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Part XIII.

Weeds and Weed Management

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Weeds and Their Impacts

There are numerous definitions of a weed. The following are some common definitions:

- A plant that is out of place and not intentionally cultivated.
- A plant that grows where it is not wanted or welcomed.
- A plant whose virtues have not yet been discovered.
- A plant that is competitive, persistent, pernicious, and interferes negatively with human activity.

No matter which definition is used, weeds are plants whose undesirable qualities outweigh their good points – at least according to humans. Human activities create weed problems because no plant is a weed in nature. Though we may try to manipulate nature for our own good, nature is persistent. Through manipulation we control certain weeds, while other, more serious weeds thrive due to favorable growing conditions. Weeds are naturally strong competitors, and those weeds that can best compete always tend to dominate.

Both humans and nature are involved in plant breeding programs. The main difference between the two programs is that humans breed plants for yield and/or aesthetic qualities, while nature breeds plants for survival.

Classification of Weeds

Almost all plants are categorized by some sort of plant classification system and given a scientific name to identify them anywhere in the world. Keep in mind that the scientific name (i.e., genus and species) is universal, but the common name of a weed can differ from region to region. For example, velvetleaf is also known as buttonweed and butter print; common lambsquarters can be referred to as pigweed, goosefoot, fat-hen, or baconweed; and wild carrot is known as Queen Anne's lace. Weeds are also classified by other means. In general, they can be classified by their structure and appearance (e.g., dicots [broadleaves] and monocots [grasses and sedges]), habitat, or physiology. A common categorization system groups them according to their life cycle (how long they live). The three major life cycle groups are annuals, biennials, and perennials.

Annuals

Annuals are generally divided further into summer annual and winter annual weeds. Summer annuals germinate in the spring, mature, produce seed, and die in one growing season. Large crabgrass, giant foxtail, smooth pigweed, common lambsquarters, common ragweed, velvetleaf, hairy galinsoga, and common purslane are examples of troublesome summer annuals.

Winter annual weeds germinate in late summer or fall, mature, produce seed, and then die the following spring or summer. Examples of winter annuals include common chickweed, henbit, shepherdspurse, and downy brome.

Biennials

Biennial weeds grow from seed at any time during the growing season. They normally produce a rosette of leaves close to the soil surface the first year, and then flower, mature, and die during the second year. A true biennial never produces flowers or seeds the first year. There are relatively few biennial weeds. Some examples include wild carrot, common burdock, bull and musk thistle, and poison hemlock.

Perennials

Perennial weeds live for more than two years and can be divided into two groups: simple and creeping. Simple perennials form a deep taproot and spread primarily by seed dispersal. Some examples of simple perennials include dandelion, broadleaf plantain, curly/broadleaf dock, autumn olive, and common pokeweed. Creeping perennials can be either herbaceous or woody and can spread by both vegetative structures and by seed. Some common creeping herbaceous perennials include Canada thistle, common milkweed, hemp dogbane, creeping buttercup, slender speedwell, ground ivy, quackgrass, and yellow nutsedge. Some examples of creeping woody perennials include poison ivy, multiflora rose, Japanese knotweed/bamboo, brambles, wild grape, and Virginia creeper. Creeping perennials become established by seed or by vegetative parts. Since perennial weeds live indefinitely, their persistence and spread are not as dependent on seed as the other two weed groups.

Weed Management Techniques

Over the past decade or so, there have been a number of rapid changes in weed management techniques and ideologies. New directions in weed management include shifting crop management practices, continuously changing weed control technologies, increasing concern for the environment, and using computer software and electronic information technology for decision-making, record-keeping, and data managing. Environmental concerns have resulted in more no-till, cover crop, and organic crop production systems. Advancements in technology have allowed the development of lower use rate herbicides with less soil persistence, biotechnology that produces genetically modified crops, and computers that allow us to develop predictive models for weed and crop development, while weed mapping and GPS units enhance more precise herbicide application on specific weed patches and at various herbicide rates. However, despite all these advances, mechanical and chemical tactics still provide the majority of weed control in many settings. Regardless of the weed control tactic or setting, knowledgeable and experienced field consultants and technicians are necessary to diagnose problems, interpret information and results, and provide practical advice about weed management.

Since weeds are so prevalent in many areas of the landscape, management techniques are necessary to maintain order. Weed management is most successful when it involves an integrated approach using a variety of methods. The common methods used to manage weeds include prevention and cultural, mechanical, biological, and chemical means. Relying on any single tactic can lead to severe problems, such as high costs and crop failure. In planning a weed management strategy, keep in mind the available equipment and time, land characteristics, weed spectrum, and yield objective. Management inputs such as herbicides can sometimes be reduced, but alternative approaches must be substituted if the production level is to be maintained.

Integrated Weed Management

In addition to the following information, please consult **A Practical Guide for Integrated Weed Management in Mid-Atlantic Grain Crops**, available at https://growiwm.org/wp-content/uploads/2019/11/IWMguide.pdf?x93413.

Corn and soybean fields that are weed-free for the first four to six weeks after planting will often yield the same as fields that are weed-free for the entire growing season. This approach relies on a residual soil-applied herbicide program. Weeds that germinate with the crop but are controlled in a timely fashion (three to four weeks after planting) will not impact final yields. This approach relies on effective and timely postemergence weed control. In addition, if weeds are kept out of the field for four to six weeks after crop emergence, any weeds that invade later will not reduce yield significantly, although they may produce seeds, cause harvesting problems, or reduce crop quality.

Also, it is not necessary to control all weeds in a field to achieve maximum yield. Weed populations of 10 to 20 weeds per 10 square yards are sufficient to cause severe yield loss. However, weed populations at one plant per 10 square yards will have no impact on final yield. The impact of weed populations between one and 10 per yard is difficult to predict. The decision to treat the field depends on the weed species present, crop vigor, weather conditions, and herbicide cost.

Prevention

Preventive methods are used to stop the spread of weeds. It is usually easier to prevent the introduction of weeds than it is to control them after establishment. Preventive practices include cleaning tillage and harvesting or mowing equipment of weed seeds and vegetative structures; planting certified, weed-free crop seed or sod; and controlling weeds in barnyards, around structures, and along fencerows, roadways, and ditch banks. Scouting areas to assess weed populations and controlling them before they spread farther is another means of preventing additional weed problems.

Early Season Weed Scouting

The first key to weed management is proper weed identification. The best method for timely identification is through field scouting. The first reports on weed conditions in a field are needed within two weeks after crop emergence to evaluate herbicide performance and determine if there is a need for rotary hoeing, cultivation, or postemergence herbicides. Earlier scouting will be needed in no-till fields where a knockdown or early pre-plant herbicide can be applied. Identify and record all weed species found. Determine the severity of the infestation by counting the number of weeds found per 10 feet of row for large infestations or per 100 feet of row for smaller infestations in all areas sampled. Sample areas should represent no more than 5 acres, so sample enough areas to get an accurate count of the different weeds present in the field or on the farm. The approximate height and growth stage of both weeds and crop should be recorded.

Along with weed reports, early soil moisture observations are important. They serve as indicators of herbicide effectiveness. Adequate moisture is necessary for effective weed control with all soil-applied herbicides. Too little rainfall can mean there is not enough moisture to allow adequate mobilization of the herbicide; too much rain can cause more soluble herbicides to move downward below the zone where they are most effective. Postemergence herbicides usually are most effective when weeds are young and actively growing. The degree of control with these herbicides will vary due to differences in weed species, growth stages, weather conditions, and herbicide application method. To select the best possible herbicide and apply it at the optimum time to maximize control, the manager needs to be able to identify weed seedlings when they are small.

