Chapter 7: Chemical Control: Herbicide Management Issues

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Summary

Herbicides are crop-protecting chemicals used to kill weedy plants or interrupt normal plant growth, and can provide a convenient, economical, and effective way manage weeds. In most cases, they can be the backbone of many weed management programs. However, they should not be used alone but integrated with effective nonchemical tactics such as tillage, crop rotation, proper soil fertility, or other appropriate management options. Herbicides may not be necessary on some farms or landscapes. If chemical weed control is not utilized, mechanical and cultural control methods then become the priority.

Introduction

Over the past 60 years, synthetic herbicides have been widely adopted as a means to control weeds. Many herbicides control weeds in different types of crops with no or negligible injury to the crop. Furthermore, herbicides allow reduced tillage at planting, earlier seeding dates, and provide additional time for farm tasks and personal life. Due to reduced tillage, soil erosion has been reduced from about 3.5 billion tons in 1938 to 0.96 billion tons in 2012 (USDA NRI Report 2015), thus decreasing the amount of soil entering waterways and improving the nation's surface water quality. Without herbicide use, no-till agriculture becomes impossible.

However, herbicide use also carries environmental, ecological, and human health risks. It is important to understand the benefits and disadvantages associated with chemical weed control prior to use. Companies spend hundreds of millions of dollars to develop and test herbicides to meet stringent standards set by the U.S. government. The herbicide label is a result of this process and is a legal document designed to maximize weed control and minimize crop injury, environmental damage, and personal injury of those applying the product, as well as any incidental contact of others near the application area.

This chapter will address issues associated with herbicide use. For specific information on herbicide effectiveness for specific weeds and specific crops see the *Mid-Atlantic Field Crop Weed Management Guide* (AGRS-136).

Herbicide Classification

Herbicides can be categorized in different ways and by certain characteristics. In this publication, herbicides are classified according to: a) mode and site of action; b) application timings and methods; c) weed control spectrum and selectivity; and d) herbicide movement in the weed. Each of these is discussed below.

Herbicide mode and site of action

The term "mode of action" refers to the sequence of events from absorption into plants to plant death, or, in other words, how a herbicide works to injure or kill the plant. The specific location the herbicide affects is called the site or mechanism of action. To be effective, herbicides must (1) adequately contact plants, (2) be absorbed by plants, (3) move within the plants to the site of action without being deactivated, and (4) reach toxic levels at the site of action. Understanding herbicide mode of action is helpful in knowing what groups of weeds are controlled, specifying application techniques, diagnosing herbicide injury problems, and preventing herbicide-resistant weeds.

A common method of grouping herbicides is by their modes of action. Although a large number of herbicides are available in the marketplace, several have similar chemical properties and the way they control the weed. Two or more families may have the same site of action and will be listed under the same group number. Table 7.1 is a simplified list of the common herbicide sites of action groups and example herbicides. For a more extensive list and utility of each refer to the *Mid-Atlantic Field Crop Weed Management Guide*.

Table 7.1. Common herbicide mode of action classes and examples.

Mode of action (effect on plant growth)	Site of action	Herbicide group #	Active ingredient	Trade name(s)
Lipid (fatty acid) inhibitor (meristem)	ACCase enzyme	1	clethodim quizalofop	Select® Assure II®
Amino acid biosynthesis inhibitor	ALS enzyme	2	chlorimuron cloransulam imazethapyr rimsulfuron	Classic® FirstRate® Pursuit® Resolve®
Seedling growth inhibitor – root & shoot	Microtubule	3	pendimethalin	Prowl®
Plant growth regulator	TIR1	4	2,4-D dicamba	2,4-D Clarity®
Photosynthesis inhibitor – mobile	Photosystem II	5	atrazine metribuzin	atrazine TriCor®
Amino acid biosynthesis inhibitor	EPSP enzyme	9	glyphosate	Roundup®
N-metabolism disrupter (contact)	GS enzyme	10	glufosinate	Liberty®
Cell membrane disrupter (contact)	PPO enzyme	14	flumioxazin fomesafen saflufenacil	Valor® Reflex® Sharpen®
Seedling growth inhibitor – shoot	Long-chain fatty acids	15	acetochlor dimethenamid s-metolachlor	Harness® Outlook® Dual®
Pigment inhibitor (bleaching)	HPPD enzyme	27	isoxaflutole mesotrione	Balance® Callisto®

