Weed Control Principles

Importance of Weed Control

Weed control is an essential part of all crop production systems. Weeds reduce yields by competing with crops for water, nutrients, and sunlight. Weeds also may directly reduce profits by hindering harvest operations, lowering crop quality, and producing chemicals which are harmful to crop plants (allelopathy). In addition, weeds left uncontrolled may harbor insects and diseases and produce seed or rootstocks which infest the field and affect future crops. Despite large expenditures for weed control, it is estimated that losses in U.S. crops due to weeds left uncontrolled exceed $7.5 billion annually.

Years of research have shown that good weed control within the first 4 to 6 weeks after crops are planted is critical in order to avoid a yield reduction from weeds. The effectiveness of any weed control program depends largely upon one factor:**TIMELINESS.** There are many cultural, mechanical, and chemical methods of weed control which are extremely effective if applied at the correct time. Fields that are kept free of weeds for the first four to six weeks after planting give the crop a "head start" which enables it to shade out or otherwise out compete weeds that emerge later in the season.

Identify specific weed problems, because different weeds vary greatly in their ability to compete with crops and reduce yields. Is 100% control of all weeds necessary? Perhaps this can be answered by stating that most successful producers design control programs to maximize profit, not just weed control. While it is true that crops are able to tolerate a certain threshold number of weeds without suffering a yield reduction, it is first important to consider weed problems on an individual basis. There are some weeds for which 100% control may be desirable because they are particularly competitive, persistent, or difficult to control. These include some annual weeds such as giant ragweed, common cocklebur, burcucumber, or shattercane, and several perennial weeds such as johnsongrass, Canada thistle, bindweeds, Jerusalem artichoke, quackgrass, and hemp dogbane.

Cultural And Mechanical (Nonchemical) Weed Control

There is no substitute for good cultural and crop management practices, for these constitute the backbone of any weed control program. **Dependence upon herbicides alone does not always provide the most economical weed control.** Herbicide performance is strongly related to environmental conditions, so not even the best herbicides are equally effective from year to year. The most desirable weed control program is one that will control existing weeds economically and prevent a buildup of weed seed or tubers, rhizomes, etc. in the soil. Such a program includes integrated use of several practices which may include any of several crop management practices in addition to chemical weed control.

Crop rotation is one of the most effective cultural practices for improving long-term weed control. Crop rotation aids in controlling weeds by: 1) allowing rotation of herbicides as well as crops, and 2) providing the opportunity to plant highly competitive crops which prevent weed establishment. Many herbicides that are available for use in corn, for instance, are extremely effective in controlling weeds for which there are no adequate controls in soybeans or sugarbeets. Rotation to a densely planted crop such as alfalfa or small grains helps prevent most annual weeds from becoming established and producing seed with little, if any, chemical input. Some production systems which utilize rotation to small seeded legumes (including alfalfa) or other densely grown perennial grass-legume forage mixtures are effective in reducing populations of some perennial weeds.

Any practice that provides optimum conditions for early and vigorous growth of crops helps give them a competitive edge over weeds. Following are some of these practices:

- Narrow row spacings (15 inches or less) for soybeans
- Proper planting date and seeding rate
- Use of disease- and nematode-resistant varieties
- Insect control
- Adequate soil fertility
- Adequate drainage

Following are several other preventative cultural practices that do not allow weeds to become established and spread:

- Control weeds in noncropland areas, including fencerows, drainage ditchbanks, and rights-of-way
- Plant only high quality weed-free crop seed
- Do not spread manure, hay, crop residues, etc. contaminated with weed seed on cropland
- Clean farm machinery between fields to avoid transport of weed seed, rhizomes, tubers, and rootstocks
- If "new" or unfamiliar weeds appear, have them identified quickly and take appropriate control measures if necessary

Mechanical weed control is still an important component of many weed control programs. Primary tillage operations involve moldboard plowing or some type of reduced tillage that destroys existing vegetation and allows adequate seedbed preparations. Secondary tillage is performed for final seedbed preparation, and is usually done with a tandem disk, field cultivator, or similar implement. The third category of tillage is selective cultivation, which is used to control weeds after the crop has emerged from the soil. Selective cultivation may be performed with a rotary hoe, rolling cultivator, shovel (sweep) cultivator, or similar implement.

Conventional tillage systems involve primary and secondary tillage. These operations may be followed by selective cultivation, depending on the crop and its row spacing. Conventional tillage is effective for reducing populations of many biennial and perennial weeds that may arise from rhizomes or rootstocks. Annual weeds that reproduce only from seed will most likely still be a problem and require additional controls.

If selective cultivation is used, it should be done early. Rotary hoes are effective for controlling small weeds (less than 1 inch tall) and should be operated at relatively high speed (7 to 10 mph) and on fairly dry soil. For maximum effectiveness, a rotary hoe should be used when weeds are in the "white stage", or just emerging from the soil. Cultivation with a shovel, sweep, or rolling cultivator is more effective on larger weeds than a rotary hoe, but should still be operated when weeds are very small. Cultivations should be shallow (1 to 2 inches deep) to prevent excessive root damage to the crop. Deeper cultivation also depletes soil moisture and can cause excessive ridging, creating problems at harvest for some crops.

Conservation or reduced tillage systems do not involve moldboard plowing and maintain some previous crop residue on the soil surface. Primary tillage in a reduced tillage system consists of using a disk, field cultivator, or chisel plow and may be the last operation before planting. No-till crop production involves no primary or secondary tillage, and the crop is planted directly into a sod or the previous year's crop residue. Conservation tillage systems generally rely more heavily on chemical weed control than conventional tillage systems. For additional details on reduced tillage systems, refer to other sections of this chapter.

Chemical Control of Weeds

When designing a weed control program based on herbicide use, consider soil type, tillage practices, crops (current and following), weed problems, and overall farming operations. **No one herbicide will control all species of weeds, so it is important to select herbicides based on the weeds present in a field.** Herbicides are often combined to control more weed species, reduce carryover, or reduce crop injury. Some weeds are not controlled by any of the currently available selective herbicides, and require specialized application of nonselective herbicides. Good herbicide performance depends upon the weather, soil conditions, and accurate application.

Soil-applied herbicides have traditionally been the mainstay of herbicide programs. Preplant and preemergence herbicides have the advantage of eliminating early competition between crops and weeds. However, research has shown that weeds will not reduce crop yields if controlled within 4 to 6 weeks after emergence. Postemergence herbicides are comparable to soil-applied herbicides in effectiveness and economics if applied within this time period. Some weeds are better controlled by soil-applied herbicides, while others are more susceptible to postemergence herbicides. Consider combining soil-applied and postemergence herbicides for maximum control of some populations of weed species.

Herbicide Nomenclature and Formulations

There is often more than one formulation of a particular herbicide. This can make selection and application of various products somewhat confusing. Each herbicide has a trade name (sometimes more than one), a common name, and a chemical name. For example, Lasso and Arena are registered trade names, alachlor is the common name, and 2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl)acetamide is the chemical name for a herbicide used in corn and soybeans.

Prepackaged mixtures typically go by a single trade name yet may contain two or more different herbicides. For example, Bicep (trade name) is actually a mixture of metolachlor and atrazine. For this reason it is important to know common names of herbicides so that one knows exactly what a product contains.

Herbicides are formulated and sold in various liquid or solid formulations, depending upon (1) the solubility of the active ingredient in water, and (2) the manner in which the product is applied (i.e. dispersed in water or applied in the dry form). Formulation type is listed on the herbicide label and may be designated by a letter or letters following the trade name. A herbicide label must also give a list of all ingredients and the amount of active ingredient contained in the product. For liquid formulations, amount of active ingredient contained is expressed both as a percentage of the total ingredients and as the number of pounds in a gallon of product. Active ingredients contained in dry formulations are expressed only as a percentage by weight. Several formulations and abbreviations are listed below.

Emulsifiable concentrate (E or EC) - a liquid formulation containing various emulsifiers that aid in dispersion of the active ingredient in water.

Water Soluble (S, AS, or WS) - usually a liquid formulation containing the active ingredient, water, and sometimes a surfactant and antifreeze agent.

Oil Soluble (OS) - a liquid formulation containing the active ingredient dissolved in oil or some other organic solvent. These herbicides must be applied in an oil-based carrier such as diesel fuel or kerosene.

Liquid Flowable (F or LF) - a thick liquid with a slurry-like consistency containing the active ingredient, water, and stabilizers to help active ingredient stay in suspension. Spray tank agitation is necessary to keep flowable formulations from settling out of suspension.

Wettable Powder (W or WP) - a dry powder containing the active ingredient, a diluent, usually bentonite or attapulgite clay, and surfactants. Spray tank agitation is necessary to avoid settling.

Dry Flowable (DF) - a dry formulation consisting of herbicide-impregnated granules that easily disperse in water. Dry flowables are easier to handle and measure than wettable powders. Spray tank agitation is necessary to avoid settling.

Dispersible Granules (DG) or Water-Dispersible Granules (WDG) - a dry formulation very similar to dry flowable formulations. The ingredients are in granules which easily disperse in water. Spray tank agitation is necessary to avoid settling.

Granules (G) - a dry formulation consisting of the active ingredient coating or adhered to some type of inert granule such as clay, vermiculite, or sand. These formulations are applied just as they are purchased with no mixing. Special granular application equipment is required.

Pellets (P) - a dry formulation of active ingredient coating some type of inert pelleted material - similar to granules only much larger. Pellets are applied directly to the target area by hand or with special spreaders.

Herbicide rates are sometimes expressed on an active ingredient basis in technical publications. To convert pounds of active material to pounds of a commercial dry formulation:

Pounds of commercial product/A =

$$\frac{\text{Pounds of active ingredient/A}}{\text{Percent Active Ingredient in Product}} \times 100$$

To convert pounds of active material to gallons of a commercial liquid formulations:

Gallons of commercial product/A =

$$\frac{\text{Pounds of Active Ingredient/A}}{\text{Pounds of Active Ingredient in Gallon}}$$

Soil-Applied Herbicides

Soil-applied herbicides can be applied preplant (or early preplant), preplant incorporated, or preemergence to the crop. Activity of these herbicides is affected by soil texture, organic matter content, pH, moisture, and tillage. Most soil-applied herbicides are more available for plant uptake in coarse-textured, low organic matter soils than in fine-textured, high organic matter soils. Many herbicide labels specify application rates based on soil texture and organic matter content. Herbicides are more likely to injure crops in sandy soils low in organic matter, and careful herbicide rate selection is required to avoid injury. Some herbicides are not labeled for use in sandy soils low in organic matter.