Cultural Techniques

Cultural crop management techniques provide a healthy crop to best compete with weeds. Competition from crop, turf, or desirable vegetative cover can be an inexpensive and effective aid to weed management if used to its fullest advantage. Examples of cultural techniques include following soil test recommendations for fertilizer and lime; selecting the best varieties for the environmental conditions; planting dense populations at the proper timing; using proper mowing practices; scouting fields or areas regularly for weeds, insects, and diseases, and controlling them when necessary; and including crop rotations and cover crops in the system. Composting, ensiling, or feeding weeds or weed-infested crops to livestock can destroy the viability of weed seeds. The heat and/or digestive acids break down the majority of weed seeds. However, some seeds pass through livestock or the composting process unharmed and can germinate if spread back onto the land.

Cover Crops

Cover crops provide important benefits to the Mid-Atlantic region, including soil and water conservation and nutrient retention. Some growers are also finding that cover crops can help reduce weed problems, especially winter annuals like horseweed. The following management factors should be considered to enhance weed suppression with your cover crops.

Species Selection

Choose cover crops based on your objectives. If weed suppression is an objective, select an aggressive species that will cover the ground quickly. If you desire a cover crop that will protect the soil through the fall and winter and suppress winter annual weeds, plant a winter cereal in late summer or early fall.

Establishment Date

Establishing a winter-hardy cover such as cereal rye as early in the fall as possible will result in greater cover crop biomass over the winter and rapid growth during the spring. Other establishment dates may be preferable for different cover crops depending on the species and your objectives.

Planting Considerations

The seeding rate and arrangement of the cover crop can influence weed suppression. Planting at higher-than-normal seeding rates and in narrow rows can influence the amount of soil cover, particularly in the first several weeks after seeding. Thick, dense cover crop stands can help reduce the establishment of weeds. Planting with a drill increases seed-to-soil contact and is more reliable for getting a good cover crop stand than broadcast seeding.

Soil Fertility

It is important to provide adequate soil fertility to cover crops to ensure they are competitive and successful. This is particularly true for small grains like cereal rye and wheat and forage radish, which require adequate nitrogen. Lime may be necessary to maintain or raise the soil pH for legumes like hairy vetch and red clover. Regular soil tests will help you determine how best to manage your cover crops so as to maximize their beneficial effects on weed suppression and soil quality.

Termination Timing

Allowing a cover crop to grow as long as possible before termination reduces weed populations through competition for light, nutrients, and moisture. In no-till, letting the cover crop achieve maximum dry matter production (often at flowering or beyond) will increase weed suppression. This may mean delaying termination and cash crop planting until the cover crop has achieved sufficient growth to suppress weeds (weed suppression can require dry matter production of at least 4,000 pounds per acre but is optimized at 7,000 pounds per acre). Keep in mind, however, that high-biomass cover crops can be more challenging to manage, might need shorter season cash crops to allow for adequate cover crop growth, and may require specialized planting equipment or may increase the potential for some insect pest problems.

Cover crops can be terminated mechanically or with herbicides. Each method has advantages and disadvantages. Mowing can be effective for some annual cover crops, but the mulch can degrade quite rapidly because it has been chopped. Plowing can be an effective physical control for cover crops, but the benefit of the weed-suppressive mulch in the subsequent cash crop is lost. The roller-crimper offers effective physical control of some annual cover crops, but without any accompanying herbicides, control is delayed until the winter annual cover crops are flowering and can be inconsistent. Rolling creates a longer lived mulch layer than mowing. Herbicides can effectively control most cover crops, but product selection and application timing are important.

Mechanical Techniques

Mechanical or physical techniques either destroy weeds or make the environment less favorable for seed germination and weed survival. These techniques include pulling weeds by hand, hoeing, mowing, plowing, disking, cultivating, and digging. If adequate weed control is obtained from other methods, such as herbicides, tillage or cultivation may not be necessary, which in turn could avoid soil crusting and soil erosion that can occur when soils are routinely tilled. Mowing removes the seed heads of most weeds and reduces the amount of seed spread in an area. Mowing is used primarily for weed control in lawns, meadows, pastures, waste areas, and along roadsides. Digging or pulling is an effective method of controlling a limited number of weeds. Smaller weeds can be easily pulled by hand or hoed in small garden areas or flower beds; however, the use of heavy machinery could be necessary to remove large woody weeds such as multiflora rose, tree of heaven, and autumn olive. Mulching (using straw, wood chips, compost, gravel, plastic, landscape fabric, etc.) can also be considered a mechanical control means because it uses a physical barrier to block light and impede weed growth. In landscaping and vegetable production, it usually helps to reduce the need for other weed management tactics.

Biological Techniques

Biological weed control involves the use of other living organisms, such as insects, diseases, or livestock, for the management of certain weeds. In theory, biological control is well suited for an integrated weed management program. However, the limitations of biological control are (1) it is a long-term undertaking, (2) its effects are neither immediate nor always adequate, (3) only certain weeds are potential candidates, and (4) the rate of failure for past biological control efforts has been fairly high. There have been a few success stories of weed species (e.g., St. Johnswort, prickly pear, multiflora rose, purple loosestrife, thistles) being managed or affected by insect or disease biocontrol agents. Herbivores such as sheep and goats can provide successful control of some common pasture weeds. Finally, conservation biological control can improve our ability to manage weeds and use less herbicide. This involves enhancing populations of natural enemies by manipulating field habitats to create more favorable environments for predator insects and rodents. Ground beetles, crickets, ants, and mice are some of the more common weed-seed predators. In general, providing cover in the form of living or dead crops, causing less soil disturbance, and avoiding the use of toxic pesticides can encourage these biocontrol agents. Research continues in this area of weed management.

Chemical Techniques

Chemicals used for the control of weeds are called herbicides. Herbicides can be defined as crop- (or desirable plant-) protecting chemicals used to kill weedy plants or interrupt normal plant growth. Herbicides provide a convenient, economical, and effective way to help manage weeds. They allow fields to be planted with less tillage, allow earlier planting dates, and provide additional time to perform the other tasks that farm or personal life require. Due to reduced tillage, soil erosion has been reduced from about 3.5 billion tons in 1938 to 1 billion tons in 1997, thus reducing soil from entering waterways and decreasing the quality of the nation's surface water. Without herbicide use, no-till agriculture becomes impossible. However, herbicide use also carries risks that include environmental, ecological, and human health effects. It is important to understand both the benefits and disadvantages associated with chemical weed control before selecting the appropriate control.

Herbicides may not be a necessity on some farms or landscape settings, but without the use of chemical weed control, mechanical and cultural control methods become that much more important. 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.

No-Till Weed Management

Successful production of no-till crops requires control of existing vegetation at planting (cover crops and weeds) and broadleaf and grass weeds that emerge after planting. A diversity of herbicides and cover crop and residue situations makes it impossible to utilize a single program to efficiently control weeds and grasses in all situations. Herbicide selection based on weed identification histories of each field is necessary to achieve maximum yield potential. Fields with heavy crop residues may require the maximum labeled rate of residual herbicides for acceptable performance. Encapsulated formulations, when available, can be less readily absorbed by heavy crop residues and could perform more consistently.

Cultivation and mechanical weed control are very difficult or impossible, and they are generally not considered an option in most no-till production systems. However, some companies manufacture high-residue cultivators that are designed for use in no-till/reduced-till systems. The authors have had a number of trials examining their effectiveness, and generally two passes will provide about a 50% reduction in weed dry matter. Combining these tools with herbicides can provide a more integrated approach to weed management.

Existing vegetation is traditionally controlled by the non-selective herbicides, which are often tank-mixed with residual herbicides. Burndown herbicide options include paraquat or glyphosate and perhaps a growth regulator herbicide (Group 4) such as 2,4-D. No-till crop production tends to favor perennial weed populations because their root systems are not disrupted by tillage. No-till also favors small-seeded grasses and broadleaf weeds (such as lambsquarters and pigweed) rather than large-seeded weeds, such as velvetleaf.