Herbicide application timings and methods

Application timings. In general, there are two times when herbicides are applied, preemergence or postemergence. Preemergence, or "soil-applied herbicides," control weeds from the seed germination stage to emergence from the soil (Figure 7.1). Herbicides such as s-metolachlor (Dual Magnum®) and pendimethalin (Prowl®) must be applied before weeds germinate, otherwise they are ineffective. Soil-applied herbicides have residual activity and in general, provide weed control for about four to six weeks after application. Major factors that influence residual activity include soil moisture, soil pH, temperature, microbial activity, chemical decomposition, adsorption to soil structures, and plant uptake. As residual herbicide activity lessens, weeds begin to emerge during the season. At this point a postemergence herbicide may be necessary to provide adequate control for the remainder of the season.

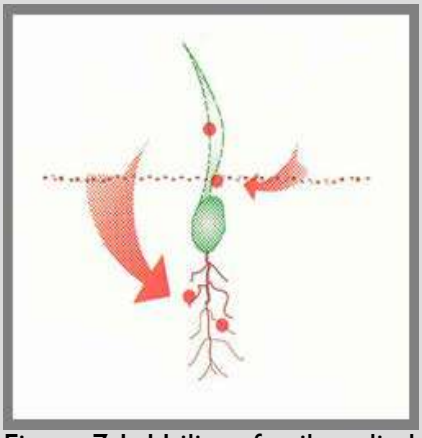

Figure 7.1. Utility of soil-applied herbicide on weed seed or seedling. (Large arrows represent placement of herbicide; dots represent site of herbicide uptake by the weed) (How Herbicides Work, Univ.

Postemergence, or "foliar herbicides," control existing weeds (Figure 7.2). Factors that influence their effectiveness include weed size, drought, temperature, rainfall, herbicide rate, spray volume, spray additives (adjuvants), and others. Certain herbicides provide both foliar and residual control (e.g., Callisto®, Classic®, atrazine, Reflex®) and are typically applied postemergence to control existing weeds and provide control of germinating seedlings. Other herbicides provide only foliar control (e.g., Roundup®, Gramoxone®, and Aim®). Combinations of preemergence and postemergence herbicides may be necessary to control various types of weeds in a field.

Soil-applied and foliar-applied herbicides can be further defined by certain factors that occur when they are sprayed. Below are some common terms used to describe these use patterns:

Preplant: applied to soil and/or existing vegetation before the crop is planted.

- Used in situations where herbicides are sprayed to control weeds present at the time of crop planting (typically for no-till). This timing is often referred to as burndown or knockdown applications
- Non-selective herbicide can be included to terminate cover crops

- Residual herbicides are often included to control weeds emerging after application
- Used in situations where residual herbicides need to be applied prior to planting to reduce the risk of crop injury
- Early preplant often refers to applications made 2 to 4 weeks before planting

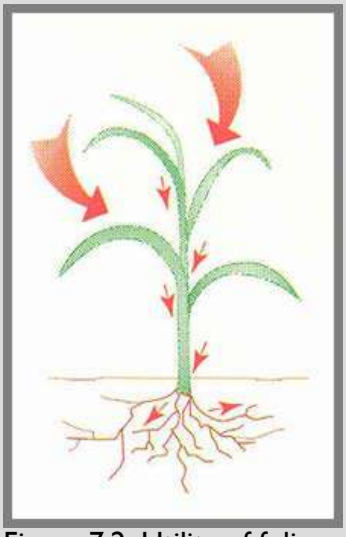

Figure 7.2. Utility of foliar-applied herbicide on weed. (Large arrows represent placement of herbicide; small arrows represent herbicide translocation or movement from site of uptake) (How Herbicides Work, Univ. Illinois).