Soil pH can influence the activity of some herbicides. Triazine herbicides are more available for plant uptake in soils with high pH, resulting in better weed control and increased risk of crop injury. The low pH conditions that can result from continuous no-tillage may reduce the availability of some herbicides, resulting in less effective weed control. In general, herbicides are most effective when soil pH is in the range recommended for optimum crop growth.

Soil-applied herbicides require adequate soil moisture for activity. Uptake of herbicide into germinating weeds occurs from the soil solution only. In the presence of adequate soil moisture, less herbicide is adsorbed to the soil and more available in the soil solution for weed control. Under dry conditions, herbicide is tightly adsorbed by soil colloids, and insufficient herbicide may be available in the soil solution to provide acceptable weed control. Preemergence herbicide applications require rainfall, usually at least 1/2 inch, to move herbicide from the soil surface into the zone of weed seed germination and emergence.

Early preplant herbicides are applied several weeks to a month or more prior to planting without incorporation. Herbicides with a fairly long period of residual soil activity can be applied early preplant. Herbicides with a shorter soil residual may not provide late season control when applied early. Early preplant herbicide programs frequently do not provide adequate season-long annual grass control in fields with high grass populations.

Advantages

- Allows more time to receive the rainfall necessary to more herbicide from the soil surface into the zone where weed seeds germinate.
- Herbicides can be applied with fertilizer, eliminating trips over the field.
- Reduces workload at planting time.
- Prevents the emergence of annual weeds, and can eliminate the need for a burn-down herbicide in no-till systems.
- Allows more time for degradation of herbicide in the soil, reducing the risk of carryover problems with persistent herbicides.

Disadvantages

- Limited herbicide options because not all herbicides have sufficient soil residual for early application.
- May require higher rates, split applications, or postemergence applications for later season control, especially of annual grasses.
- Early application of herbicides when soils are wet may cause soil compaction from application equipment.

Preplant incorporated herbicides are incorporated into the soil prior to planting. Incorporation of some herbicides is necessary to prevent surface-loss from volatility or photodecomposition. Other herbicides are incorporated to reduce the dependence upon rainfall required to more herbicide into the zone of weed seed germination. Incorporation also provides the herbicide placement required for control of some weeds, especially perennials.

Advantages

- Reduced dependence upon rainfall to position herbicides in the soil.
- Overall more reliable weed control than preemergence applications.
- More effective control of some perennial weeds than with preemergence applications.
- Herbicide may be applied with or impregnated on dry fertilizer or in liquid fertilizers.

Disadvantages

- Incorporation represents added cost in herbicide application.
- Incorporation can result in soil compaction and crusting.
- Weed control can be reduced if herbicide is diluted by incorporation that is too deep.
- Streaking of herbicide due to improper incorporation can result in erratic weed control.
- Planting operations can be slowed due to the time required for herbicide application and incorporation.
- Herbicides cannot be incorporated in some reduce tillage situations.

The depth and thoroughness of incorporation depend upon the type of equipment used, the depth and speed of operation, soil texture, and the amount of soil moisture. Incorporation should place the herbicide uniformly throughout the upper 1 to 2 inches of soil for best control of small-seeded annual weeds that germinate at shallow depths. Slightly deeper placement may improve control of certain weeds from deep-germinating seeds,especially under dry conditions. The field cultivator and tandem disk place most of the herbicide at about one-half the depth of operation. The suggested depth of operation for these implements is thus 3 to 4 inches.

The most thorough and uniform incorporation, especially with a tandem disk or field cultivator, requires two passes at an angle to each other. However, some of the newer combination tools can provide more uniform single-pass incorporation. The effectiveness of single-pass incorporation can depend upon the soil conditions as much as the implement used to incorporate. One-pass incorporation is not a good approach with less than optimum soil tilth. Incorporation in soils that are too wet can result in streaked weed control; this may be increased with one-pass as compared to two pass incorporation. High crop residue levels make one-pass incorporation difficult. Two-pass incorporation is advised if residue is sufficient to clog the incorporation tool.

Field cultivators are frequently used for herbicide incorporation. Two passes are recommended for uniform weed control, but field cultivators can give acceptable one-pass incorporation with proper set-up and operation. They should have 3 or more shanks with an effective shank spacing of no more than 8 to 9 inches. These shanks can be equipped with points or sweeps. Sweeps usually provide better incorporation, especially when soil conditions are too wet or dry for optimum soil flow and mixing. Sweeps for "C" shank cultivators should be at least as wide as the effective shank spacing. For one-pass incorporation, wider sweeps or narrower spacing with a 3- to 5- bar harrow or rolling baskets pulled behind will provide more uniform incorporation and weed control.

The recommended operating depth for the field cultivator is 3 to 4 inches. The ground speed should be at least 6 miles per hour. The field cultivator must be operated in a level position. If the back shanks are lower than the front, untreated soil will be brought to the surface and the result will be streaked weed control.

Tandem disk harrows invert the soil and usually place the herbicide deeper in the soil than most other incorporation tools. Tandem disks used for herbicide incorporation should have disk blade diameters of 20 inches or less and blade spacings of 7 to 9 inches. Spherical disk blades provide better herbicide mixing than conical disk blades.

The suggested operating depth for incorporation of most herbicides is from 3 to 4 inches. Two passes are recommended to obtain uniform incorporation with a double disk. A leveling device (harrow or rolling baskets) should be used behind the disk to obtain proper mixing. Recommended ground speeds are usually between 4 and 6 miles per hour. Speed should be sufficient to move the soil the full width of the blade spacing.

Combination tools are tillage and incorporation tools that combine disk gangs, field cultivator shanks, and leveling devices. Many of these tools can handle large amounts of surface residue without clogging, and still leave considerable residue on the surface for erosion control. Combination tools may provide more uniform one-pass incorporation than a disk or field cultivator. Good soil tilth is still a prerequisite for effective one-pass incorporation. One-pass incorporation with these tools is generally no better than two passes with a disk or field cultivator.

Preemergence herbicides are applied to the soil surface after the crop is planted but before crop seedlings and weeds appear above the ground. For maximum preemergence activity, 1/2 to 1 inch of rainfall should occur within one week following application. Where this rain does not occur, a rotary hoe is recommended for control of weed escapes as they are emerging.

Advantages

- Planting and herbicide application may be done in one operation.
- When rainfall is adequate to move herbicide into the soil, preemergence applications can provide better weed control than preplant incorporated applications.
- Preemergence herbicides can be used in all tillage systems.
- Preemergence herbicides can be applied in liquid fertilizers.

Disadvantages

- Rainfall is required for activity, and preemergence applications are ineffective under dry soil conditions.
- On sandy soil, heavy rains may leach the herbicide down to the germinating crop seed and cause injury.
- Perennial and deep-germinating weeds are not as well-controlled compared to preplant incorporated applications.

Postemergence Herbicides

Postemergence herbicides are applied after the crop and weeds have emerged. Most postemergence herbicides have foliar activity only, while a few do provide foliar and soil activity.

Advantages

- Soil type does not affect herbicide activity.
- Herbicide decisions are based on a knowledge of weed species and populations present at the time of application.
- Postemergence herbicides can be used in any tillage system.

Disadvantages

- Timing of application is critical for good weed control and to avoid crop injury.
- Weed control can be reduced if environmental conditions cause weeds to be stressed at the time of application.
- Rain may prevent the application of herbicide at the proper weed growth stage.

In order to achieve effective postemergence control, it is critical to follow label recommendations on rate and timing of application, weed species controlled, and the use of spray additives. The rate and timing of application are based on weed size and climatic conditions. Weeds can usually be controlled with a lower application rate when they are small and tender. Larger weeds often require a higher rate or an additional spray additive, especially if the weeds have developed under droughty conditions. Avoid applying postemergence herbicides during abnormally cool or dry weather, since weeds may not be actively growing under these conditions. Delaying application until weeds resume active growth will ensure better control. Herbicide penetration and action are usually greater when the temperature and relative humidity are high, resulting in better weed control and greater crop injury.

Many of the herbicides applied postemergence cause some crop injury, and crop size limitations may be specific on the label to minimize injury. Weed control can be reduced if rainfall occurs too soon after application. Postemergence herbicides labels specify an interval of 1/2 to 8 hours between application and rainfall, depending upon the herbicide.

The use of an adjuvant such as surfactant, crop-oil concentrate, or fertilizer solution is often recommended to improve spray coverage and herbicide uptake. Weed control may be increased with the use of additives, but crop injury may be increased also. For this reason, follow label directions regarding the use of additives.

Other considerations for postemergence applications are spray volume, pressure, and nozzle selection. Translocated herbicides (move throughout plant) can be effective with partial foliar coverage, while contact herbicides (active only where in contact with plant) require more complete spray coverage. Foliar coverage increases as spray volume and pressure are increased. For contact herbicides, 20 to 40 gallons per acre are often recommended for ground application. Translocated herbicides can often be applied in a minimum volume of 5 to 10 gallons per acre. Minimum spray pressures of 30 to 40 psi are recommended; this pressure range produces smaller droplets and improves penetration of dense canopies. Flat-fan nozzles are generally preferred for postemergence applications, although some herbicides can be applied with flood-type nozzles. However, most labels do not recommend the use of low-pressure flooding nozzles for postemergence application.

Directed Postemergence Herbicides

Directed postemergence applications minimize crop injury because herbicide is placed on the weeds rather than on the crop. Precise application and a height differential between the crop and the weeds are required for directed applications. If the weeds are smaller than the crop, spray can be directed at the base of the crop so that little herbicide reaches the upper parts of the crop plant. Spray pressure should be set fairly low for this type of application, so that fine spray particles or mist are not produced. Safety of applications directed at the base of the crop will be increased through the use of shielded nozzles.