Escalating herbicide costs and an interest in keeping herbicide use to a minimum encourage many people to consider the use of postemergence herbicide programs. Experience leads the authors to strongly recommend that existing vegetation should always be controlled prior to planting. In the Mid-Atlantic region, soil moisture is often the factor that most limits yield. The decision to apply burndown herbicides early pre-plant, at planting, or as a delayed preemergence (spike) treatment to control existing emerged vegetation should always be made with consideration to the impact of the existing vegetation on the availability of soil moisture. Preemergence or postemergence herbicides that can provide residual weed control can then be selected that will control weeds that emerge after planting. Reducing or eliminating some or all of the residual preemergence herbicides can reduce costs in fields that historically have required postemergence herbicide applications.

Herbicides

Herbicides are the primary weed management tool in no-till production systems. Careful selection and application are critical to maximizing their effectiveness.

Some Considerations When Using Herbicides

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. Consider the following points before you choose or apply any herbicide.

- Is it registered for use on the crop or area you want to treat? If it is, the directions for use and rate of application will appear on the label. Recommended rates for soil-applied herbicides can vary according to the soil texture and the amount of organic matter in the soil. Labels usually give a range of rates because soil types differ in the amount of herbicide that binds to soil particles. The application for postemergence treatments varies with weed size and climatic conditions. Weeds that are growing under dry conditions or during prolonged cool weather will not actively translocate a systemic herbicide. A herbicide rate that is higher than the rate used on actively growing weeds may be needed.
- Will it control the weeds that are causing the biggest problem, and does it take into account methods for managing herbicide resistance? Many weed control measures fail because the chosen herbicide will not control the weeds that are present.
- Can it be used effectively at the current stage of crop or weed growth? Very few herbicides can be applied at any stage during the growth cycle of a plant. Pendimethalin and metolachlor are good examples of how growth stage affects herbicide performance. They are excellent herbicides for annual grasses when applied before the grass weeds emerge; however, they are useless if applied after the weeds have emerged.
- Can the herbicide be used effectively and safely under the current conditions? Soil-applied herbicides must move into the soil to be taken up by roots and shoots of weed seedlings and perennial plant parts. Rainfall is usually adequate to provide soil incorporation of soil-applied herbicides, but in the absence of rainfall, weed control may be poor. The effectiveness of soil-applied herbicides can be reduced if the chemical is intercepted by debris from a previous crop, a prior application of livestock manure, thatch, or other barrier. Depending on the amount of crop residue, reduced-tillage cropping systems may require higher application rates of soil-applied herbicides than are required by conventional systems. Vegetation remaining on the soil surface binds some of the herbicide and prevents even distribution of the herbicide. Herbicides can also be lost to runoff, leaching, or volatilization.
- Will the herbicide(s) interact negatively with other pesticides, fertilizers, or other inputs being used on the crop or area? Because of such interactions, injury or death to desirable plants may occur.

- Is the herbicide being applied to a "normal" crop or a genetically modified crop? Since genetically modified crops look similar to normal crops when growing, misapplication can occur and the crop can be unintentionally killed or severely injured. Make sure to record the type of crop that was planted in each field.
- Will carryover of the herbicide result in a residue that might affect the crop or cover crop you want to plant next in rotation? Herbicide carryover is a problem with chemicals that persist in sufficient quantity to injure succeeding plantings. Some examples of herbicides prone to carryover include the triazines (atrazine and simazine), dinitroanilines (Treflan, Curbit, Barricade, Prowl), ALS inhibitors (Classic, Cimarron, Steadfast, Outrider, Spirit, Pursuit, Python), and pigment inhibitors (Command, Balance, Callisto, Impact). These herbicides can provide season-long control of certain weeds. However, if an excessive rate is applied, if the soil pH is above 7.0, or if the weather during the growing season is cool and dry, the natural breakdown of the chemicals might not occur and carryover may result. Read labels carefully for warnings about carryover and rotation.
- What is the appropriate method of application (e.g., broadcast, band, directed, spot)? Is it convenient to use ready-to-use products, or does it require special equipment or need to be mixed with water before application? Are there other characteristics, such as compatibility with other herbicides when tank mixing or staining, that make it difficult to use?
- Does the herbicide label recommend that a surfactant, crop oil, or other additive be used to improve leaf coverage or herbicide performance? Many postemergence herbicides require the use of an adjuvant in the mixture (see the Herbicide Spray Additives section later in this chapter).
- Can this product be used safely on the intended planting? What is required to handle, mix, and apply it safely during and after use? Is it a restricted-use pesticide?
- Can the herbicide injure nontarget plants in adjacent areas? Exercise caution to avoid drift, runoff, leaching to groundwater, and cross-contamination of other materials. Be especially alert to the potential for residues left in sprayers when spraying a different crop.

Classification of Chemical Weed Control

Herbicides can be classified several ways, including weed control spectrum, labeled crop usage, chemical families, mode of action, application timing/method, and others. For this publication, herbicides will be grouped according to mode and site of action, which are also important in understanding herbicide resistance in weeds.

Timing of Application: Preemergence or Postemergence

Preemergence or soil-applied herbicides control weeds at the seed germination stage or as they are emerging from the soil. Postemergence or foliar herbicides control emerged weeds. Combinations of preemergence and postemergence herbicides may be necessary to control the various types of weeds in an area.

Contact or Translocated

Contact herbicides kill or injure only the part of the plant that the spray droplets come into contact with, so adequate spray coverage is very important. Annual weeds may be killed, but regrowth of perennial weeds from belowground parts usually occurs following application of a contact herbicide. (On a side note, sometimes the term "contact" is used to describe an herbicide that is applied postemergence or sprayed directly on the weed and thus "contacts" the foliage of the plant. When used in this context, it may have a different meaning and the herbicide could have systemic activity throughout the plant, depending on the product.) Translocated (or systemic) herbicides are absorbed by the leaves or roots of the plants and move within the plant. They are needed to kill underground parts of perennial weeds.

Selective or Nonselective

Nonselective herbicides kill or injure almost all plants, while selective herbicides kill some plants but do little or no damage to others. Herbicides would be of little value if it were not for the fact that most herbicides can be applied just before crop planting or emergence, and even over the top after crop emergence, without excessive injury. Most of the herbicides labeled for use today will selectively remove most of the weeds without injuring the crop or planting.

Selectivity is accomplished primarily by two methods: selectivity by placement and true selectivity. Selectivity by placement is accomplished by avoiding or minimizing contact between the herbicide and the desired crop. An example is wiping or directing an herbicide, such as glyphosate, on a weed without exposing the desired plant. Selectivity by this means is as good as any, as long as the excess herbicide is not washed off the weeds and leached into the root zone where it might be absorbed by the root. Selectivity by placement is also accomplished when an herbicide that does not readily leach is applied to the soil surface for control of shallow-rooted weeds but does not leach into the root zone of a more deeply rooted crop such as fruit trees or established alfalfa.

Selectivity that is true tolerance as a result of some morphological, physiological, or biochemical means is referred to as true selectivity. The herbicide can be applied to the foliage of the crop or to the soil in which the crop is growing without danger of injury. Although true tolerance may be the best type of selectivity, it is not perfect. Such things as crop growth stage, cuticle thickness, hairiness of the leaf surface, location of the growing point, air temperature and humidity, spray droplet size, and the surface tension of spray droplets all can influence herbicide activity. When conditions are ideal for herbicide activity, even true selectivity may not adequately prevent some crop injury.

Fumigants

Fumigants may kill all living things in the soil, including weeds, weed seeds, insects, and disease organisms.

Herbicide Mode and Site 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. 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 site the herbicide affects is referred to as the site or mechanism of action. Understanding herbicide mode and site of action is helpful in knowing what groups of weeds are killed, specifying application techniques, diagnosing herbicide injury problems, and preventing herbicide-resistant weeds.