Preplant incorporated (PPI): applied to soil and mechanically incorporated into the top two to three inches of soil before the crop is planted.

- Used with certain herbicides that are only effective when incorporated into the soil
- This technique is not conducive to no-till situations
- Incorporate herbicides into the top 1 to 2 inches of soil; incorporating herbicides deeper can dilute the herbicide and reduce its effectiveness

Preemergence (PRE): usually applied after the crop is planted but before the crop and weeds emerge.

- Rainfall or irrigation are typically required to move the herbicides into the soil (referred to as "activation")
- Application should be delayed until after crop planting to prevent herbicide-treated soil from being disrupted and untreated soil exposed by the planter, row cleaners, or other operations

Postemergence (POST): applied after crop and weeds have emerged.

- Most postemergence herbicides need to be applied before the weeds are three inches tall and not intercepted by crop canopy to be most effective
- Postemergence applications can be further distinguished into other stages and time frames:
    - Early POST: weeds – ≤3 inches; corn – ≤6 inches; soybean – one unifoliate to trifoliate stage
    - Mid POST: weeds – 2 to 6 inches; corn – ≤12 inches; soybean – one to three trifoliates
    - Late POST: weeds – <8 inches tall or as part of a split-application;

corn – 12 to 20 inches; soybean - >3 trifoliates but before flowering stage

- Rescue treatment: when weather prevents earlier treatment or initial treatment was not successful; weeds >12 inches; effectiveness is generally poor

Herbicide applications to weeds that have flowered may not stop viable seeds from being formed. Viable seeds are formed within 1 to 2 weeks of flowering.

- An adjuvant (i.e. nonionic surfactant, crop oil concentrate) is typically included to improve postemergence herbicide effectiveness

Application methods. Herbicides can be applied differently depending on the situation. The following terms refer to the ways herbicides can be sprayed.

Broadcast: applied over the entire field typically with a boom sprayer (Figures 7.3 and 7.4).

- Refers to all application timings mentioned above

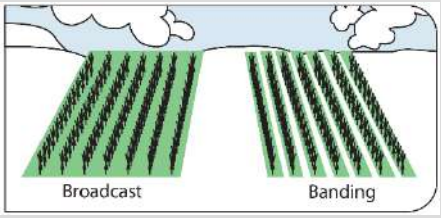

Figure 7.3. Example of broadcast vs. band application. Green color represents areas to which the herbicide has been applied (Graphic credit: TeeJet Technologies).

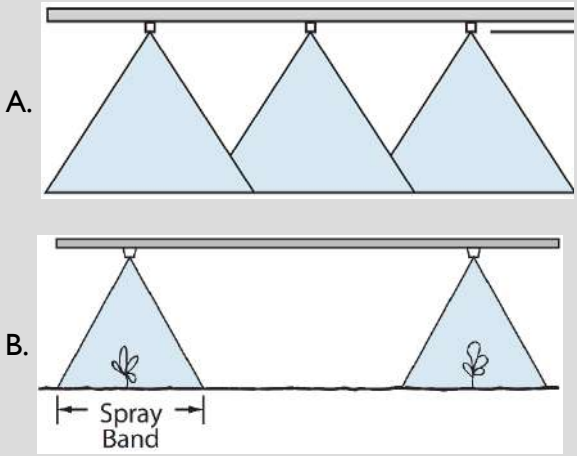

Figure 7.4. Examples of sprayer boom set-up for different types of applications: A.) broadcast B.) band (Graphic credit: TeeJet Technologies).

Band: applied as a narrow strip (ten to 12 inches) over the crop row (Figures 7.3 and 7.4).