“Wipers” (sponge or rope wick applicators) operate above the crop canopy to control weeds growing taller than the crop. This type of application works best for soybeans, since weeds must generally be at least a foot taller than the crop. Control of johnsongrass, hemp dogbane, and volunteer corn is often achieved using concentrated solutions of Roundup Ultra, Touchdown, or postemergence grass herbicides applied in this manner.

No-Tillage Weed Control

No-till production systems are more dependent upon herbicides for weed control, compared to conventional or reduced-tillage systems where soil is tilled in the spring prior to planting. In no-till, those weeds that emerge from the previous fall through spring must be controlled with fall-applied residual herbicides, or with foliar-applied (e.g. glyphosate, Gramoxone, 2,4-D) and/or residual herbicides in the spring. The weed population in the spring in no-till fields can consist of perennials (e.g. Canada thistle, dandelion), winter annuals (e.g. mustards, pennycress, chickweed), and early-emerging summer annuals (e.g. common lambsquarters, giant ragweed, Pennsylvania smartweed). If not killed at the time of planting, these weeds often become too large to be controlled by postemergence herbicides that are typically applied about three weeks after planting, and may reduce crop yield.

Broadleaf weeds emerge earlier in the spring than grasses, and application of 2,4-D with a preplant herbicide program may provide adequate burndown where grasses are not present. Several preplant herbicides have foliar activity in addition to soil activity, and can control or help control small broadleaf weeds. These herbicides include atrazine, Callisto, Lumax, Lexar, Canopy XL, Hornet, Balance, Gangster, Steel, Python, and Sencor. Where annual grasses more than a few inches tall are present, the burndown herbicide program should include Gramoxone Extra or glyphosate. Glyphosate should be applied in the spring if quackgrass is present. Combinations of glyphosate or Gramoxone plus 2,4-D may provide more complete control of a mixed population of weeds than either herbicide alone.

Applying preplant herbicides earlier in the spring when weeds have not emerged or are very small will minimize the need to include glyphosate or Gramoxone Extra. Early application allows more opportunity for herbicide to receive adequate rain and move into the upper few inches of soil, compared to application at planting. However, early application can result in poor late-season control of some weeds, especially giant foxtail and fall panicum, when crop growth is slow and rain is abundant in the early part of the growing season. Moving herbicide application closer to planting can prevent this problem to some extent. Preemergence herbicides applied at or after planting can provide acceptable control in no-till, but more rainfall will be needed than in a conventional tillage seedbed for activity, since herbicide must move through crop residue to reach the soil surface.

Postemergence herbicide programs seem to fit well into no-till production systems. There can be a reduction in the population of large-seeded annual broadleaf weeds in no-till over time, possibly reducing the need for a broad-spectrum preplant herbicide program. The application of postemergence herbicides on an as-needed basis may ultimately result in a reduction in herbicide inputs and costs in no-till. Giant foxtail and waterhemp often increases in population in no-till during the first several years, but effective control will eventually reduce the foxtail population, due to a lack of seed return to the soil surface. When planning a postemergence herbicide program in no-till, use of a burndown herbicide at planting is critical for success. Do not count on postemergence herbicides to control weeds that have already emerged at planting.

A major change in weed management programs that must occur in no-till is increased attention toward control of perennial weeds, which become more prevalent and difficult to control as tillage is reduced. These can include hemp dogbane, bindweeds, milkweeds, dandelion, and other weeds. Most of these emerge fairly late in the season, so that they cannot be killed by application of glyphosate at planting. Likewise, most postemergence herbicides only suppress perennials, and this is more easily accomplished in corn than soybeans. The main key to control of perennial weeds is application of glyphosate, dicamba (Banvel), and/or 2,4-D when they are are in the bud to bloom stage, or as late in the fall as possible before the weeds senesce or growth ceases due to frost or freeze. At this growth stage, the weeds will move herbicide throughout the plant and into the roots, resulting in maximum kill of the entire plant. The best opportunity for making this type of application is during the late-summer through fall after wheat harvest when plants have grown undisturbed for several months. Including wheat in a rotation to allow fall herbicide applications will aid greatly in management of perennial weeds. Throughout the rest of the rotation, apply burndown or postemergence herbicides as necessary to at least suppress perennials, since this can keep infestations in check until a fall application can be made.

Pesticide Interactions in Crops and Weeds

When crop plants and weeds are exposed to more than one pesticide, the effects may be described as: a) additive - when no interaction occurs and effects on plants are independent and predictable, b) synergistic - when the biological activity of the pesticide mixture is greater than the sum activity of its individual components, or c) antagonistic - when the biological activity of the mixture is less than the sum activity of its individual components. Interaction of pesticide combinations in crops or weeds may be due to an alteration in the uptake, translocation, or metabolism of one or more of the active ingredients. The response of crops and weeds to mixtures is highly species-dependent, so that a given mixture might be synergistic in a weed while showing no adverse effects on the crop or vice-versa.

Herbicide Antagonism

When two or more herbicides are mixed together, the result can be a reduction in the activity of one of the herbicides on certain weeds. This is known as herbicide antagonism. The most common example of this is the reduction in grass control that can occur in soybeans when postemergence grass herbicides (Assure II, Fusion, etc) are tank-mixed with postemergence broadleaf herbicides. The degree of antagonism is dependent upon the target grass weed and the herbicides applied. Antagonism rarely is a problem when volunteer corn or shattercane is the target grass, tends to occur to some degree for giant foxtail, and can be a severe problem when the target grass is yellow foxtail or a perennial such as johnsongrass.

While all postemergence broadleaf herbicides are capable of causing antagonism to some degree in soybeans, those most likely to do so are Pursuit, Classic, Basagran, Raptor, Scepter, FirstRate, Synchrony, and HarmonyGT. Tank mixes of postemergence grass herbicides with Pursuit are generally labeled for control of volunteer corn and shattercane only. Classic, Basagran, Synchrony, and HarmonyGT can be tank-mixed with grass herbicides for control of certain grasses only (including giant foxtail), and an increased rate of the grass herbicide may be required. Under conditions when grass plants are stressed and herbicide activity is reduced, the control of grass from Pursuit and Raptor can be reduced when tank-mixed with Cobra and other contact herbicides. Herbicide labels generally indicate the grass herbicide rates required and grasses controlled when combined with other herbicides. Antagonism can sometimes be reduced by using different spray additives or including nitrogen fertilizer solution or ammonium sulfate in the spray mix.

Antagonism between postemergence grass and broadleaf herbicides is most likely to occur when grasses are stressed due to cold or dry conditions and are not actively growing. Antagonism will also tend to be more evident when grass size exceeds that indicated on the grass herbicide label. To minimize antagonism, apply when grass size is well within label guidelines and do not tank-mix grass and broadleaf herbicides when conditions are not favorable for active plant growth. Applying herbicides separately is the most effective method for avoiding problems with antagonism. However, antagonism may still occur when the grass herbicide is applied too soon after the broadleaf herbicide. In general, allow 7 days after the broadleaf herbicide appliction before applying the grass herbicide. Where the grass herbicide is applied first, the waiting period is usually only a day or so. These intervals vary with the herbicides applied, so check labels for specific directions.

Herbicide - Insecticide Interactions

Herbicide-insecticide interactions are of special concern because they usually result in synergistic action and injury to crop plants. Crop injury results because some insecticides temporarily render crop plants unable to metabolize and detoxify herbicides that otherwise cause little or no injury. Application of some organophosphate corn rootworm insecticides (Thimet, Lorsban, etc) in combination with or followed by treatment with ALS inhibitor herbicides (Accent, Beacon, Exceed, Lightning, Option, Equip, Steadfast, etc.) can injure corn significantly. Symptoms of this injury can include stunting, yellowing, and a failure of the corn leaves to properly unfurl.

The severity of injury is dependent upon environmental conditions, the insecticide used, and the method of insecticide application. Injury is most likely when insecticides are applied in-furrow, rather than T-banded. Thimet is the insecticide that tends to cause the most problems, especially when applied in-furrow. Some herbicide labels prohibit application where Thimet has been or will be applied to corn, while others prohibit in-furrow application.

Most research indicates that injury from a herbicide-insecticide interaction is likely to be most severe when rain is adequate to ensure effective insecticide and herbicide uptake and activity. Some studies have shown that significant rain during the week prior to the postemergence application of an ALS inhibitor increases the severity of injury. Injury may be more likely when the corn plant is under stress from weather or a previous herbicide application. However, conditions suitable for rapid crop growth following injury will provide an opportunity for the crop to outgrow injury.

To avoid problems with herbicide-insecticide interactions, make sure the use of an insecticide is warranted based on scouting or cropping history. A preventative insecticide treatment is generally not needed in corn that is planted following any crop other than corn. Pyrethroid-type insecticides (Force, for example) do not increase the risk of injury from a herbicide, and can be substituted for organophosphate insecticides where use of an insecticide is warranted. Apply organophosphate insecticides as a band rather than in-furrow to minimize the risk of injury. See Table 9 for a list of restrictions on insecticide use for ALS-inhibiting herbicides.

Herbicide Use Precautions

Herbicides like all pesticides, should be handled with extreme care and respect in order to protect yourself and others from poisoning, avoid harming and polluting the environment, and avoid crop injury. Whenever handling pesticides, stop and read the label. Labels provide specific safety suggestions and requirements for handling particular products. Following are general guidelines to reduce the risks in pesticide use.

- Apply herbicides only to those crops for which use has been approved.
- Clean tanks thoroughly when changing herbicides, especially when using a postemergence herbicide.
- Correctly calibrate the sprayer and check the nozzle output and adjustment before adding herbicide to a tank.
- Use recommended rates. Applying too much herbicide is costly, may damage crops, and is against the law. Using too little herbicide can result in poor weed control.
- Apply herbicides only at times specified on the label. Observe the recommended intervals between treatment and pasturing or harvesting of crops. Observe the recommended interval between application and planting of follow crops
- Wear goggles, rubber gloves, and other protective clothing as suggested by the label.
- Guard against drift injury to nearby susceptible plants, such as ornamental and vegetables, as well as agronomic crops.
- Apply herbicide only when all animals and persons not directly involved in the application have been removed from the area. Avoid unnecessary exposure.
- Check the label for the proper method of container disposal. Triple rinse, puncture, and haul metal containers to an approved sanitary landfill. Haul paper containers to a sanitary landfill or burn them in an approved manner.
- Promptly return unused herbicides to a safe storage space. Store them in original containers away from unauthorized persons, especially children. Keep storage areas locked.
- Formulations and labels are frequently changed and government regulations modified, so always refer to the most recent product label.