A common method of grouping herbicides is by their mode of action. Although a large number of herbicides are available in the marketplace, several have similar chemical properties and herbicidal activity. Herbicides with a common chemistry are grouped into families. Also, two or more families may have the same mode of action and can thus be grouped into classes. **Table 1** lists several groups of herbicides and information related to their mode of action.

The following section provides a brief overview of herbicide functions in the plant and associated injury symptoms for each of the herbicide classes found in **table 1**.

Growth Regulators – Groups 4 and 19

Also called auxins, synthetic auxins, and hormones, growth regulators are effective on annual and perennial broadleaf plants and usually have no activity on grasses or sedges except at high application rates. They produce responses similar to those of natural growth-regulating substances called auxins. Application of artificial auxins, such as 2,4-D, upsets normal growth as follows:

- Cells of leaf veins rapidly divide and elongate, while cells between veins cease to divide. This results in long, narrow, straplike young leaves.
- Water content increases, making treated plants brittle and easily broken.
- Cell division and respiration rates increase, and photosynthesis decreases. Food supply of treated plants is nearly exhausted at their death.
- Roots of treated plants lose their ability to take up soil nutrients, and stem tissues fail to move food and water effectively through the plant.

The killing action of growth-regulating chemicals is not caused by any single factor but results from the effects of multiple disturbances in the treated plant.

Injury symptoms: Broadleaf plant leaves become crinkled, puckered, strap-shaped, stunted, and malformed; leaf veins appear parallel rather than netted; and stems become crooked, twisted, and brittle, with shortened internodes. If injury occurs in grasses (e.g., corn), new leaves do not unfurl but remain tightly rolled in an onion-like fashion, and stems become brittle, curved, or crooked, with short internodes. A lesser effect in corn is the fusion of brace roots, noticed later in the season.

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage.

Herbicide Class/MOA					
WSSA group[1]	Site of action	No. resistant in U.S.	Family	Common name	Trade name
Lipid synthesis inhibitors					
1	ACCase inhibitors (acetyl CoA carboxylase)	15	Aryloxyphenoxy-propionate (fops)	fenoxaprop	Puma, Tacoma
				fluazifop	Fusilade
				quizalofop	Assure II, Targa
			Cyclohexanedione (dims)	clethodim	Select Max
				sethoxydim	Poast
			Phenylpyrazolin	pinoxaden	Axial XL

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage. (cont.)					
Amino acid synthesis inhibitors					
2	ALS inhibitors (acetolactate synthase)	52	Imidazolinone	imaxamox	Beyond, Raptor
				imazapic	Plateau
				imazapyr	Arsenal
				imazethapyr	Pursuit
				pyrithiobac	Staple
			Pyrimidinylthio-benzoic acid	flucarbazone	Everest
			Sulfonylaminocarbonyltriazolinone	propoxy-carb-azone	Olympus
				thiencarba-zone	component of Capreno, Corvus
			Sulfonylurea	chlorimuron	Classic
				chlorsulfuron	Glean
				foramsulfuron	Option
				halosulfuron	Permit, Sandea
				imazosulfuron	League
				iodosulfuron	Autumn
				mesosulfuron	Osprey
				metsulfuron	Cimarron, others
				nicosulfuron	Accent Q
				prosulfuron	Peak
			Sulfonylurea	rimsulfuron	Matrix, Resolve
				sulfosulfuron	Outrider
				thifensulfuron	Harmony
				tribenuron	Express
				triflusulfuron	UpBeet
			Triazolopyrimidine	cloransulam	FirstRate
				flumetsulam	Python
				pyroxsulam	PowerFlex

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage. (cont.)

9	EPSP synthase inhibitor (5-enolpyruvyl-shi-kimate-3-phos-phate)	17	Organophosphorus	glyphosate	Roundup, Touch-down, others
Growth regulators					
4	T1R1 auxin re-ceptors (synthetic aux-ins)	10	Arylpicolinate	halauxi-fen-methyl	Elevore
			Benzoic acid	dicamba	Clarity
			Carboxylic acid	aminopyralid	Milestone
				clopyralid	Stinger
				fluroxypyr	Starane, Vista
				picloram	Tordon
				quinclorac	Facet
				triclopyr	Garlon, Remedy
			Phenoxy	2,4-D	Various
				2,4-DB	Butyrac, various
				MCPA	Various
19	Auxin transport inhibitor	0	Semicarbazone	diflufenzopyr	Component of Status
Photosynthesis inhibitors					
5	Photosystem II inhibitors (mobile) differ-ent binding than 6 and 7	26	Phenylcarbamate	phenmedip-ham	Spin-Aid
			Triazine	atrazine	Atrazine
				prometon	Pramitol
				simazine	Princep
			Triazinone	hexazinone	Velpar
				metribuzin	Glory, Metribuzin, TriCor
			Uracil	terbacil	Sinbar
6	Photosystem II inhibitors (nonmobile) different binding than 5 and 7	1	Benzothiadiazole	bentazon	Basagran
			Nitrile	bromoxynil	Maestro
7	Photosystem II inhibitors (mobile) differ-ent binding than 5 and 6	11	Urea	diuron	Direx, Karmex
				linuron	Linex, Lorox
				tebuthiuron	Spike

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage. (cont.)

Nitrogen metabolism inhibitor					
10	Glutamine synthetase inhibitor	1	Amino acid derivative	glufosinate	Finale, Liberty, Rely
Pigment inhibitors					
12	Phytoene desaturase biosynthesis inhibitor	1	Pyridazinone	norflurazon	Solicam
13	DOXP synthase inhibitor (1-deoxy-D-xyulose 5-phosphate)	1	Isoxazolidinone	clomazone	Command
27	HPPD inhibitors (4-hydroxy-phenyl-pyruvate-dioxygenase)	2	Isoxazole	isoxaflutole	Balance Flexx
			Pyrazole	pyrasulfotole	Component of Huskie
			Pyrazolone	tolpyralate	Shieldex
				topramezone	Armezon, Impact
			Triketone	mesotrione	Callisto
				tembotrione	Laudis
Cell membrane disrupters					
14	PPO inhibitors (protoporphyrinogen oxidase)	2	Aryl triazolinone	carfentrazone	Aim
				fluthiacet	Cadet
				sulfentrazone	Authority, Spartan
			Diphenyl ether	acifluorfen	Ultra Blazer
				fomesafen	Reflex
				lactofen	Cobra, Phoenix
				oxyfluorfen	Goal
			N-phenylphthalimide	flumiclorac	Resource
				flumioxazin	Château, Valor
			Oxadiazole	oxadiazon	Ronstar
			Pyrimidinedione	saflufenacil	Kixor, Sharpen
22	Photosystem I electron diverter	6	Bipyridylium	diquat	Reglone
				paraquat	Gramoxone

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage. (cont.)

Seedling root growth inhibitors					
3	Microtubule inhibitors	6	Benzamide	pronamide	Kerb
			Dinitroaniline	ethalfluralin	Curbit, Sonalan
				oryzalin	Surflan
				pendimethalin	Pendulum, Prowl, others
				prodiamine	Barricade
				trifluralin	Treflan, others
			Phthalic acid	DCPA	Dacthal
			Pyridazine	dithiopyr	Dimension
Seedling shoot growth inhibitors					
8	Lipid synthesis inhibitors (not ACCase)	5	Phosphorodithioate	bensulide	Prefar
			Thiocarbamate	cycloate	Ro-Neet
				EPTC	Eptam, Eradicane
15	Long-chain fatty acid inhibitors	1	Acetamide	napropamide	Devrinol
			Chloroacetamide	acetochlor	Breakfree, Degree, Harness Topnotch, Warrant, others
				dimethenamid	Outlook
				metolachlor	Dual, Cinch, others
			Oxyacetamide	flufenacet	Define
			Pyrazole	pyroxasulfone	Zidua
16	Specific site unknown	0	Benzofurane	ethofumesate	Nortron
Cell wall synthesis inhibitors					
20	Cellulose inhibitor (Site A)	0	Nitrile	dichlobenil	Casoron, others
21	Cellulose inhibitor (Site B)	0	Benzamide	isoxaben	Gallery
29	Cellulose inhibitor (unspecified site)	0	Alkylazaine	indaziflam	Alion

[1] WSSA group is a system of classifying herbicides, based on site of action, developed by the Weed Science Society of America.

