of 20 gallons per acre spray volume and 40 psi spray pressure to insure adequate coverage. 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.

Herbicides are available in a number of different formulations and concentrations. For this reason, the recommended rates are given as pounds of active ingredient per acre. Thus, when a liquid formulation contains 4 lb of active ingredient (or acid equivalent) per gallon, 1 pt will provide ½ lb of active ingredient, or 1 qt will provide 1 lb of active ingredient.

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, as the spray volume with these nozzles is the same across the entire band.

Cleaning of 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.

When cleaning a sprayer used only for soil applications of herbicides, usually only a thorough water rinse is necessary. Exceptions are sulfonyl urea herbicides, such as *Accent, Beacon, Basis, Basis Gold, Synchrony STS, Classic, Express, Harmony Extra, Harmony GT,* and *Canopy XL;* and also *Command.* Consult these specific herbicide labels for detailed spray tank cleaning procedures.

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 gal household ammonia in 100 gal of water as a cleaning agent.

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 crop land. 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 based on 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 varies 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 *Banvel* (dicamba) or *Eptam* (EPTC) 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. *Eptam*).

Photodegradation is the breakdown of herbicides, such as *Treflan,* 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 an 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, 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 type of chemical reactions that occur. Some pesticides, especially the organophosphate insecticides, are susceptible to degradation by hydrolysis in high pH (alkaline) soils or spray mixes. Some herbicides, such as atrazine and *Classic,* are more rapidly degraded on low pH soils.

Absorption of plant uptake 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, which can 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 an 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. In addition, adjuvants that promote postemergence herbicide retention on leaf surfaces can reduce the pesticide content in runoff water. 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.

Surface water contamination is a major concern associated with the runoff of herbicides from treated fields, mixing and rinsing sites, waste disposal areas, and manufacturing facilities. In the 1988 inventory of water quality, pesticides were ranked sixth as river and stream pollutants, behind siltation, nutrients, pathogens, organic enrichment, and metals. Refer to the next section, “Groundwater and Surface Water Contamination” for information on how to prevent contamination.

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 an 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 contamination is a major concern associated with the leaching of herbicides from treated fields, mixing and rinsing sites, waste disposal areas, and manufacturing facilities. Refer to the next section, "Groundwater and Surface Water Contamination", for information on how to prevent contamination.

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 call 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 nonpoint source pollution. The key to preventing pesticides in groundwater and surface waters is identification of the source and route to the water. Point source contamination refers to situations where movement of a pesticide into water can be traced to a specific site. Nonpoint sources occur over a wide area and 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 well head.

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

Earlier we discussed herbicide fate and the numerous transfer and breakdown processes that occur in the environment. Those 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

Nonpoint 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 ppb.

The majority of pesticides detected in surface water are from surface runoff events. The pesticides are either 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 compared to applications where the herbicide is incorporated and applications where 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 of 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 while 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 specialists from an Extension office or your chemical dealer, if necessary.

The following herbicides contain advisory statements regarding groundwater protection:

Aatrex
Accent Gold
Accent Gold WDG
Atrazine
Axiom
Basis Gold
Bicep II Magnum
Bicep Lite II Magnum
Boundary
Buctril-Atrazine
Bullet
Canopy SP
Curtail
Define
Degree
Degree Xtra
Domain
Fieldmaster
FirstRate
Fultime
Gauntlet
G-Max Lite
Guardsman
Guardsman Max
Harness
Harness Xtra
Harness Xtra 5.6L
Hornet WDG
Keystone
Keystone LA
Laddok
Lariat
Lasso
Liberty ATZ
Lumax
Marksman
Micro-Tech
Outlook
Partner
Python
Ready Master ATZ
Salute
Sencor
Shotgun
Stinger
Surpass
TopNotch
Turbo
Volley
Volley ATZ
Volley ATZ Lite

(continued on next page)

The following herbicides contain advisory statements regarding surface water protection:

Aatrex
Atrazine
Axiom
Basis Gold
Bicep II Magnum
Bicep Lite II Magnum
Boundary
Buctril-Atrazine
Bullet
Callisto
Camix
Cinch ATZ
Cinch ATZ Lite
Define
Degree Xtra
Domain
Fultime
G-Max Lite
Guardsman
Guardsman Max
Harness Xtra
Keystone
Laddok
Lariat
Liberty ATZ
Lumax
Marksman
Outlook
Ready Master ATZ
Shotgun
Volley ATZ
Volley ATZ Lite

These herbicides 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 only be applied to HEL (highly erodible land) acres 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 which provides adequate pest control. Band applications of preemergence herbicides reduce the potential of herbicides to leach or runoff 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.