Sprayer Calibration

Proper application of herbicides helps ensure crop safety, weed control performance, and cost effectiveness. For these reasons, **calibration and maintenance of spray equipment are essential.** Over-application of herbicides is costly and may result in crop injury or carryover. Under-application may result in poor weed control. Similarly, sprayers that are not well-maintained may deliver an uneven spray pattern, resulting in weedy “streaks” through the field.

The procedures for maintaining and calibrating spray equipment are really quite simple and consist of two major steps: (1) selection of the proper nozzle tip, and (2) calibrating the equipment to deliver the correct amount of spray.

Selecting the Proper Nozzle Tip

Many different nozzle tips are available for applying herbicides, and a number of new tips have been introduced recently that can greatly reduce spray drift while maintaining herbicide activity. With the exception of drift concerns, almost any nozzle can be used to apply preemergence herbicides to tilled soil when control of emerged weeds is not a concern. Likewise, application of systemic herbicides to emerged weeds can involve many different nozzles, since spray coverage is not as important as the absolute dose of herbicide reaching the plant. However, nozzle selection is more of a concern for application of contact (non-systemic) herbicides to emerged weeds, and nozzles that result in large droplets should generally be avoided. For example, two nozzles that reduce drift, the Turbo Teejet and AI (air induction) Teejet nozzle, are rated excellent for systemic herbicides but only good for contact herbicides in the Spraying Systems nozzle selection guide. Consult technical information from nozzle manufacturers or a professional with knowledge of spray technology for more information on proper nozzle selection and use.

Droplet size is an important consideration when applying herbicides alone or in combination with other pesticides such as fungicides or insecticides. Recommended droplet size for fungicides is 150 – 250 microns, insecticides 200-300 microns, contact herbicides is 250-400 microns, and systemic herbicides 400 microns or higher. These considerations will influence the efficacy of the product used and should be used as a guide to select the appropriate nozzle and spray pressure to maximize performance. Consult technical information from nozzle manufacturers or a professional with knowledge of spray technology for more information on proper nozzle selection and use and appropriateness of herbicide mixtures with insecticides or fungicides.

Nozzles on the spray boom should be spaced according to spray tip manufacturers’ recommendations because the correct amount of spray overlap between adjacent nozzles is critical to achieve a uniform spray pattern. For the same reason, it is important that the height of the boom be adjusted according to nozzle tip manufacturers’ recommendations. Manufacturers also specify the correct pressure range in which the nozzle tips should be operated. The pressure and size of the nozzle tip orifice determine the spray output, and nozzle tip sizes should be matched with the desired spray application rate and ground speed. Nozzle tip manufacturers have selection guides that simplify this process.

Nozzle tips are available in a variety of materials which vary considerably in price and wear life. The most common materials are hardened stainless steel, stainless steel, thermoplastics, and ceramics. Hardened stainless steel is the most wear-resistant material, but it is also the most expensive. Stainless steel, ceramic, and hardened stainless steel tips have excellent wear-resistance with either abrasive or corrosive materials (e.g. wettable powders, liquid fertilizer solutions). Thermoplastic tips have generally shown good resistance to abrasion and corrosion, but may vary in wear life depending on the specific material used to mold the tips.

In general, flat fan or extended range flat fan nozzles give the most satisfactory performance over a wide variety of conditions. Nozzles placed on 30 inch spacings with the height and angle adjusted to give 100% overlap provide uniform coverage and some insurance against pattern skips in the event of a plugged nozzle or boom rocking in rough terrain. Do not angle tips more than 30 degrees from vertical as the drift potential greatly increases. For floaters and sprayers with boom heights greater than 3 feet, 80 degree flat fan tips are recommended. For lower boom heights, 100 degree tips are recommended. The 110 degree tips are needed to maintain 100% overlap at lower boom heights. For farmer application with lower boom heights and 110 degree tips, recommended nozzles types include extended range flat fan, Turbo TeeJet, air induction (AI), and Turbo Floodjet.

The formula given below may be used both for tip selection and for calibration of the sprayer once the tips are installed.

Formula for Nozzle Tip Selection and Calibration

A single formula may be used both for nozzle tip selection and sprayer calibration. The formula is:

GPM (per nozzle) = GPA x MPH x W / 5940

$$\text{GPM (per nozzle)} = \frac{\text{GPA} \times \text{MPH} \times \text{W}}{5940}$$

Where:

GPM = required output per nozzle in gallons per minute

GPA = desired total carrier volume in gallons per acre

MPH = desired ground speed in miles per hour

W = space between nozzles in inches (or band width if making band applications)

A. Nozzle tip size (orifice) selection:

Once a total carrier volume and speed are decided on and the nozzle spacing is known, substitute those numbers in the above formula. Select a nozzle that will give the required flow rate when the nozzle is operated within the recommended pressure range. Recommended carrier volumes (GPA) usually are specified on all herbicide labels and typically range from 10 to 40 gallons per acre. Ground speed (MPH) should be accurately determined, since speedometers on many tractors are unreliable.

B. Measuring ground speed:

Mark off a distance of 200 feet in the field to be sprayed or in a field with similar surface conditions. At the engine throttle speed (rpm) and gear to be used for actual spraying, determine the time required to travel the 200 feet. Use the table below to determine actual speed in MPH.

Time (seconds) required to travel 200 feet	Speed in MPH
45	3.0
39	3.5
34	4.0
30	4.5
27	5.0
23.	6.0
19	7.0
18	7.5
17	8.0
15	9.0
14	10.0

C. Calibrating the sprayer

Install the selected nozzle tips in the sprayer, turn the sprayer on, and collect the output from a single nozzle for one minute in a container marked in ounces. The number of ounces collected in one minute can be converted to GPM by dividing by 128 (1 gallon = 128 ounces). If the GPM collected from the nozzle is below that required by the above formula, then increase the spray pressure. Decrease pressure if the output is too large. Check each nozzle separately for the correct output. Ideally, they should all be within 5% of the correct output.

Maintaining Spray Equipment

Check nozzle flow rates frequently and adjust the pressure to compensate for small changes in nozzle output resulting from normal wear. It is also important to recalibrate each time a different material is applied - for example, when changing from application of a wettable powder to a soluble liquid product, or from a water carrier to liquid fertilizer. Since each of these spray mixtures have different densities, actual flow rates can be quite different at a single pressure setting. Replace nozzle tips and recalibrates when output has changed 10% or more from that of new nozzle tips or when the spray pattern becomes uneven.

Cleaning Spray Equipment

Clean sprayers immediately after use. Most herbicides will injure crops other than those for which they are labeled, and small quantities of these herbicides left in the sprayer from a previous application can cause extensive damage to the next field sprayed. The amount of these products left in the spray lines, filters, sumps, tank, or screens can be sufficient to injure nonlabeled crops even when diluted by refilling the tank. Sprayer contamination can be more of a problem with plastic or poly spray tanks, compared to stainless steel, since small amounts of some herbicides can adhere to the plastic. These herbicides can then be released from the tank walls when nitrogen fertilizer solution or solvent-based herbicides are used for subsequent applications.

Use of water alone is generally not sufficient to adequately clean spray tanks when switching from one crop to another, especially for glyphosate, growth regulator herbicides or some of the newer low-rate systemic herbicides. Labels for these products generally recommend use of household ammonia or a commercial tank cleaner. Labels vary somewhat in their directions for sprayer cleanup. The labels of most postemergence herbicides contain specific instructions on cleanout procedures for a specific product. A publication titled Cleaning Field Sprayers to Avoid Crop Injury – Publication G4852 contains a concise summary of the cleanout procedures for most products and is available on the web at http://muextension.missouri.edu/xplor/aguides/crops/g04852.htm. he following is an example of a thorough sprayer cleanup procedure:

1. Drain sprayer and spray tank completely from the lowest point.

2. Thoroughly hose down the interior surfaces of the tank. Flush tank, boom, and hoses with clean water for a minimum of 5 minutes.

3. Partially fill the tank with water and add houshold ammonia (one gallon per 100 gallons of water) or a commercial tank cleaner (follow label directions). Completely fill the tank with water, then flush the cleaning solution through the boom, hoses, and nozzles and drain the system from the lowest point again. Then go to 4a or 4b.

4a. If spraying crops that are relatively tolerant to the product used in the previous load, add water to completely fill the tank again, and allow to agitate or recirculate for at least 15 minutes. Again, flush the boom, hoses, and nozzles, and drain the system from the lowest point.

4b. If growth regulators were used and sensitive crops will be sprayed next, add more water + ammonia to the spray tank, agitate or recirculate, flush a portion of the solution through the booms, hoses and nozzles, and let the solution sit in the sprayer overnight.

5. Remove the nozzles and screen, and clean separately in a bucket containing water and the cleaning agent.

6. Thoroughly rinse the tank with clean water for a minimum of 5 minutes, flushing water through the boom and hoses.

This procedure may need to be preceded by a pressure wash or steam cleaning of the tank to help remove caked deposits.

To prepare spray equipment for storage over the winter, disconnect all hoses and allow water to drain out. Coat bare metal parts with oil or a rust inhibitor. Disassemble metal nozzles and store in oil. Prepare the spray pump for storage based on the manufacturer's recommendations.

Compatibility of Herbicide-Fertilizer Combinations

Herbicides can be applied in combination, using either water or liquid fertilizer as a carrier, to decrease trips over the field. Compatibility of these mixtures is critical, and should be tested prior to application even though product labels allow mixing. Most labels contain instructions for testing compatibility and tank-mixing herbicides with liquid fertilizer. Follow label directions closely when applying these combinations.