Amino Acid Biosynthesis Inhibitors – Groups 2 and 9

These herbicides are effective mostly on annual broadleaves, while a few in this large group have activity on grasses, nutsedge, and/or perennial plants. (Glyphosate [Roundup], for example, is a broad-spectrum herbicide and has activity on all types of plants.) These herbicides work by interfering with one or more key enzymes that catalyze the production of specific amino acids in the plant. When a key amino acid is not produced, the plant's metabolic processes begin to shut down. Different herbicides affect different enzymes that catalyze the production of various amino acids, but the result is generally the same – the shutdown of metabolic activity with eventual death of the plant.

Injury symptoms: Plants that are sensitive to these herbicides stop growth almost immediately after foliar treatment: seedlings die in two to four days, established perennials in two to four weeks. Plants become straw-colored several days or weeks after treatment, gradually turn brown, and die.

Fatty Acid (Lipid) Biosynthesis Inhibitors – Group 1

These herbicides are rapidly absorbed by grasses and translocated to the growing points, where they inhibit meristematic activity, stopping growth almost immediately. They have no activity on broadleaf plants and are most effective on warm-season grasses such as Johnsongrass, shattercane, corn, fall panicum, giant foxtail, and crabgrass. Cool-season grasses like quackgrass, annual and perennial ryegrass, orchardgrass, timothy, and small grains are not as sensitive as warm-season grasses. Some of these herbicides are weaker on perennial species than other products. They are frequently referred to as "postgrass" and "graminicide" herbicides.

Injury symptoms: Growing points are killed first, resulting in the death of the leaves' inner whorl. Older, outer leaves of seedlings appear healthy for a few days, and those of perennials for a couple of weeks, but eventually they also wither and die. After several weeks, the growing points begin to rot, allowing the inner leaves to be easily pulled out of the whorl. Sensitive grasses commonly turn a purplish color before dying.

Seedling Growth Inhibitors (Root and Shoot) – Groups 3 and 8

Herbicides in this group prevent cell division primarily in developing root tips and are effective only on germinating small-seeded annual grasses and some broadleaves.

Injury symptoms: Seeds of treated broadleaved plants germinate, but they either fail to emerge or emerge as severely stunted seedlings that have thickened, shortened lower stems, small leaves, and short, club-shaped roots. Seedlings of taprooted plants, such as soybeans and alfalfa, usually are not affected, nor are established plants with roots more than a couple inches deep.

Grass seeds germinate but generally fail to emerge. Injured seedlings have short, club-shaped roots and thickened, brittle stem tissue. Seedlings die from lack of moisture and nutrients because of the restricted root system.

Seedling Growth Inhibitors (Shoot) – Group 15

Herbicides in this class are most effective on annual grasses and yellow nutsedge. Depending on the product, some will control small-seeded annual broadleaves. These herbicides cause abnormal cell development or prevent cell division in germinating seedlings. They stop the plant from growing by inhibiting cell division in the shoot and root tips while permitting other cell duplication processes to continue. This is followed by a slow decline in plant vigor.

Injury symptoms: Germinating grasses normally do not emerge. If they do, young leaves fail to unfold, resulting in leaf looping and an onion-like appearance. The tip of the terminal leaf becomes rigid and not free-flapping (flaglike). The leaves of broadleaved plants turn dark green, become wrinkled, and fail to unfold from the bud. The roots become shortened, thickened, brittle, and clublike.

Photosynthesis Inhibitors (Mobile) – Groups 5 and 7

These herbicides are effective primarily on annual broadleaves, while some provide control of grasses as well. Photosynthesis-inhibiting herbicides block the photosynthetic process so captured light cannot be used to produce sugars. In the presence of light, green plants produce sugar from carbon dioxide and water. Energy is needed for carbon, hydrogen, and oxygen atoms to rearrange and form sugar. To supply this necessary energy, electrons are borrowed from chlorophyll (the green material in leaves) and replaced by electrons split from water. If chlorophyll electrons are not replaced, the chlorophyll is destroyed and the plant's food-manufacturing system breaks down. The plant slowly starves to death due to lack of energy.

As soil-applied treatments, these herbicides permit normal seed germination and seedling emergence but cause seedlings to lose their green color soon afterward. With the seeds' food supply gone, the seedlings die. These herbicides are more effective on seedling weeds than on established perennial weeds. Herbicides such as prometon (Primitol) and tebuthiuron (Spike) are considered soil sterilants. Soil sterilants are nonselective chemicals that can kill existing vegetation and keep the soil free from vegetation for one or more years.

Injury symptoms: In broadleaved plants, early seedling growth appears normal, but shortly after emergence (when energy reserves in cotyledons are depleted), leaves become mottled, turn yellow to brown, and die. In most cases, the oldest leaves turn yellow on the leaf margins first, the veins remain green, and eventually the plant turns brown and dies. Herbaceous and woody perennials starve very slowly because they have large energy reserves in roots or rhizomes to live on while photosynthesis is inhibited. The herbicide may have to effectively inhibit photosynthesis for a full growing season to kill trees or brush. This kind of death may be slow, but it is certain.

Photosynthesis Inhibitors (Nonmobile, "Rapid-Acting") – Group 6

Herbicides in this group have activity primarily on annual and some perennial broadleaves and are applied to the plant foliage. The mode of action is the same as the mobile photosynthesis inhibitors.

Injury symptoms: Their activity within the plant is similar to that of the mobile photosynthesis inhibitors except the injury occurs at the site of contact, causing "leaf burning" and eventual death of the plant.

Cell Membrane Disrupters – Groups 14 and 22

These herbicides control mostly broadleaves. Certain products have some activity on grasses, and paraquat (Gramoxone) provides broad-spectrum control of many different species.

These herbicides are referred to as contact herbicides, and they kill weeds by destroying cell membranes. They appear to burn plant tissues within hours or days of application. Good coverage of the plant tissue and bright sunlight are necessary for maximum activity. The activity of these herbicides is delayed in the absence of light.

Injury symptoms: All contact herbicides cause cellular breakdown by destroying cell membranes, allowing cell sap to leak out. Affected plants initially have a water-soaked appearance, followed by rapid wilting and "burning" or leaf speckling and browning. Plant death occurs within a few days.

Pigment Inhibitors – Groups 12, 13, and 27

These herbicides provide control of many annual broadleaves and some grasses. These products are referred to as "bleachers" because they inhibit carotenoid biosynthesis or the HPPD enzyme by interfering with normal chlorophyll formation, turning plant parts white.

Injury symptoms: Symptoms are very evident and easy to identify. Affected plants either do not emerge or emerge white or bleached and eventually die. Older leaf tissue is affected first.

Phosphorylated Amino Acid (Nitrogen Metabolism) Disrupters – Group 10

This herbicide (glufosinate) provides broad-spectrum control of most annual grasses and broadleaves and some perennials. It affects growth by disrupting nitrogen metabolism, thus interfering with other plant processes. It is a contact herbicide with slight translocation throughout the plant. Good spray coverage and sunlight are important for maximum efficacy.