- Typically refers to a preemergence herbicide applied after planting with spray nozzles attached to the planter
- Unlike a broadcast application, this allows for the herbicide to be applied only on a fraction of the field (i.e., width of spray pattern)

- Ensures herbicide-treated soil is not disturbed by planting operation (as often occurs with row cleaners)
- Used in areas not treated with a herbicide, cultivation, plastic mulch, or other means of weed control is utilized

Directed: applied between the rows of crop plants with little or no herbicide applied to the crop foliage.

- Nozzles are placed below the top of the crop canopy with drop-tubes that extend from sprayer boom
- Crop safety and/or coverage of weeds can be improved when the herbicide is directed below the crop canopy

Spot treatment: applied only to small or limited weed-infested areas within a field.

- Often used in areas prone to high weed pressure, such as pastures, roadsides, or field edges

Wiper application: uses a roller that contains herbicide at a high concentration or rope wick that applies the herbicide directly to the weeds.

- Herbicide(s) being applied with a wiper will damage the crop plant so the wiper must not come in contact with the crop
- Weeds must be taller than the crop so there is enough tissue to be treated with the herbicide
- Used as a rescue treatment or to aid in crop harvest

Weed Control Spectrum and Selectivity

Herbicide activity can be either selective or nonselective. Selective herbicides control certain weed species but do little or no damage to others including desirable plants or crops. However, not all crops are tolerant to all herbicides; similarly, not all weeds are controlled by all herbicides. Certain herbicides only control broadleaf plants, while others only control grasses. Many herbicides have activity on various broadleaf, grassy, and sedge weed species. Each herbicide has its strengths and weaknesses and for this reason, many of them are used in combinations to help complement their deficiencies.

Non-selective herbicides kill or injure almost all plants, including crops. Herbicide manufactures spend millions of dollars to test and develop many different chemicals in hopes of finding those that control a wide spectrum of weeds but are safe on a number of crops. Herbicide selectivity provides great value to the user in the fact that weeds can be discriminately and effectively controlled preemergence and/or postemergence without injuring the crop.

Selectivity is accomplished primarily by two methods: selectivity by placement and true selectivity. Selectivity by placement avoids or minimizes contact between the herbicide and the desired crop. An example is wiping or directing a herbicide, such as

glyphosate, on a weed without exposing the crop. Another way to direct a herbicide is the use of specialized shields or drop nozzles to focus the spray onto weeds without affecting crops. Applying a herbicide that does not readily leach beyond the soil surface for control of shallow-rooted weeds also is selectivity by placement – the herbicide does not leach into the root zone of a deeply rooted crop such as fruit trees or established alfalfa.

True selectivity is crop tolerance to certain herbicides as a result of some morphological, physiological, or biochemical process in the plant. The herbicide can be applied to the crop foliage or to the soil in which the crop is growing without danger of injury yet weeds that are susceptible to that herbicide will be controlled. In essence, the crop detoxifies the herbicide and is not injured. Although true tolerance may be better than selectivity by placement, since it is essentially unaffected by the herbicide, it is not perfect. Sometimes true selectivity may not adequately prevent some crop injury under unfavorable growing conditions that make the crop more sensitive or stressed.

Herbicide Movement in the Weed: Contact or Translocated

Contact herbicides kill or injure only the part of the plant with which the spray droplets come into contact, so adequate spray coverage is very important (Figure 7.5). Annual weeds may be controlled, but regrowth of perennial weeds from belowground parts usually occurs following application of a contact herbicide (Table 7.2). Translocated (or systemic) herbicides are absorbed by the leaves or roots of the plants and move within the plant through the xylem or phloem tissue (Figure 7.5). Translocated herbicides are needed to kill underground parts of perennial weeds.

Figure 7.5. Difference between contact (left) and systemic (right) herbicides. (Large arrows represent placement of herbicide; dots represent site of herbicide activity on the weed; small arrows represent herbicide translocation or movement from site of uptake) (How Herbicides Work, Univ. Illinois).