Testing for compatibility requires a glass jar and the herbicides and liquid fertilizer to be mixed. Place one pint of liquid fertilizer in the jar and add two teaspoons of the liquid herbicide. If the herbicide is a dry formulation, mix two teaspoons of herbicide with 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, each batch of liquid fertilizer should be checked, as they vary in mixing properties. The pH and mineral content of water will also influence compatibility.

If more than one herbicide is to be mixed with water or liquid fertilizer, the herbicides 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 herbicide is added, and a specific mixing order followed. Generally, unless label directions state otherwise, add the herbicide to water or fertilizer in the following order:

1) wettable powders or dispersible granules,
2) flowable or aqueous liquids (solutions),
3) emulsifiable concentrates,
4) crop oil concentrates.

Spray tanks should be at least half filled with the carrier before the herbicides are added. Compatibility agents are available which may be added to improve compatibility. If the mixture foams excessively, separates, or becomes syrupy, do not apply. Even if all components appear compatible, the tank mixture will require constant agitation to prevent separation or poor distribution in the tank. Be sure the entire tank is agitated and mixed before spraying. Do not store tank mixtures of herbicides for long periods or overnight without constant agitation. Best results will be obtained by applying tank mixtures promptly.

Off-Target Movement of Herbicides

Spray drift is the downwind movement of spray particles from the target site to areas with sensitive plant species. The extent of spray drift increases as (1) the size of spray droplets decreases, (2) the height above the ground from which the droplets are released increases, and (3) wind speed increases. Drift can be minimized by following these guidelines.

- Spray when wind speed is low.
- Use the maximum nozzle orifice size without distorting spray pattern.

- Reduce spray pressure to the lowest setting without distorting spray pattern.
- Using nozzles that minimize drift, such as Air Induction, Turbo Teejet, and Flat Fan DriftGuard nozzles.
- Use drift control agents when permitted by the label.
- Follow label precautions for drift reduction measures.

Volatility and vapor drift is the tendency of a herbicide to vaporize and drift through the air as a gas. A herbicide with a high vapor pressure has a greater tendency to volatilize than one with a low vapor pressure. Application of Command is prohibited near sensitive plants because of the phytotoxicity of spray particles and vapors. Dicamba and the ester formulations of 2,4-D may vaporize at temperatures as low as 70°F and be moved by wind to areas with sensitive plants, including soybeans and vegetable crops. Amine formulations of 2,4-D are essentially nonvolatile. The volatility of dicamba varies with the formulation. Clarity and Distinct are less volatile than Banvel, but still have some potential to volatilize.

The rate of herbicide volatilization increases with increasing temperature. In the summer, temperatures at the soil surface may exceed 140°F on a clear day, greatly enhancing conditions for volatility. Vapors drift farther and over a longer time than spray droplets. Changes in temperature and wind direction following application can move damaging vapors to sensitive plants. To avoid vapor drift, carefully observe label precautions when applying a volatile herbicide.

Herbicide Carryover

The length of time a herbicide persists or remains active in the soil determines the period of weed control that can be expected through the current growing season and the potential for carryover to the following year. Although most herbicides dissipate within the same growing season in which they are applied, some herbicides persist longer than others and may be especially harmful to specific crops grown next in the rotation. The overall potential for carryover is a function of the herbicide used, the accuracy of application, the follow crop grown, and the environmental conditions following herbicide application.

Degradation of most herbicides in soil is the result of chemical and microbial breakdown processes. The rate of breakdown increases with soil temperature, and both processes generally require adequate soil moisture. Because a large portion of the herbicide is degraded in the summer and early fall following application, very dry conditions during this period will increase the potential for carryover of many herbicides.

Soil moisture level and temperature also affect the follow crop's growth and thus its tolerance to herbicide injury. The crop is more likely to show injury symptoms from herbicide carryover if it is weakened by stress from adverse climate, disease, or nutritional deficiencies. Yield reduction from early herbicide injury is more likely to occur when adverse growing conditions continue throughout the growing season. The crop may overcome herbicide injury if favorable growing conditions occur throughout the season.

Herbicide carryover is also influenced by herbicide rate, distribution, soil type, and time. While most herbicides are safe in rotation at use rates, higher rates occurring where herbicide is not uniformly distributed may result in carryover problems. Poor distribution is generally the result of improper calibration or agitation, sprayer overlapping, or non-uniform incorporation.

Longer intervals between herbicide application and follow crop planting allow the herbicide more time to break down, reducing the risk of carryover. Delayed planting the year following application reduces the probability of injury from carryover. Where double cropping or intercropping practices are used, carryover problems may increase due to the number of crops planted within a fairly short period of time.

Herbicides are more persistent in fine-textured, high organic matter soils than in coarse-textured, low organic matter soils. The soil's absorptive capacity for herbicide increases as organic matter and clay content increases. Because microbial and chemical degradation reactions occur mainly in the soil solution, absorption of herbicide on soil can "protect" the herbicide from breakdown. However, adsorption also results in a reduced availability of herbicide for plant uptake and increased persistence does not always result in an increased potential for carryover.

The persistence of some triazine (atrazine) and sulfonylurea (chlorimuron, prosulfuron) herbicides is greater at high soil pH than at low pH. Persistence of Scepter and Command is longest at low pH (<5.9). Follow label directions regarding the application of herbicides and soil pH.

The sensitivity of a crop and its genetic makeup affect the potential for carryover injury. Vegetable and ornamental crops are generally more sensitive to herbicide carryover than field crops. Within a specific crop, some varieties are more tolerant of a given herbicide than others. Herbicide labels contained restrictions regarding the interval that must occur between application of a herbicide and the planting of various crops.

Guidelines To Avoid Carryover Problems:

1) Select the appropriate herbicide rate based on soil type.
2) Calibrate the sprayer and apply herbicide accurately and uniformly.
3) If incorporating, make sure it is done thoroughly and uniformly.
4) Consider applying reduced rates of a persistent herbicide in combination with a less persistent herbicide.
5) Select herbicides based on rotation plans. Follow the recrop restrictions on herbicide labels.
6) Apply herbicide as early as possible and delay planting of the follow crop if carryover is suspected.

Testing for Herbicide Residues

In fields where a carryover problem is suspected, bioassays or soil tests may be performed to determine if unacceptable levels of herbicide residue are present. In a bioassay, one or more sensitive species are grown in the "suspect" soil and compared to the growth in "check" soil not treated with the herbicide in question. This comparison makes it possible to separate carryover injury from injury caused by plant disease, environmental stress, or failure to water plants at the right time. It may be most appropriate to bioassay soil with the plant species that is to be planted in the "suspect" field. For suspected triazine carryover, a bioassay using oat plants is often effective. For dinitroaniline (e.g. Treflan), sulfonylurea (e.g. Classic), and imidazolinone (e.g. Scepter), herbicides, corn can be an effective bioassay species. These three classes of herbicide chemistry inhibit root growth, so it is important to observe corn root growth in the bioassays.

Samples for bioassays should be taken from the field in early to mid-spring, leaving enough time to observe the effects before making a recrop decision. The method of sampling can be critical. A group of samples mixed together may not be accurate because the resulting average will not show whether "hot spots" of high herbicide concentration exist. Where soil has been moldboard plowed, sample to the depth of tillage (about 6 inches). In no-till or where soil has been chisel plowed, herbicide remains more concentrated in the upper few inches of the soil and samples should be taken from fairly shallow depths (about 3 inches).

Some laboratories will test soil samples for herbicide residues, but the procedure can be expensive. Interpretation of test results is difficult, since carryover potential is dependent not only on the actual herbicide concentration but also the availability of the herbicide to plants. Availability of herbicide varies with soil texture, organic matter content, and moisture. For the triazine herbicides and others that have been used for a number of years, it is possible to estimate carryover potential from test results. For some of the newer herbicides, a lack of information in general may preclude meaningful interpretation of test results.

The following table provides a rough guideline for planting various crops based on laboratory soil test results for triazine residues.

Triazine Residue Level		"Safe" to plant
3 inch sample (no-till)	6 inch sample (moldboard plow)	
less than 0.17 ppm	less than 0.08 ppm	oats, alfalfa
0.17 to 0.35 ppm	0.08 to 0.17 ppm	soybeans
greater than 0.35 ppm	greater than 0.17	corn

Avoiding Water Contamination

Surface Water

Traces of several common herbicides have been found in the water sources for some municipal water systems in Ohio. Herbicides and other pesticides can reach streams, lakes, and reservoirs in water that runs off treated fields. Herbicides can be carried dissolved in runoff water or held on the surface of eroded soil particles. Runoff risk is greatest when heavy rains closely follow herbicide application to steep slopes. Reducing water runoff and soil erosion can protect surface water quality by keeping herbicides on treated fields.

Conservation tillage systems generally reduce water runoff and soil erosion compared to conventional tillage, and thus reduce runoff of herbicides. Runoff and erosion decrease as the amount of residue remaining on the surface increases. Incorporation of herbicides may reduce runoff potential by reducing the concentration of herbicide on the soil surface. Grass strips are effective in reducing herbicide runoff because they trap sediment carrying herbicides and slow runoff water, allowing more herbicide to fall out of solution. Leaving untreated grass strips next to streams and ponds will help protect water quality. Never clean or dump sprayers or dispose of empty containers near streams, ponds, or lakes due to the risk of contamination.

Some herbicide labels contain a surface water advisory statement, indicating they may have a high potential for runoff into surface water under some conditions. All products containing sulfentrazone, atrazine, isoxaflutole, flufenacet, diflufenzopyr, terbacil, mesotrione, foramsulfuron, and cloransulam-methyl have this advisory.

Groundwater

The potential for contamination of groundwater with herbicides appears to be reduced in most of Indiana and Ohio, compared to many other states. However, herbicide users should be aware of the ways that groundwater becomes contaminated by herbicides. Most instances of groundwater contamination are due to leaching of herbicides from loading or disposal sites. Potential for groundwater contamination can be reduced through careful application, handling, and storage of herbicides.

Leaching. While the majority of herbicide applied generally remains in the top few inches of soil until it degrades, a small percentage of certain herbicides can leach below the root zone to possibly contaminate shallow groundwater. This is most likely to happen in sandy soils, which have a low capacity for absorbing herbicide. Herbicides that are low in solubility, strongly absorbed on soil particles, and fairly nonpersistent are least likely to leach. Conversely, herbicides that are high in solubility, weakly absorbed on soil, and very persistent are most likely to have a potential to leach.