Injury symptoms: Injury is similar to that of the cell membrane disrupter herbicides. Sensitive plants show leaf burning, yellowing and browning, and eventual death after a week or so. Perennials generally take longer for symptoms and death to occur.

Unknown Herbicides

This category contains miscellaneous products for which the mode of action and family are unknown. Dazomet (Basamid) and metam (Vapam) are considered soil fumigants. These products are applied to the soil and covered with a gas-tight tarp, where they are converted to gases and penetrate the soil to kill weeds, diseases, and nematodes. Endothall (Aquathol) is used for aquatic weed control. Fosamine (Krenite) is used in noncrop areas to control perennial weeds and brush.

Other compounds – such as pelargonic acid (Scythe), fatty acid herbicides, and clove oil and vinegar – are contact, nonselective, broad-spectrum, foliar-applied products that are sometimes used for weed control in organic crop production settings. However, because they basically "burn" only the plant tissue they contact, there is potential for plant regrowth.

Trade Name, Formulation Notations, and Premixes

Certain publications list many herbicides by trade name (or product name) and formulation, for example: Roundup 4S or Permit 75WDG. Roundup is the trade name and 4S stands for 4 pounds of active ingredient (glyphosate) per gallon of product in a soluble (S) formulation. Permit is formulated as a water-dispersible granule with each granule (or certain unit) containing 75% active ingredient (halosulfuron) in a water-dispersible granule (WDG) formulation. The remaining parts of the formulation contain inert ingredients, which have no effect on weed control. Additional information about formulation and ingredients can be found in another part of this publication and on the product's label and safety data sheet.

Premixes contain two or more herbicide active ingredients mixed into one product by the manufacturer. The actual premix formulation can vary but commonly contains two or more herbicides that are already used together. The primary reason for using premixes is convenience. Many herbicide products are now marketed as premixes.

Herbicide Safeners

Herbicide safeners, also called antidotes or protectants, are chemicals that help prevent injury to crops without reducing weed control. Early discovery of compounds capable of safening herbicides started in the late 1940s with the phenoxy herbicides, but commercialization really started with seed treatments and soil-active safeners in the 1970s and early 1980s. In general, herbicide safeners allow crops with fair tolerance to an herbicide to metabolize or detoxify the herbicide more quickly, thus providing increased crop safety. To date, safeners have only been developed for grass crops such as corn and wheat with few advances in dicot or broadleaf crops. Some of the more notable of these safeners include dichlormid (Eradicane and some acetochlor formulations), benoxacor (Dual II), and the seed treatment fluxofenim (Concept), which allows chloroacetamide herbicide use in sorghum. More recently, a number of Group 2 (ALS) and other herbicides use isoxadifen (Accent Q, Resolve Q, Status, Steadfast Q, etc.), which provides increased safety from foliar applications. The most recently launched safener is cyprosulfamide, which provides preemergence and foliar safening with several herbicides. Cyprosulfamide is used in a number of Bayer CropScience products, including Balance Flexx, Corvus, Capreno, and DiFlexx.

Generic or Post-Patent Products

The pace of novel herbicide active ingredient commercialization has greatly slowed over the last 20 years and many herbicides are going off patent. Also, several new manufacturers have entered the herbicide market and are reintroducing older active ingredients. Most original brands still dominate, but the post-patent product market is growing. Be cautious and consider all factors when looking at generic herbicide alternatives, especially guarantees for resprays on product failures. Contact your local dealer for details.

Herbicide Spray Additives (Adjuvants)

Additives, or adjuvants, are substances in herbicide formulations or that are added to the spray mixture to improve herbicidal activity or application characteristics. Over 70% of all herbicides recommend the use of one or more adjuvants in the spray mixture. In general, there are two types of adjuvants: formulation and spray. Formulation adjuvants are "already in the container" from the manufacturing process. These help with mixing, handling, effectiveness, and providing consistent performance.

Spray adjuvants can be divided into special-purpose adjuvants and activator adjuvants. Special-purpose adjuvants include compatibility agents, buffering agents, antifoam agents, drift retardants, and others that widen the range of conditions for herbicide use. Activator adjuvants are commonly used to enhance postemergence herbicide performance by increasing herbicide activity, absorption, and rainfastness and decreasing photodegradation. These include surfactants (i.e., "surface active agents"), crop oil concentrates, vegetable oil concentrates, wetting agents, spreader stickers, nitrogen fertilizers, penetrants, and others. Commonly used surfactants are nonionic surfactants and organosilicones, which are typically used at a rate of 1 quart per 100 gallons (0.25% volume/volume) of spray mixture. Crop oil concentrates are 80% to 85% petroleum-based plus 15% to 20% surfactant, while vegetable oil concentrates contain vegetable or seed oil in place of petroleum oil. Oil concentrates are typically included at a rate of 1 gallon per 100 gallons (1% volume/volume) of spray mixture. In general, oil concentrates are "hotter" than surfactants, so they provide better herbicide penetration into weeds under hot/dry conditions, but they are more likely to cause greater crop injury under normal growing conditions. Nitrogen fertilizers such as UAN (a mixture of ammonium nitrate, urea, and water) or AMS (ammonium sulfate) are used in combination with surfactants or oil concentrates to increase herbicide activity and reduce problems with hard water. Many blended adjuvants are available that include various combinations of special purpose adjuvants or activator adjuvants.

Be sure to include the proper adjuvant(s) for the herbicide being used. Most herbicide labels specify the type and amount of additive to use. Failure to follow the recommendations can result in poor weed control or excessive crop injury.

Managing Herbicides

Proper management of herbicides is critical to mitigate human health, environmental, and other potential hazards as well as maximize herbicidal efficacy.

Environmental Hazard Warnings

Some herbicide labels carry Environmental Hazard Warnings on the label. The environmental hazard may specify a "water-quality advisory," which requires special precautions for coarse-textured (sandy) soils, soils with a shallow water table, and soils with other potential water-contamination risks. Herbicides with water-quality advisories have been detected in small amounts in water supplies after normal agricultural use. Additional environmental dangers include toxicity to fish and wildlife and hazards to endangered species. Check the label or specific hazard warning information before using a product.

Herbicide Use Rate

The recommended use rates of soil-applied herbicides often vary with soil texture, organic matter content, and tillage systems. The use of soil-applied herbicide rates that are incorrect for the soil texture, pH, and organic matter can result in poor weed control or crop injury. Consult the herbicide label for the proper herbicide rate for your soils.

Most of the herbicides recommended in this publication are selective. At the recommended rate of application, they will selectively control or injure weeds but not seriously damage the crop in which these weeds are growing. When using selective herbicides, you should carefully follow the recommended application rate and follow instructions related to the use of surfactants and other additives. Using higher herbicide rates or additives that are not recommended can result in severe crop injury. You must accept responsibility if you use an herbicide in a manner other than that directed on the herbicide label.

Herbicide Persistence and Crop Rotation Intervals

Herbicides are applied to the soil to manage weeds. It is desirable for the chemicals to control weeds during the season of application, but they should not persist and affect subsequent crop growth. The length of time that an herbicide remains active in the soil is called "soil persistence" or "soil residual life." With some herbicides, there may be a fine line between controlling the weeds for the entire growing season and then planting a sensitive rotation crop. Anything that affects the disappearance or breakdown of herbicides will affect persistence. Herbicides vary in their potential to persist in the soil. Some herbicide families that have persistent members include the triazines (Group 5), uracils (Group 7), ureas (Group 7), sulfonylureas (Group 2), dinitroanilines (Group 3), isoxazolidinones (Group 13), imidazolinones (Group 2), and pyridines (Group 23). Factors that determine the length of time herbicides will persist fall into three categories: soil factors, climatic conditions, and herbicidal properties. The factors within each of these categories can strongly interact with one another.