Michigan Groundwater Stewardship Program (MGSP)

The MGSP *HAS BEEN AUTHORIZED THROUGH THE YEAR 2010* by the state legislature. It is funded by assessments on the sale of nitrogen fertilizers and pesticides, generating $3.5 million dollars each year. The program delivers educational programs, technical assistance and cost share that meet the needs and interests of local pesticide and fertilizer users. Growers may request an assisted farmstead pollution risk assessment (Farm*A*Syst), develop a groundwater stewardship plan, install groundwater stewardship practices using cost share funds, attend an on-farm demonstration and participate in an educational workshop sponsored by the MGSP.

The MGSP also sponsors the Spill Response Program (1-800-405-0101) to assist individuals dealing with pesticide, fertilizer and manure spills; Clean Sweep to dispose of unused and unwanted pesticides in an environmentally sound manner; and Container Recycling to boost the industry's efforts for collecting plastic and aerosol pesticide containers.

Contact your MSU Extension, Conservation District or USDA NRCS representative to learn more about the MGSP serving your county.

Pesticide Emergency Preparedness

When purchasing a pesticide, obtain a specimen label from the dealer and keep it on file on the farm. This label will be available immediately if an emergency involving a pesticide occurs. Take the label along to a medical treatment center if an individual has suffered pesticide poisoning.

Read and observe closely the *Precautionary Statements* section of the label. Make sure that several people are aware of and can administer treatments for pesticide poisoning contained in the *Statement of Practical Treatment* on the label.

Transporting Pesticides

Have pesticides delivered directly to your pesticide storage facility to avoid liability and potential accidents and spills in transit whenever possible. DOT shipping rules must be followed for transporting large quantities of pesticides, including proper placarding of the vehicle, liability insurance, special handling requirements, etc.

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.

For additional information on pesticide storage, refer to Midwest Plan Service bulletin 37, *Designing Facilities for Pesticide and Fertilizer Containment,* and MSU Bulletin E-2335.

Handling and Mixing Pesticides

Always wear protective clothing and equipment when handling, mixing, and applying pesticides and during cleanup of application equipment. Protective clothing should include full coverage clothing, chemical resistant gloves and boots, eye protection, hard hat and a MSHA/NIOSH approved respirator with a chemical absorbent material as specified on the pesticide label.

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 which 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, containers that may be recycled, or in water soluble bags to avoid disposal problems.

All pesticide containers can be rendered nonhazardous 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.

Unused and Unwanted Pesticides/Clean Sweep

The proper disposal of unused and unwanted pesticides is the goal of the Clean Sweep program in Michigan. The Michigan Groundwater Stewardship Program (MGSP), in cooperation with county and local units of government, has established permanent Clean Sweep sites located throughout the state.

Individual Michigan residents may dispose of unused and unwanted pesticides by taking them to one of these Clean Sweep sites where they will be collected, packaged for shipping, and disposed of properly. There is no charge for this service. Program costs are covered by MGSP, a grant from the U.S. Environmental Protection Agency, and services provided by the local cooperators.

Pesticide dealers and individuals who sell and/or apply pesticides for hire may also, at the Clean Sweep site manager's discretion, dispose of unused or unwanted pesticides at cost. This cost is typically less than 20% of the normal cost of pesticide waste disposal because of economies of scale and competitive bidding of waste disposal accounts.

Persons interested in participating in the Clean Sweep program should contact their local MSU Extension office for the location nearest them.

Protect Nontarget Organisms

Applying pesticides carelessly can harm nontarget 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 Max* (paraquat), for example, is an herbicide toxic to bees. Be aware of how bee poisoning can occur and how to prevent them.

The following precautions reduce the chance of bee poisoning.

- Do not apply herbicides (such as *Gramoxone Max*) 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; or are exposed directly to the spray; or consume a treated crop; or drink and use contaminated water; or feed on pesticide-contaminated prey.

Worker Protection Standard

New federal rules for farm worker protection, issued during 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) 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 1990 Farm Bill requires that all applicators who apply restricted use pesticides (RUP) keep records and maintain them for two years. Records to be kept include:

- brand name or product name and the EPA registration number.
- 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 and year of the application.
- name and certification number of the applicator or applicator's supervisor.