The potential for groundwater contamination can be reduced by selecting and using herbicides with low leaching potential. This is especially important where soils are sandy. Applying lower herbicide rates and reducing the total amount applied, as in banding, can lower contamination potential.

Groundwater warning statements are required on the labels of herbicides that have been detected frequently in groundwater monitoring. Most groundwater statements have similar wording: "This product is a chemical which can travel seep or leach) through the soil and can contaminate groundwater which may be used as drinking water. This product has been found in groundwater as a result of agricultural use. Users are advised not to apply this product where the water table (groundwater) is close to the surface and where soils are very permeable, i.e., well drained soils such as loamy sands. Your local agricultural agencies can provide further information on the type of soil in your area and the location of groundwater."

All products containing any of the following active ingredients are labeled with a groundwater advisory statement:

acetochlor	alachlor	isoxaflutole
atrazine	metolachlor	flufenacet
cyanazine	clopyralid	diflufenzopyr
metribuzin	flumetsulam	terbacil
simazine	dimethenamid	hexazinone
sulfentrazone	cloransulam-methyl	

Leaching from mixing or disposal areas. High soil herbicide concentrations occur through spillage or improper disposal of herbicides in small areas. These high concentrations can overload the ability of the soil to adsorb and degrade herbicides. Leaching of herbicides from these areas is much greater than in treated fields. If sprayers are dumped or washed out in the same place over the years, concentrated sources of herbicide are created. If this activity takes place near a well, risk of contamination is increased, especially if the well is not properly cased and surface runoff can enter the well. Herbicides should be stored and mixed away from the well.

The best method for disposing of excess spray mix is to use it up on a crop field. The excess can sometimes be applied at low rates on a portion of the field by increasing sprayer speed. Be careful not to exceed the total label rates for the crop, risking crop injury, carryover, or illegal applications. Applying sprayer rinsate to the field avoids similar problems with disposal.

Backsiphoning can allow large quantities of herbicide to directly enter groundwater at the depth of the well. This happens when the end of the water hose is allowed to extend into the spray solution when filling sprayers. If the water is shut off with the hose in the tank, the spray solution can backsiphon down the well or into the water system. To avoid backsiphoning, position the hose above the spray solution while filling and remove the hose prior to shutting off the water. Use an anti-backflow valve when drawing water from a well or pond. Inexpensive anti-backflow devices for hoses that are used to fill sprayers can be purchased from sprayer equipment dealers. A state regulation in Ohio requires an anti-backsiphoning device in certain sprayer systems.

Herbicide Resistance in Weeds

A number of crops and weeds exhibit tolerance to some herbicides by preventing their absorption and/or translocation, or by rapidly metabolizing the herbicide to a non-toxic form. These are the basic mechanisms of herbicide selectivity upon which modern herbicide use is based. Herbicide-resistant plants have biochemical differences in the site of action normally attacked by a herbicide in susceptible plants, thus leaving them unaffected by the herbicide. In weed populations throughout the world, large populations of single weed species can contain a relatively small number of biotypes that have slight genetic differences from the rest of the population. Experience since the herbicide revolution began in the 1940s indicates that some naturally occurring weed biotypes can be resistant to herbicides that are normally lethal to the majority of the population.

The phenomenon of resistance can be explained as follows. When the same herbicide or herbicides having the same site of action (for example, a photosynthesis inhibitor) are applied to an area repeatedly over time, the portion of a weed population susceptible to that herbicide is gradually depleted. This creates an opportunity for other weeds naturally resistant to that herbicide (including resistant biotypes of species normally susceptible to the herbicide) to become established. If the same herbicide or others with an identical mode of action are applied on a year-to-year basis, there is no interruption of the resistant weeds' yearly reproductive cycle, and the population will continue to expand rapidly over time.

Common lambsquarters and pigweed species are examples of weeds that have developed populations resistant to the triazine herbicides. In Ohio, triazine-resistant populations are most prevalent in areas where atrazine and/or simazine have been applied annually in continuous corn-growing areas. Some wild carrot populations have developed resistance to 2,4-D in Ohio. Elsewhere in the United States, there are reports of triazine-resistant velvetleaf, triazine-resistant giant foxtail, dinitroaniline-resistant goosegrass, and ACCase resistant giant and green foxtail and johnsongrass. More recently, there is growing concern because of reports that some weed biotypes are showing resistance to the newer herbicides, especially ALS inhibitors. The latter is of special concern because both classes of herbicides attack exactly the same site of action in plants, and evidence is growing that weeds resistant to imidazolinones may also be resistant to sulfonylureas and sulfonamides, a phenomenon known as cross-resistance. Populations of several weeds in Ohio and Indiana have developed resistance to ALS inhibitors, including: giant and common ragweed, horseweed (marestail), waterhemp, cocklebur, Powell amaranth, smooth pigweed, and shattercane. More recently, populations of marestail resistant to glyphosate have been identified in 35 counties in Indiana and Ohio, and two populations in Ohio are resistant to both glyphosate and ALS inhibitors.

Prevention is the key to avoiding development of herbicide-resistant weed populations in agricultural land. The following management techniques help keep resistant populations from developing:

Crop rotation - Some weed problems are more easily managed in some crops than others because different control options may be available. Crop rotation also helps disrupt weed life cycles and helps prevent any single weed species from becoming firmly established.

Herbicide rotation - Herbicide rotation is generally practiced along with crop rotation, and as long as herbicides used in one crop have a different mode of action from those used in other crops in the rotation, it will be more difficult for resistant populations to become established. Herbicides should also be rotated in a continuous monoculture system. Where two herbicide applications are made to a crop in the same year, avoid using herbicides with the same mode of action in both applications. Be sure to understand the components of premix herbicides when planning herbicide programs.

Timely postemergence practices - In general, triazine-resistant weed populations appear to develop more rapidly in no-till cropping systems. Timely cultivation and/or posteómergence herbicide application are possible control options for conventional tillage. No-till growers have a number of postemergence herbicide options available for timely control of weed escapes. Control of escaped weeds is necessary to prevent reseeding and development of resistant weed populations.

The following two tables indicate the site of action for herbicides used in crop production in Ohio and Indiana. When rotating herbicide site of action to minimize resistance problems, it is essential to know the site(s) of action for herbicide products. Site of action definitions are as follows:

4-HPPD Inhibitors (4-HPPD). Inhibit the enzyme 4-HPPD (4-hydroxyphenyl-pyruvate-dioxygenase), an enzyme involved in the synthesis of carotenoids (See Carotenoid Biosynthesis Inhibitors).

ACC-ase Inhibitors (ACC). The ACC-ase inhibitors block the activity of an enzyme (Acetyl-CoA Carboxylase) involved in fatty acid biosynthesis.

ALS Inhibitors (ALS). ALS (acetolactate synthase) is an enzyme involved in the synthesis of several amino acids. This enzyme is also referred to as acetohydroxy acid synthase (AHAS).

Auxin Transport Inhibitors (ATI). Herbicides inhibit the flow of natural and synthetic auxins, which are necessary for proper plant growth. The auxins become more concentrated in growing points, causing abnormal growth similar to synthetic auxin herbicides.

Cell Division Inhibitors (CDI). Herbicides inhibit proper cell division. The exact site of action for these herbicides is unknown, but they are believed to inhibit synthesis of very-long-chain fatty acids (VLCFAs) during cell division. There may be multiple sites of action.

Carotenoid Biosynthesis Inhibitors (CBI). Clomazone inhibits the synthesis of carotenoids by possibly inhibiting production of all diterpenes, although the exact target site is unknown. A lack of diterpenes results in the loss of carotenoids and other compounds. A primary role of carotenoids is to protect chlorophyll from photo-oxidation. These herbicides are known as bleachers because sensitive plants turn white due to the loss of chlorophyll.

EPSP Inhibitors (EPSP). Glyphosate inhibits EPSP synthase (5-enolpyruvyl-shikimate-3 phosphate synthase), an enzyme involved in the production of several amino acids. Both ALS-inhibiting and EPSP-inhibiting herbicides inhibit amino acid synthesis, but their target sites affect different enzymes and they disrupt the synthesis of different amino acids.

Glutamate Synthetase Inhibitors (GSI). Glufosinate inhibits glutamine synthetase, a key enzyme in incorporating ammonium into amino acids. Blockage of this enzyme allows a buildup of phytotoxic ammonia.

Lipid Synthesis Inhibitors (LSI). The thiocarbamate herbicides inhibit lipid synthesis, but the exact site and mode of action is unclear. These herbicides may have multiple sites of action.

Microtubule Assembly Inhibitors (MAI). The dinitroanilines and other herbicides in this class interfere with the organization of microtubules. They prevent polymerization of the protein tubulin into microtubules. Microtubules are involved in cell division and cell wall structure.

Photosynthesis Inhibitors Binding Site A (PS2 - A). Several classes of herbicides disrupt photosynthesis by blocking electron transfer in Photosystem II (PSII). Herbicides in Classes PS2-A, PS2-B, and PS2-C bind to the same protein in PSII, but the herbicides exhibit different binding characteristics. For example, resistance to the triazine herbicides usually is due to a modification of the binding site. This modification usually provides resistance to herbicides in class PS2-A, but not for herbicides in classes PS2-B and PS2-C. Because of this, Basagran and Buctril will control triazine resistant weeds, even though the binding site for these herbicides has been modified.

Photosynthesis Inhibitors Binding Site A (PS2 - B). See Photosynthesis Inhibitors Binding Site A.

Photosynthesis Inhibitors Binding Site A (PS2 - C). See Photosynthesis Inhibitors Binding Site A.

Photosytem I Inhibitors (PS1). These herbicides intercept electrons moving through Photosystem I (PSI). These electrons are then passed on to other compounds, resulting in the formation of hydrogen peroxide, which disrupts cellular integrity.