Soil Factors

The soil factors affecting herbicide persistence include soil composition, soil chemistry, and microbial activity. Soil composition is a physical factor that is determined by relative amounts of sand, silt, and clay (the soil texture) and the organic-matter content. An important chemical property of the soil that can influence herbicide persistence is pH. The microbial aspects of the soil environment include the type and abundance of soil microorganisms present. Soils containing more clay and organic matter (heavier) tend to bind herbicides more strongly and they will persist longer. Also, higher soil pH (>7) can be more problematic for some herbicides.

Climatic Factors

The climatic variables involved in herbicide breakdown are moisture, temperature, and sunlight. Herbicide degradation rates generally increase as temperature and soil moisture increase because both chemical and microbial decomposition rates increase with higher temperatures and moisture levels. Cool, dry conditions slow down herbicide degradation. Carryover problems are always greater the year following a drought. If winter and spring conditions are wet and mild following a previously dry summer, the likelihood of herbicide carryover is lower.

Herbicide Properties

An herbicide's chemical properties affect its persistence. Properties include water solubility, vapor pressure, and susceptibility of the molecule to chemical or microbial alteration or degradation. Much of this boils down to the herbicide half-life – the time it takes for 50% of the active ingredient to dissipate. Soil and climatic factors influence the rate of dissipation. The basic manufacturers, along with universities and some other research organizations, have evaluated the persistence of herbicides in soil for local conditions, and it can vary widely.

Avoiding Herbicide Persistence in Subsequent Crops

There are several ways to avoid herbicide carryover problems. First, check the re-crop statement on the herbicide label and do not plant a sensitive crop prior to the specified time. Second, always apply the correct rate of any pesticide for your specific soil type and weed problem. This means applying the lowest rate of the chemical consistent with obtaining the desired effect. Higher rates of more persistent products certainly carry more risk of injury to following crops. Accurate acreage determination, chemical measurement, proper sprayer calibration, and uniform application are essential for avoiding misapplication problems. **Always read the label before applying any herbicide.**

In summary, the first step in avoiding herbicide persistence problems is choosing less persistent products. Check the herbicide label for re-crop statements before selecting any material. With all pesticides, use the appropriate rates and application timings. The use of selective tillage, herbicide combinations, and tolerant crops and varieties will also help reduce the risk of carryover crop injury. Wise herbicide use will ensure the continued availability of these important weed management tools for the future. **Table 2 (page 195)** provides the cash crop rotation restrictions for common herbicides that are used in multiple crops. These restrictions are the label guidelines and may be due to concerns about herbicide residues accumulating in forage or feed or carryover injury.

Herbicide Persistence and Rotation to Cover Crops

The question about whether corn or soybean herbicide programs will pose a problem for establishing fall cover crops has become a common one, particularly in areas of severe drought, where corn is harvested earlier than normal and the desire to plant a cover/forage crop is strong. If you look at the rotation crop restrictions for corn and soybean herbicides in this guide **table 2**, you will see that many products limit rotation to alfalfa and/or the clovers, as well as some of the small grains. This is a good place to start when thinking about rotation to fall cover crops. However, these tables are inadequate because these cash crop rotation restrictions may be due to the concern for herbicide residues accumulating in forage or feed rather than carryover injury. If the crop is not going to be harvested and consumed by livestock or humans, the primary concern is carryover injury and achieving an acceptable stand that provides the benefits of a fall or winter cover. Cover crops that are not harvested can be planted after any herbicide program, but the grower assumes the risk of crop failure.

Two factors become important when trying to predict the potential for carryover injury to rotation crops: (1) how long the herbicide lasts or persists in the soil, assuming it has soil activity, and (2) how sensitive the rotation crop is to potential herbicide residues. Most guidelines are for “normal” conditions (e.g., not severe drought). In general, products with a four-month or less rotation restriction for the species of interest, close relative, or sensitive species (e.g., clovers) should pose little problem. These products typically have half-lives of less than 30 days. Species sensitivity can play a role if only a small amount of residue is necessary to cause injury, and the herbicide persists. Quite often, small-seeded legumes and grasses like the clovers and ryegrass, and mustard species like canola are very sensitive to some herbicides.

Table 2. Herbicide rotation restrictions for cash crops.

The information listed in this rotation restriction table is the authors' interpretation of label statements. Consult the label if two or more of these materials are applied during the same season. Herbicide labels are constantly changing; therefore, this list is not a substitute for the most recent herbicide label.

AH = After harvest

B = Bioassay of soil recommended before planting

NI = No information

NR = No restrictions

NS = Next season

NY = Next year

SY = Second year following application

Rotation restriction (months after application)																										
Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
2,4-D[1]	3	3	3	1	3	0.25 -1	1	3	3	3	1	3	3	3	3	0.25 -1[1]	1	3	1	3	3	3	1	1	1	1
Accent/ Accent Q	10[1]	10[2]	10	10	10[2]	NR	10-18[1]	10-18[1]	10[2]	10[2]	10[2]	10	10[2]	10[2]	10	0.5	8	10[2]	10	10[2]	10[2]	10[2]	10[1]	4	4	4
Acuron	18	18	18	10	18	NR	10	18	18	18	10	18	18	18	18	10	4	18	NR	18	18	18	10	4	4	4
Acuron Flexi[23]	10	18	18	10	18	NR	10	18	18	18	10	18	18	18	18	10	4	18	NR	18	18	18	10	4	4	4
Afforia (2.5 oz)	4[24]	4[24]	4[24]	1	4[24]	0.5[24]	1	4[24]	4[24]	4[24]	1.5	3	4[24]	4[25]	3	NR[24]	4[24]	4[24]	3	1.5	4[24]	4[24]	4[24]	3	3	1[24]

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Aim	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Anthem Flexx (5.46 oz)				25							25												0			
Anthem Maxx (4.87 oz)	10	18	18	4	18	NR	10[25]	11	18	18	4	11	18	18	11	NR	11[25]	18	NR	18	9	18	1	11[25]	11[25]	4[25]
Armezon/ Impact (0.75 oz)	9	18	18	9	18	NR	9	9	18	18	9	9	18	18	9	9	3	18	NR	18	18	18	9	3	3	3
Armezon PRO (16-20 fl oz/A)	9	18	18	9	18	NR	9	9[3]	18	18	9	9[3]	18	18	9[3]	9	4	18	NR	18	18	18	9	4	4	4
Assure II	4	4	4	NR	4	4	4	4	4	4	4	NR	4	4	NR	NR	4	4	4	4	4	4	4	4	4	4
Atrazine	SY	SY	SY	NY	SY	NR	NR	SY	SY	SY	NY	SY	SY	SY	SY	NY	SY	SY	NR	SY	SY	SY	SY	NY	NY	NY
Authority Edge	12	18[9]	18	12[1]	18	4	10-18[1]	9	18	18	4	9	18	18	9	NR[1]	12-18[1]	18	12	18	18	18	4	11-18[1]	11-18[1]	4-10[1]
Authority Elite/Broad Axe XC	12	2[9]	12B	18[4]	12B	10	10	12B	12B	12	4	12B	12B	12B	12B	NR	12	12B	18	10	4	12B	4	4.5	4.5	4.5
Authority First/Sonic	12	30B	30B	12-18[1]	30B	10-18[1]	12	12	30B	30B	12	9	30B	30B	12	NR	12	30B	10-18[1]	30[1]	30B	30B	18	12	12	4
Authority MTZ	12	18	18	18[4]	18	10	12	18	18	18	12	18	18	18	18	NR	18	18	18	12	NR[9]	18	12	4	4	4