Table 7.2. Effect of herbicide type on weeds with different life cycles. (Ross and Lembi. 1985. Applied Weed Science. Page 215) G= good; F= fair; P= poor

	Annual			Simple perennial	Creeping Perennials	
Herbicide type	Grasses	Broadleaves	Biennial		Seedling	Established
Contact	F to G	G	P to G	P to G	G	P
Limited translocated	G	G	G	G	G	P - F
Well-translocated	G	G	G	G	G	F - G
Residual soil-applied	G	G	P - G	P - G	G	P - G
Long residual soil-applied	G	G	G	G	G	G

Herbicides Use – What To Consider

There are many kinds of herbicides from which to choose. Many factors determine when, where, and how a particular herbicide can be used most effectively. Understanding some of these factors enables you to use herbicides to their maximum advantage. Below are some fundamental issues about herbicides and their use. For additional and specific information on herbicide use in field crops refer to the *Mid-Atlantic Field Crop Weed Management Guide*.

As previously mentioned, the perfect herbicide does not exist. No single herbicide is capable of controlling all weeds that can develop in a field without injuring the crop. Since every herbicide has advantages and disadvantages, selecting the correct herbicide or herbicide combination is crucial. Before choosing or applying a herbicide, the following should be considered:

- **Is it registered for use on the crop or area to be treated?** If so, read and follow label directions for use and rate of application. Recommended rates for soil-applied herbicides may vary according to soil texture and the amount of organic matter in the soil. Labels typically provide a range of rates to accommodate the effect that different soil types have on herbicide activity. Application rates for postemergence treatments may vary with weed size and climate. Weeds growing under dry conditions or during prolonged cool weather will not actively translocate a systemic herbicide. A higher herbicide rate may be needed for dry conditions as compared to the rate needed when weeds are actively growing under ideal conditions.
- **Will the herbicide control the most troublesome weeds and does it include methods for managing herbicide resistance?** Many herbicides applications fail because the chosen herbicide will not control weeds that are present (see Chapter

8: *Weed Resistance to Herbicides*).

- **Can the herbicide be used effectively at the current stage of crop or weed growth?** Very few herbicides can be applied at all stages of plant growth. Pendimethalin (Prowl®) and s-metolachlor (Dual Magnum®) are good examples of how growth stage affects herbicide performance. They are excellent herbicides for annual grasses when applied before weed emergence. However, they are useless if applied after the weeds have emerged. Postemergence herbicides tend to be most effective when applied to small weeds (i.e., less than four inches tall). Aside from weed size, the size of the crop can also affect postemergence herbicide applications. If crops are too large (as defined on the herbicide label), the herbicides may cause reduced crop vigor, interfere with reproductive processes, and ultimately reduce yield. Also as a crop gets larger, its leaves can intercept the herbicide before it reaches its intended weed target and result in poor weed control.
- **Can the soil-applied herbicide be used effectively and safely under the current conditions?** Soil-applied herbicides must be absorbed by roots and shoots of weed seedlings. Rainfall is usually needed to incorporate soil-applied herbicides, and without rainfall, weed control may be poor. The effectiveness of soil-applied herbicides also can be reduced if the herbicide is not applied at a high enough rate or is intercepted by crop residue, existing vegetation, a prior application of livestock manure, or other barrier. Reduced-tillage cropping systems may require higher application rates of soil-applied herbicides than tilled systems with no residue, depending on the amount of crop residue. Herbicides also can be lost to runoff, leaching, or volatilization/vaporization.
- **How does the herbicide or herbicide combination interact with other pesticides, fertilizers, or other inputs being used on the crop?** Certain combinations may cause undesirable results if mixed together in the same spray solution resulting in injury or death to desirable plants or disabling equipment. For example, some organophosphate (OP) insecticides interact negatively in the crop with ALS-inhibitor (Group 2) herbicides. Water mixes well with 2,4-D amine in the spray tank but if liquid nitrogen solution is used in place of water (e.g., in a "weed and feed" application), a gelatinous precipitate results and cannot be sprayed; furthermore, the sprayer is rendered useless until a very difficult clean out procedure is accomplished.
- **How does herbicide utility interact with other integrated weed management (IWM) strategies?** The use of herbicides must complement other weed control tactics to be effective. For example, herbicides can be an important tool to terminate cover crops prior to planting the cash crop. If the herbicide is also intended to control weeds near ground level, the cover crop may intercept most of the herbicide, resulting in poor weed control. Another IWM approach, for