The spray record sheet at the end of this publication, or E-2340 to E-2345 which includes directions and forms for a complete farm record keeping system, can be used for recording your sprays. Any record form is acceptable as long as the required data is included. Penalties are up to $500 for the first violation and up to $1000 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. Contact your Extension office for final revisions.

Endangered Species Act

To minimize the adverse impact of pesticides on endangered species, the EPA has initiated The Endangered Species Act. The Michigan Department of Natural Resources (MDNR) administers the Michigan Endangered Species Act and maintains the federal and state endangered species lists in the state. Pesticide applications are a potential problem, particularly affecting birds, butterflies and moths. Alteration of the farm landscape can also negatively affect resident endangered species.

The Environmental Protection Agency (EPA) has determined threshold pesticide application rates that may affect listed species. This information is or will be included on pesticide labels. Counties with vulnerable endangered or threatened species will be identified on pesticide labels. Farmers must take the initiative and consult with the MDNR and the Fish and Wildlife Service (FWS) to be sure there are no endangered species in their area. The Nature Conservancy, a private land and habitat conservation organization, is working with the MDNR and the FWS and is conducting a landowner contact program to work with landowners who own property important for endangered species protection.

SARA Title III Emergency Planning and Community Right to Know Act

The Emergency Planning and Community Right to Know Law, under SARA Title III, requires farmers to notify their State Emergency Response Commission (SERC), Local Emergency Planning Committee (LEPC), and local fire department that they store extremely hazardous materials along with the name and telephone number of the facility representative. Check with your state Department of Natural Resources or Extension to receive a list of EPA established

"Extremely Hazardous Substances" and their threshold planning quantities.

The LEPC and fire chief may request maps of your storage facility and detailed lists of materials you store.

This law also requires, in the event of a spill, the SERC, LEPC and National Response Commission be notified. The reportable quantities for spills is much less than for storage and can be obtained from the above sources.

Right to Farm

Farmers in Michigan are protected from nuisance lawsuits under the Right to Farm Act if they follow specific acceptable management practices. The Generally Accepted Agricultural and Management Practices for pesticide utilization and pest control, nutrient utilization, and manure management have been completed and are revised annually. Contact your Extension agent or regional office of the Michigan Department of Agriculture to obtain copies. In addition, the latest version of the voluntary guidelines are available at the following web address: **www.mda.state.mi.us/right2farm/farm.htm**

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. The following list (on next page) contains the herbicides included in this guide that are classified as Restricted Use Pesticides.

Restricted Use Herbicides

Aatrex	Harness
Atrazine	Harness Xtra
Basis Gold	Harness Xtra 5.6L
Bicep Lite II Magnum	Keystone
Bicep II Magnum	Keystone LA
Buctril-Atrazine	Laddok
Bullet	Lariat
CinchATZ	Lasso
Cinch ATZ Lite	Liberty ATZ
Degree	Lumax
Degree Xtra	Marksman
DoublePlay	Micro-Tech
Fieldmaster	Ready Master ATZ
Fultime	Shotgun
G-Max Lite	Surpass
Gramoxone Max	TopNotch
Guardsman	Volley
Guardsman Max	Volley ATZ
	Volley ATZ Lite

Herbicide Resistance in Weeds

Triazine-resistant common lambsquarters has been confirmed in sites throughout most of the corn production regions of Michigan. In addition, resistance has been confirmed in pigweed species, common ragweed, common groundsel, and marestail (horseweed). The occurrence of triazine-resistance is generally associated with cropping systems where triazine herbicides (i.e., atrazine, *Bladex,* and *Princep*) have been frequently used for weed control. Triazine-resistant common lambsquarters are often identified in fields where corn is grown continuously. Triazine-resistant biotypes of several other species have been identified in other states and countries.

There is growing concern about resistance to sulfonylureas and imidazolinones. Resistance to these herbicides has been observed in Michigan and has become a serious problem in western regions of the U.S. Resistance to these herbicides has been recently confirmed in many sites throughout the north central region of the U.S. Resistance to these herbicide groups is a major concern because both affect the same process in plants.

An understanding of the practices that lead to herbicide resistance is important since prevention is the best approach. This is particularly important with the introduction of herbicide resistant crops such as Pursuit resistant corn hybrids. Herbicide resistant crops increase the possibilities for one herbicide to be applied for multiple years to the same field even with rotation of crops.