PPO Inhibitors (PPO). These herbicides inhibit PPO (protoporphyrinogen oxidase). Inhibition of this enzyme results in the accumulation of Proto IX, a molecule that generates singlet oxygen. Singlet oxygen is highly reactive and disrupts membranes, resulting in rapid degeneration of plant tissues.

Synthetic Auxins (SA). The synthetic auxins interfere with plant growth by disrupting hormone balance and protein synthesis. The exact mode of action is unclear, and it is believed these herbicides have several sites of action.

Table 1. Herbicide Trade Names, Active Ingredients, and Chemical Families Grouped Together by Site of Action

This table shows what active ingredients are in which herbicide trade names and grouped together by chemical family and site of action. The first trade name listed is usually a single active ingredient product. Trade names that follow in alphabetical order may be additional single active ingredient products. The trade names after that are usually premixes containing that active ingredient. This table is adapted from an Iowa State University publication on the web (http://www.weeds.iastate.edu).

Group	Site Of Action	Chemical Family	Active Ingredient	U.S. Trade Names
1	4-HPPD Inhibitors **(4-HPPD)**	Isoxazole	isoxaflutole	Balance Pro, Epic, Radius
		Callistemone	mesotrione	Callisto, Camix, Lexar, Lumax
2	ACCase Inhibitors **(ACC)**	Aryloxyphenoxy propionate	fenoxaprop	Whip, Acclaim, Fusion
			fluazifop	Fusilade DX, Fusion, Typhoon
			quizalofop-p	Assure II
		Cyclohexanediones	clethodim	Select, Arrow, Prism
			sethoxydim	Poast, Poast Plus, Conclude Xact G, Manifest G, Rezult G
3	ALS-Inhibitors **(ALS)**	Sulfonylurea	chlorimuron-ethyl	Classic, Canopy, Canopy EX, Canopy XL, Synchrony STS
			foramsulfuron	Option, Equip
			halosulfuron	Permit, Sempra, Priority, Yukon
			iodosulfuron	Equip
			mesosuluron-methyl	Ospery
			metsulfuron	Ally, Cimarron, Cimarron Max, Escort
			nicosulfuron	Accent SP, Accent Gold, Basis Gold, Celebrity Plus, Steadfast, Steadfast ATZ
			primisulfuron	Beacon, Exceed, NorthStar, Spirit
			prosulfuron	Peak, Exceed, Spirit
			rimsulfuron	Accent Gold, Basis, Basis Gold, Steadfast, Steadfast ATZ
			sulfosulfuron	Maverick
			thifensulfuron	Harmony GT, Pinnacle, Basis, Harmony Extra, Synchrony STS
			tribenuron	Express, Canopy EX, Harmony Extra
		Imidazolinone	imazamox	Raptor, Beyond
			imazapyr	Arsenal, Lightning
			imazaquin	Scepter, Backdraft SL, Detail, Squadron, Steel, TriScept
			imazethapyr	Pursuit, Contour, Extreme, Lightning, Pursuit Plus, Resolve, Steel
		Triazolopyrimidines	cloransulam-methyl	FirstRate, Amplify, Gangster, Gauntlet
			flumetsulam	Python, Accent Gold, Bicep Magnum TR, Broadstrike + Dual, Broadstrike + Treflan, Hornet
		Sulfonylaminocarbonyltriazolinone	propoxycarbazone-Na	Olympus

Group	Site Of Action	Chemical Family	Active Ingredient	U.S. Trade Names
4	Auxin Transport Inhibitors **(ATI)**	Semicarbazones	diflufenzopyr-Na	Distinct, Celebrity Plus
5	Cell Division Inhibitors **(CDI)**	Chloroacetamides	acetochlor	Degree, Harness, Surpass, TopNotch, Confidence, Volley, Degree Xtra, FulTime, Harness Xtra, Harness Xtra 5.6L, Keystone, Keystone LA, Surpass 100, Confidence Xtra 5.6, Volley ATZ
			alachlor	Lasso, Micro-Tech, Alachlor, Intrro, Bullet, Lariat, various trade names
			metolachlor	Dual Magnum, Dual II Magnum, Cinch, Parallel, Parallel PCS, Stalwart C, Bicep II Magnum, Bicep Lite II Magnum, Bicep Magnum TR, Boundary, Broadstrike + Dual, Camix, Cinch ATZ, Expert, Lexar, Lumax, Stalwart Xtra, Turbo
			propachlor	Ramrod
			dimethenamid	Frontier, Outlook, Detail, Guardsman, Guardsman Max, Leadoff, Op-Till
		Oxyacetamides	flufenacet	Define, Axiom, Domain, Epic, Radius
6	Carotenoid Biosynthesis Inhibitors **(CBI)**	Isoxazolidinone	clomazone	Command 3ME, Commit 3ME, Command Xtra, Commence
7	EPSP Inhibitors **(EPSP)**	Glycine derivatives	glyphosate	Roundup WeatherMAX, Accord, Buccaneer, Buccaneer Plus, Clearout 41 Plus, Cornerstone, Cornerstone Plus, Credit, Credit Duo, Credit Duo Extra, Credit Extra, Durango, Engame, Gly-4, Gly-4 Plus, Gly-Flo, Gly Star 5, Gly Star Original, Gly Star Plus, Glyfos, Glyfos X-TRA, Glyphomax, Glyphomax Plus, Glyphomax XRT, Glyphosate, Glyphosate Original, Helosate Plus, Honcho, Honcho Plus, Mirage, Mirage Plus, Rattler, Rattler Plus, Rodeo, Roundup Custom, Roundup Original, Roundup Original II, Roundup Original Max, Roundup Ultra, Roundup UltraDry, Roundup UltraMAX, Touchdown HiTech, Touchdown IQ, Touchdown Total, Backdraft SL, Credit Master, Expert, Extreme, Field Master, Ready Master ATZ, various trade names
8	Glutamine Synthetase Inhibitors **(GSI)**	Phosphonic acid	glufosinate	Liberty, Liberty ATZ
9	Lipid Synthesis Inhibitors **(LSI)**	Thiocarbamates	butylate EPTC	Sutan + Eptam, Eradicane

Group	Site Of Action	Chemical Family	Active Ingredient	U.S. Trade Names
10	Microtubule Assembly Inhibitors **(MAI)**	Dinitroanilines	benefin	Balan
			ethalfluralin	Sonalan
			oryzalin	Surflan
			pendimethalin	Prowl, Pendimax, Pentagon, Pursuit Plus, Squadron, Steel,
			trifluralin	Treflan, Trifluralin, Broadstrike + Treflan, Commence, TriScept
		Benzamides	pronamide	Kerb
11	Photosynthesis Inhibitors - Binding Site A **(PS2 - A)**	Triazines	ametryne	Evik
			atrazine	AAtrex, Atrazine, Axiom AT, Banvel-K+atrazine, Basis Gold, Bicep II Magnum, Bicep Lite II Magnum, Bicep Magnum TR, Bromox + Atrazine, Brozine, Buctril + Atrazine, Bullet, Cinch ATZ, Contour, Confidence Xtra 5.6, Degree Xtra, Expert, Field Master, FulTime, Guardsman, Guardsman Max, Harness Xtra, Harness Xtra 5.6L, Keystone, Keystone LA, Laddok S-12, Lariat, Leadoff, Lexar, Liberty ATZ, Lumax, Marksman, Moxy + Atrazine, Ready Master ATZ, Shotgun, Stalwart Xtra, Steadfast ATZ, Sterling Plus, Stratos, Surpass 100, Volley ATZ, various trade names
			cyanazine	Bladex
			prometon	Pramitol
			simazine	Princep, Simazine
		Triazinones	hexazinone	Velpar
			metribuzin	Sencor, Axiom, Boundary, Canopy, Domain, Turbo
		Uracils	bromacil	Hyvar XL
			terbacil	Sinbar
12	Photosynthesis Inhibitors - Binding Site B **(PS2 - B)**	Nitriles	bromoxynil	Buctril, Broclean, Bromox, Moxy, Bromox + Atrazine, Brozine, Buctril + Atrazine, Moxy + Atrazine
		Benzothiadiazinones	bentazon	Basagran, Conclude Xact B, Galaxy, Laddok S-12, Manifest B, Rezult B, Storm
		Phenyl-pyridazine	pyridate	Tough
13	Photosynthesis Inhibitors - Binding Site C **(PS2 - C)**	Ureas	diuron	Karmex
			linuron	Lorox, Linex
			tebuthiuron	Spike

Group	Site Of Action	Chemical Family	Active Ingredient	U.S. Trade Names
14	Photosystem I Inhibitors **(PS1)**	Bipyridyliums	diquat dibromide	Diquat, Reglone
			paraquat	Gramoxone Extra, Gramoxone Max
15	PPO Inhibitors **(PPO)**	Diphenylethers	acifluorfen	Blazer, Status, Ultra Blazer, Conclude Xact B, Galaxy, Manifest B, Storm
			fomesafen	Reflex, Flexstar, Typhoon
			lactofen	Cobra, Phoenix, Stellar
			oxyfluorfen	Goal
		Thiadiazoles	fluthiacet	Action
		N-phenylphthalamides	flumiclorac	Resource, Stellar
			flumioxazin	Valor, Gangster
		Triazolinones	sulfentrazone	Authority, Blanket, Spartan, Authority Broadleaf, Command Xtra, Canopy XL, Gauntlet
			carfentrazone	Aim EW, Priority
16	Synthetic Auxins **(SA)**	Phenoxys	2,4-D	Weedar 64, Weedone 638, Weedone 650, Barrage, Barrage HF, E-99, Brash, Cimarron Max, Credit Master, Crossbow, Curtail, Grazon P+D, Shotgun, Weedmaster, various trade names
			2,4-DB	Butoxone 200, Butyrac 200, various trade names
			MCPA	Rhomene MCPA, Rhonox MCPA, Various trade names
		Benzoic acids	dicamba	Banvel, Banvel SGF, Clarity, Oracle, Sterling, Banvel-K + Atrazine, Brash, Celebrity Plus, Cimarron Max, Distinct, Marksman, NorthStar, Op-Till, Resolve, Sterling Plus, Stratos, Weedmaster, Yukon
		Pyridine Carboxylic acids	clopyralid	Stinger, Accent Gold, Curtail, Hornet, WideMatch
			fluroxypyr	Starane, Vista, WideMatch, PastureGard, Surmount
			picloram	Tordon, Grazon P+D, Surmount
			triclopyr	Garlon, Remedy, Crossbow, PastureGard

Table 2. Quick Reference of Herbicide Trade Names to Herbicide Site of Action

This table indicates what herbicide site of action is found in a single Herbicide Trade Name. The presence of a black box in a column within a single row indicates that site of action is found in that herbicide. This table does not indicate what active ingredients are found in a single product. A description for each of the sites of action is listed at the end of this table.