example, combines mechanical and chemical tactics to control weeds. A field could be tilled in order to stimulate weed seed germination. Once the weed flush appears, a herbicide can be applied to control the newly emerged weeds.

- **Does the crop require the use of a "safener"?** Herbicide safeners, also called antidotes or protectants, are chemicals that help prevent injury to crops without reducing weed control. Some safeners are included in the herbicide formulation while others need to be applied to the seed prior to planting. Herbicides such as Dual II Magnum® and Resolve Q® include safeners. Grain sorghum seed is usually treated with a safener to reduce the risk of injury from Dual II Magnum®.
- **Is the herbicide being applied to a "conventional" (i.e., non-GMO) or genetically modified (GMO) crop?** Since genetically modified crops look similar to conventional crops, misapplication can occur and the crop can be unintentionally injured or killed. Make sure to record the type of crop planted in each field.
- **Will herbicide residues carryover to the next crop or cover crop and result in injury?** Herbicide carryover is a problem with herbicides that persist in sufficient quantity to injure successive plantings (often referred to as "rotational crops"). Herbicides prone to carryover include triazines (atrazine and simazine), dinitroanilines (Treflan®, Curbit®, Prowl®), ALS inhibitors (Classic®, FirstRate®, Pursuit®), and pigment inhibitors (Command®, Balance®, Callisto®). These herbicides can provide season-long control of certain weeds. However, if an excessive rate is applied, soil pH is above 7.0, or weather during the growing season is cool and dry, natural breakdown of the herbicides may not occur, leading to carryover. Read labels carefully for warnings about carryover and crop rotation concerns.
- **What factors are necessary for a successful application?** What is the appropriate method of application (i.e., broadcast, band, directed, spot)? Is it convenient to use in such a form as a ready-to-use (RTU) product, or does it require special equipment? Should it be mixed with water before application? Are there other characteristics, such as compatibility with other pesticides when tank-mixing or staining, that make it difficult to use?
- **Does the herbicide label recommend that a surfactant, crop oil, or other additive (adjuvant) be used?** Many postemergence herbicides require the use of an adjuvant in the mixture. These are special products that are added to the spray mixture to improve herbicide activity or optimize application characteristics.
- **Can this herbicide be used safely?** What is required during and after use to safely handle, mix, and apply the herbicide? Is it a restricted-use pesticide (RUP)? When using an RUP, the handler and applicator must have a special license (obtained through the state's Department of Agriculture) to work with

such herbicides.

- **Can the herbicide injure non-target plants in adjacent areas?** Exercise caution to avoid drift, runoff, leaching to groundwater, and cross-contamination of other materials. Be especially aware of herbicide residues in sprayers when spraying a different crop.
- **Does the herbicide require specific tank cleaning procedures?** Even low amounts of some herbicides can cause severe injury to susceptible crops; thus tank cleaning can be very important. Some herbicides have specific tank clean out procedures, including using recommended tank-cleaning agents.

Herbicide Resistance

A number of weed species that were once susceptible to and effectively managed by certain herbicides have developed resistance to those herbicides and are no longer controlled by them. Certain precautions, such as tank-mixing multiple and effective herbicides, crop rotations, and a combination of weed management tactics, must be taken to prevent resistance. However, some cases of suspected herbicide resistance may actually be due to improper herbicide application (e.g., weeds too large, dry weather, or improper herbicide used) and not actual resistance to a herbicide (see Chapter 8: *Weed Resistance to Herbicides*).