Farmers should include weed control practices that delay or prevent the development of herbicide resistance. The following list of practices was modified from a list developed by the North Central Weed Science Society Herbicide Resistance Committee. Some practices may be impractical in certain situations. However, 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 which include multiple sites of action. Combining herbicides with different sites of action and similar persistence in soil will help prevent herbicide resistance. **Note: The herbicide sites of action which are at greatest risk of developing resistant weed populations are the following:**

A. ACCase Inhibitors
B. ALS Inhibitors
C. Photosynthesis Inhibitors

(See description of sites of action below.)

(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 which are not infested.

Herbicide Site 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 prevent herbicide resistance. The following list categorizes herbicides into general sites of action. 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 Site of Action

Site of Action	Chemical Family	Herbicide
ACCase Inhibitors	Cyclohexanediones	Sethoxydim *(Poast, Poast Plus)* Clethodim *(Select, Arrow)*
	Aryloxyphenoxypropionates	Fluazifop *(Fusilade DX,* component in *Fusion)* Fenoxaprop *(*component in *Fusion)* Quizalofop *(Assure II)*
ALS Inhibitors	Imidazolinones	Imazaquin *(Scepter)* Imazethapyr *(Pursuit)* Imazethapyr + Imazapyr *(Lightning)* Imazamox *(Raptor)*
	Sulfonylureas	Chlorimuron *(Classic,* component in *Canopy SP, Canopy XL)* Foramsulfuron *(Option)* Thifensulfuron *(Harmony GT,* component in *Harmony Extra)* Tribenuron *(Express,* component in *Harmony Extra)* Triflusulfuron *(UpBeet)* Nicosulfuron *(Accent)* Primisulfuron *(Beacon)* Halosulfuron *(Permit)* Rimsulfuron + Thifensulfuron *(Basis)* Rimsulfuron + Nicosulfuron *(Basis Gold, Steadfast)*
	Sulfonamides	Flumetsulam *(Python, Hornet WDG)* Cloransulam-methyl *(FirstRate)*
Photosynthesis Inhibitors	Triazines	Atrazine Simazine *(Princep)* Metribuzin *(Sencor)* Hexazinone *(Velpar)*
	Phenylureas	Linuron *(Lorox)*
	Uracils	Terbacil *(Sinbar)*
Photosynthesis Inhibitors (Nonmobile)	Benzothiadiazoles	Bentazon *(Basagran)*
	Nitriles	Bromoxynil *(Buctril, Moxy,* others)
Growth Regulators	Phenoxy Acetic Acids	2,4-D 2,4-DB *(Butyrac 200, Butoxone 200)* MCPA
	Benzoic Acids	Dicamba *(Banvel, Clarity;* component in *Distinct)*
	Pyridines	Clopyralid *(Stinger)*
EPSPS Inhibitors	Amino Acid Derivatives	Glyphosate (See Table 10)
Seedling Growth Inhibitors (Root Inhibitors)	Dinitroanilines	Trifluralin *(Treflan, Tri-4)* Ethalfluralin *(Sonalan)* Pendimethalin *(Prowl/Pendimax/Prowl H_20)*
Unknown (Shoot Inhibitors)	Acetamides	Alachlor *(Lasso, Micro-Tech, IntRRo)* Acetochlor *(Harness, Surpass, Topnotch, Degree,Volley)* Dimethenamid-P *(Outlook)* Metolachlor *(Stalwart C)* s-metolachlor *(Dual Magnum, Dual II Magnum, Cinch)* Flufenacet (*Define*, component of *Axiom, Domain*)
	Thiocarbamates	EPTC *(Eptam)* Cycloate *(Ro-Neet)*

(continued on next page)

Herbicide Site of Action (continued)

Site of Action	Chemical Family	Herbicide
Photosystem I Inhibitors	Bipyridiliums	Paraquat *(Gramoxone Max)* Diquat *(Reglone)*
Protoporphyrinogen Oxidase Inhibitors (PPO)	Diphenylether	Acifluorfen *(Ultra Blazer)* Fomesafen *(Flexstar, Reflex)* Lactofen *(Cobra)*
	N-phenylphthalimide	Flumiclorac *(Resource)* Flumioxazim *(Valor)*
	Aryltriazinone	Sulfentrazone *(Authority, Blanket, Spartan)* Carfentrazone *(Aim EW)*
Diterpene Synthesis Inhibitor (Bleaching)	Isoxazolidinone	Clomazone *(Command)*
4 –HPPD Inhibitor (Bleaching)	Callistomone	Mesotrione *(Callisto)*
Glutamine Synthetase Inhibitor	Amino Acid Derivatives	Glufosinate *(Liberty)*