	Herbicide Site of Action															
Herbicide Trade Name	4-HPPD Inhibitors (4-HPPD)	ACC-ace Inhibitors (ACC)	ALS-Inhibitors (ALS)	Auxin Transport Inhibitors (ATI)	Cell Division Inhibitors (CDI)	Carotenoid Biosynthesis Inhibitors (CBI)	EPSP Inhibitors (EPSP)	Glutamine Synthetase Inhibitors (GSI)	Lipid Synthesis Inhibitors (LSI)	Microtubule Assembly Inhibitors (MAI)	Photosynthesis Inhibitors – Binding Site A (PS2 – A)	Photosynthesis Inhibitors – Binding Site B (PS2 – B)	Photosynthesis Inhibitors – Binding Site C (PS2 – C)	Photosystem I Inhibitors (PS1)	PPO Inhibitors (PPO)	Synthetic Auxins (SA)
2,4-D																■
2,4-DB																■
AAtrex											■					
Accent SP			■													
Accent Gold			■													■
Acclaim		■														
Accord							■									
Action															■	
Aim EW															■	
Alachlor					■											
Ally			■													
Amplify			■													
Arrow		■														
Arsenal			■													
Assure II		■														
Atrazine											■					
Authority															■	
Authority Broadleaf			■												■	
Axiom					■						■					
Axiom AT					■						■					
Backdraft SL			■				■									
Balan										■						
Balance Pro	■															
Banvel																■
Banvel-K + Atrazine											■					■
Banvel SFG																■
Barrage																■
Barrage HF																■
Basagran												■				
Basis			■													
Basis Gold			■								■					

Table 2. Quick Reference of Herbicide Trade Name to Herbicide Site of Action (continued)

Herbicide Trade Name	4-HPPD	ACC	ALS	ATI	CDI	CBI	EPSP	GSI	LSI	MAI	PS2 – A	PS2 – B	PS2 – C	PS1	PPO	SA
Beacon			X													
Beyond			X													
Bicep II Magnum					X						X					
Bicep Lite II Magnum					X						X					
Bicep Magnum TR			X		X						X					
Bladex											X					
Blanket															X	
Blazer															X	
Boundary					X						X					
Brash																X
Broadstrike + Dual			X		X											
Broadstrike + Treflan			X							X						
Broclean												X				
Bromox												X				
Bromox + Atrazine											X	X				
Brozine											X	X				
Buccaneer							X									
Buccaneer Plus							X									
Buctril												X				
Buctril + Atrazine											X	X				
Bullet					X						X					
Butoxone 200																X
Butyrac 200																X
Callisto	X															
Camix	X															
Canopy			X								X					
Canopy EX			X													
Canopy XL			X												X	
Celebrity Plus			X	X												X
Cimarron			X													
Cimarron Max			X													X
Cinch					X											
Cinch ATZ					X						X					
Clarity																X
Classic			X													
Clearout 41 Plus							X									
Cobra															X	
Command						X										
Command Xtra						X									X	
Commence						X				X						
Commit						X										
Conclude Xact		X										X			X	
Confidence					X											
Confidence Xtra 5.6					X						X					
Contour			X								X					
Cornerstone							X									
Cornerstone Plus							X									

Table 2. Quick Reference of Herbicide Trade Name to Herbicide Site of Action (continued)

Herbicide Trade Name	Herbicide Site of Action															
	4-HPPD	ACC	ALS	ATI	CDI	CBI	EPSP	GSI	LSI	MAI	PS2 – A	PS2 – B	PS2 – C	PSI	PPO	SA
Credit							■									
Credit Duo							■									
Credit Duo Extra							■									
Credit Extra							■									
Credit Master							■									■
Crossbow																■
Curtail																■
Define					■											
Degree					■											
Degree Xtra					■						■					
Detail			■		■											
Diquat														■		
Distinct				■												■
Domain					■						■					
Dual Magnum					■											
Dual II Magnum					■											
Durango							■									
E-99																■
Engame							■									
Epic	■				■											
Eptam									■							
Equip			■													
Eradicane									■							
Escort			■													
Evik											■					
Exceed			■													
Expert					■		■				■					
Express			■													
Extreme			■				■									
Field Master					■		■				■					
FirstRate			■													
Flexstar															■	
Frontier					■											
FulTime					■						■					
Fusilade DX		■														
Fusion		■														
Galaxy												■			■	
Gangster			■												■	
Garlon																■
Gauntlet			■												■	
Gly-4							■									
Gly-4 Plus							■									
Gly-Flo							■									
Gly Star 5							■									
Gly Star Original							■									
Gly Star Plus							■									
Glyfos							■									
Glyfos X-TRA							■									

Table 2. Quick Reference of Herbicide Trade Name to Herbicide Site of Action (continued)

	Herbicide Site of Action															
Herbicide Trade Name	4-HPPD	ACC	ALS	ATI	CDI	CBI	EPSP	GSI	LSI	MAI	PS2 – A	PS2 – B	PS2 – C	PSI	PPO	SA
Glyphomax							X									
Glyphomax Plus							X									
Glyphomax XRT							X									
Glyphosate							X									
Glyphosate Original							X									
Goal															X	
Gramoxone Extra														X		
Gramoxone Max														X		
Grazon P&D																X
Guardsman					X						X					
Guardsman Max					X						X					
Harmony Extra			X													
Harmony GT			X													
Harness					X											
Harness Xtra					X						X					
Harness Xtra 5.6L					X						X					
Helosate Plus							X									
Honcho							X									
Honcho Plus							X									
Hornet			X													X
Hyvar XL											X					
Intrro					X											
Karmex													X			
Kerb										X						
Keystone					X						X					
Keystone LA					X						X					
Laddok S-12											X	X				
Lariat					X						X					
Lasso					X											
Leadoff					X						X					
Lexar	X				X						X					
Liberty								X								
Liberty ATZ								X			X					
Lightning			X													
Linex													X			
Lorox													X			
Lumax	X				X						X					
Manifest B & G		X										X			X	
Marksman											X					X
Maverick			X													
MCPA																X
Micro-Tech					X											
Mirage							X									
Mirage Plus							X									
Moxy												X				
Moxy + Atrazine											X	X				
NorthStar			X													X

Table 2. Quick Reference of Herbicide Trade Name to Herbicide Site of Action (continued)

Herbicide Trade Name	Herbicide Site of Action															
	4-HPPD	ACC	ALS	ATI	CDI	CBI	EPSP	GSI	LSI	MAI	PS2 – A	PS2 – B	PS2 – C	PSI	PPO	SA
Olympus			X													
Op-Till					X											X
Option			X													
Oracle																X
Osprey			X													
Outlook					X											
Parallel					X											
Parallel PCS					X											
PastureGard																X
Peak			X													
Pendimax										X						
Pentagon										X						
Permit			X													
Phoenix															X	
Pinnacle			X													
Poast		X														
Poast Plus		X														
Pramitol											X					
Princep											X					
Priority			X												X	
Prism		X														
Prowl										X						
Pursuit			X													
Pursuit Plus			X							X						
Python			X													
Radius	X				X											
Ramrod					X											
Raptor			X													
Rattler							X									
Rattler Plus							X									
Ready Master ATZ							X				X					
Reflex															X	
Reglone														X		
Remedy																X
Resolve			X													X
Resource															X	
Rezult B & G		X										X				
Rhomene MCPA																X
Rhomox MCPA																X
Rodeo							X									
Roundup Custom							X									
Roundup Original							X									
Roundup Original II							X									
Roundup Original Max							X									
Roundup Ultra							X									
Roundup UltraDry							X									
Roundup UltraMAX							X									
Roundup WeatherMAX							X									

Table 2. Quick Reference of Herbicide Trade Name to Herbicide Site of Action (continued)

Herbicide Trade Name	Herbicide Site of Action															
	4-HPPD	ACC	ALS	ATI	CDI	CBI	EPSP	GSI	LSI	MAI	PS2 – A	PS2 – B	PS2 – C	PSI	PPO	SA
Scepter			■													
Select		■														
Sempra			■													
Sencor											■					
Shotgun											■					■
Simazine											■					
Sinbar											■					
Sonalan									■							
Spartan															■	
Spike													■			
Spirit			■													
Squadron			■							■						
Stalwart C					■											
Stalwart Xtra					■						■					
Starane																■
Status															■	
Steadfast			■													
Steadfast ATZ			■								■					
Steel			■							■						
Stellar															■	
Sterling																■
Sterling Plus											■					■
Stinger																■
Storm												■			■	
Stratos											■					■
Surmount																■
Sutan +									■							
Surflan										■						
Surpass					■											
Surpass 100					■						■					
Synchrony STS			■													
TopNotch					■											
Tordon																■
Touchdown HiTech							■									
Touchdown IQ							■									
Touchdown Total							■									
Tough												■				
Treflan										■						
Trifluralin										■						
TriScept			■							■						
Turbo					■						■					
Typhoon		■													■	

Table 2. Quick Reference of Herbicide Trade Name to Herbicide Site of Action (continued)

Herbicide Trade Name	Herbicide Site of Action															
	4-HPPD	ACC	ALS	ATI	CDI	CBI	EPSP	GSI	LSI	MAI	PS2 – A	PS2 – B	PS2 – C	PS1	PPO	SA
Ultra Blazer															■	
Valor															■	
Velpar											■					
Vista																■
Volley					■											
Volley ATZ					■						■					
Weedar 64																■
Weedmaster																■
Weedone 638																■
Weedone 650																■
Whip		■														
Yukon			■													■

This table was adapted from an Iowa State University publication on the web – http:/www.weeds.iastate.edu/