Farmers, consultants, and herbicide applicators should know which herbicides are best suited to combat specific resistant weeds. The Weed Science Society of America (WSSA) developed a grouping system to help with this process. Herbicides that are classified as the same WSSA group number use the same site of action to control weeds. WSSA group numbers can be found on many herbicide labels. They can be used as a tool to choose herbicides with different sites of action so mixtures or rotations of active ingredients can be planned to better manage weeds and reduce the potential for resistant species.

Drift

Drift is the movement of any pesticide through the air to areas not intended for treatment. During application, physical drift occurs as spray droplets or dust particles are carried by air movement from the application area to other places. Vapor drift takes place after application as herbicides evaporate (volatilize) and the vapors (gases) are carried on wind currents and deposited on soils or plants in untreated areas. In general, physical drift of spray droplets occurs before the droplets reach their intended target whereas, vapor drift occurs after the herbicide reaches its target and changes to gas and then moves.

Drift may injure sensitive crops, ornamentals, gardens, livestock, wildlife, or people and may contaminate streams, lakes, or buildings. It may contaminate crops and cause illegal or excess residues. Excessive drift may mean poor performance in the

target spray area because the actual amount of herbicide working in the area is lower than expected.

Drift control should be considered with each pesticide application. Risk of severe drift problems can be minimized by using:

- Sprayer nozzles designed for drift reduction
- Low volatile or nonvolatile formulations
- Low spray-delivery pressures (15–40 psi) and nozzles with a larger orifice (hole)
- Drift-inhibiting adjuvants in the spray mixture when spraying under less-than-ideal conditions
- Nozzles that allow for lowered boom height

Drift problems can also be prevented through the following practices:

- Avoiding application of volatile herbicides during hot weather (>85°F)
- Spraying when wind speeds are low (<10 mph) or when the wind is blowing away from areas that should not be contaminated
- Spraying during the early morning or evening hours when there is usually less wind
- Avoiding application when conditions are favorable for temperature inversions (very still air, usually early evening into early morning hours)
- Leaving field borders unsprayed if they are near sensitive crops

Herbicides in Organic Cropping Systems

Using synthetic herbicides is generally not allowed in organic crop production systems. The USDA National Organic Program (NOP) does allow certain nonsynthetic soap-based herbicides or plant-based oil herbicides for use in farmstead maintenance (roadways, ditches, right of ways, building perimeters) and ornamental crops. In addition, several products that contain natural or nonsynthetic ingredients (e.g., vinegar, clove oil, cinnamon oil, citrus oil, or lemon grass oil) are classified as approved by the Organic Materials Review Institute (OMRI). Currently these herbicides are non-selective and can cause severe injury if sprayed on the crop. The OMRI listing does not imply product approval by any federal or state government agency. It is the user's responsibility to determine the compliance of a particular product. Allowable materials can change frequently. Because the classification of a material as allowable for organic production is subject to change, it is strongly recommended that organic farmers confer with their certifiers before purchasing or applying any pest management substance to avoid loss of organic certification. Additional information about "organic herbicides" or "bio-herbicides" and their utility can be found in the *Penn State Organic Crop Production Guide.* As with all pesticides, read and follow the label of OMRI-approved herbicides.

Key Points

- Herbicides can be defined as crop-protecting chemicals used to kill weedy plants or interrupt normal plant growth.
- Herbicides provide a convenient, economical, and effective way to help manage weeds.
- In most cases, they can be the backbone of many weed management programs. However, they should not be used alone but integrated with effective nonchemical tactics.
- The perfect herbicide does not exist. No single herbicide is capable of controlling all weeds that can develop in a crop or planting. Since every herbicide has advantages and disadvantages, selecting the correct herbicide(s) is crucial.
- Most herbicides are typically applied to the soil (preemergence) before weeds germinate or after weeds are growing (postemergence).
- Herbicides can be categorized in different ways and by certain characteristics, including: a) mode and site of action; b) application timings and methods; c) weed control spectrum and selectivity; and d) herbicide movement in the weed.

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