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Authority Supreme	12	18[9]	18	12–18[1]	18	4	10[1]	9	18	18	4	9	18	18	9	NR[1]	12[1]	18	10	18	18	18	4	11[1]	11[1]	4[1]
Authority XL	12–18[1]	18	18	18	18	10–18[1]	10–18[1]	36	36	36	18	36	36	18	36	NR	12–18[1]	36	18	10–18[1]	12–18[1,9]	18	36	4	4	4
Autumn Super[1]	18B	18B	18B	10	18	1	18B	18B	18B	18B	18B	18B	18B	18B	18B	2	18B	18B	9	18B	18B	18B	18B	9	18B	3
Axial Bold, Axial Star, Axial XL	3	1	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	1	NR	3	NR
Axiom	12	12B	12	8	12B	NR	12	12B	12B	18	12B	12B	12B	12B	12B	NR	12	12B	12B	12B	12B	12B	1	12	12	0.23–4
Balance Flexx[1]	10[1]	18	18	10[1]	18	NR	6	18	18	18	11	18	18	18	18	6	18	18	6	12	18	18	6	6	4	4
Basagran	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Basis	10[6]	18	10[6]	1[6]	10	NR	10[6]	18	18	18	18	10	18	18	10	10[6]	9	18	10	18	1	18	NR	3	3	3
Basis Blend[6.]	10[6]	18	10[6]	1[6]	10	NR	10[6]	18	18	18	1.5	10	18	18	10	10[6]	9	18	10	1.5	1	18	1	3	3	3
Beyond	3	9	18	9	9	8.5[8]	9	NR	9	9	9	NR	9	9	NR	NR	9	9	8.5	9	9	9	9	9	4	3[8]
Bicep products	SY	SY	SY	NY	SY	NR	NR[10]	SY	SY	SY	NY	SY	SY	SY	SY	NY	SY	SY	NY	SY	SY	SY	SY	NY	NY	NY
Boundary	4.5	12	12	12	12	4	12	12	12	18	12	8	12	12	12	NR	12	12	4	12	12	12	NR	4.5	12	4.5
Buctril/ Maestro	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cadet	AH	AH	AH	AH	AH	NR	AH	AH	AH	AH	AH	AH	AH	AH	AH	NR	AH	AH	NR	AH	AH	AH	AH	AH	AH	AH

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Callisto	10	18	18	10	18	NR	NR	18	18	18	10	10[1]	18	18	10[1]	10	NR	18	NR	10	18	18	10	4	4	4
Callisto Xtra	NY	18	18	NY	18	NR	NR	18	18	18	NY	18	18	18	18	NY	18	18	NR	NY	18	18	NY	NY	18	NY
Canopy[1]	10	18	12	10	18	10	12	30	30	30	18	12	30	18	12	NR	30	30	18	10[9]	10[9]	18	30	4	4	4
Canopy Blend	10	18	18	18	18	10[26]	18	30	30	30	18	12	30	18	18	NR	4	30	18	18[9]	10[9]	18	30	4	30	4
Canopy EX	10	18	12	10	18	10[1]	10[1]	30	30	18[1]	8	12	30	18	12	0.25[1]	4	30	18	10[9]	10[9]	18	18[1]	4	4	4
Caparol	12	5	12	5	12	5	12	12	12	8	12	5	12	12	12	12	12	12	5	12	12	12	12	12	12	12
Capreno[1]	10–18	18	18	10	18	NR	10	18	18	18	11	18	18	18	18	10	10	18	10	12	18	18	18	10	18	4
Chaparral	SYB	SYB	SYB	SYB	SYB	NY	NY	SYB	SYB	SYB	SYB	SYB	SYB	SYB	SYB	SYB	NY	SYB	SYB	SYB	SYB	SYB	SYB	NY	NY	NY
Chateau (up to 3 oz)[11]	5[11]	12B	5[11]	2[11]	12B	0.5–1	1[1]	12B	12B	12B	NR	4	12B	12B	4	NR	5[11]	12B	4	2	12B	12B	5[11]	4	4	2
Cimarron Max/met-sulfuron[1]	12[1]	NYB	12[1]	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	10	NYB	NYB	NYB	NYB	NYB	NYB	10	NYB	1
Cimarron Plus	4	B	4–12[1]	B	B	12[1]	B	B	B	B	B	B	B	B	B	12[1]	10	B	B	B	B	B	B	10	NYB	1
Clarity	4	4	4	0.75–1.5[5]	4	NR	NR	4	4	4	4	4	4	4	4	0.5–1[5]	0.5–1.5[5]	4	4	4	4	4	4	0.5–1.5[5]	0.5–1.5[5]	0.5–1.5[5]
Classic[1]	12	18	12	9	18	9	9	30	30	30	15	9	30	18	9	NR	3	30	18	10[9]	10[9]	18	30	3	3	3
Cobra	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Command/ Upstage	12	9	12	NR[12]	9	9	9	12	9	12	9	NR[1]	NR	NR[1]	9	NR	12	NR[1]	9	NR	9[9]	9	9	12	12	12
Corvus	17	17B	17B	10	17B	NR	17B[1]	17B	17B	17B	11[1]	17B	17B	17B	17	9	17	17B	9	12[1]	17B	17B	17	9	4	4
Crossbow[30]	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
Curbit	AH	AH	AH	AH	NR	AH	AH	AH	NR	AH	NR	AH	AH	NR	AH	NR	AH	NR	AH	AH	AH	NR	AH	AH	AH	AH
Curtail	10.5–18[1]	10.5–18[1]	10.5B	10.5B	10.5B	1	10.5–18[1]	10.5B	10.5B	10.5–18[1]	10.5B	18	10.5B	10.5B	10.5B	10.5–18[1]	1	10.5B	10.5–18[1]	10.5B	10.5B	10.5B	18	1	10.5B	1
Dacthal	8	AH	8	8	8	8	8	8	AH	AH	8	8	AH	8	8	8	8	8	8	8	AH	NR	AH	8	8	8
Degree Xtra	SY	SY	SY	NY	SY	NR	NR[10]	SY	SY	SY	SY	SY	SY	SY	SY	NY	SY	SY	NR	NY	SY	SY	SY	SY	SY	AH
Devrinol	12	NR	12	12	12	12	12	12	12	12	12	12	NR	12	12	12	6	12	12	NR	NR	12	12	6	6	6
DiFlexx	4	4	4	2	4	NR	2	4	4	4	4	4	4	4	4	2[1]	2	4	4	4	4	4	4	2	4	2
DiFlexx Duo	10	18B	18B	10	18	NR	10	18B	18	8/ 18[27]	11	10	18B	18	10	8	4	18	4	12	10	18	10	4	4	4
Distinct[1]	1	4	4	1	4	0.25	1	4	4	4	4	4	4	4	4	1	1	4	4	4	4	4	4	1	1	1
Dual products	4	2[1]	9	NR	12	NR	NR[10]	NR	12	2[1]	NR	NR	2	2[1]	NR	NR	4.5	12	NR	NY	2[1]	12	NR	4.5	4.5	4.5
DuraCor	24B	24B	24B	24B	24B	12	24B	24B	24B	24B	24B	24B	24B	24B	24B	24B	12	24B	12	24B	24B	24B	24B	12	12	12
Elevore	9	15B	9	1	15B	0.5	0.5	15B	15B	15B	9	9	15B	15B	15B	0.5	0.5	15B	15B	15B	15B	15B	24B	0.5	0.5	0.5
Enlist Duo	NI	NS	NS	1[32]	NS	0.23–0.5[32]	NS	NS	NS	NS	NS	NS	NS	NS	NS	1[32]	NS	NS	0.2–0.5	NS	NS	NS	NS	NS	NS	NI

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Envive	10	18	12	10	18	10	12	30	30	30	8	12	30	18	12	NR	10	30	18	10[9]	12[9]	18	30	4	4	4
Eptam	NR	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	NR	AH	AH	AH	AH	AH	AH	AH	NR	AH	AH	AH
Evik	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	3	11	11	11	11	11	10	3	3	3
Expert	SY	SY	SY	NY	SY	NR	NR[10]	SY	SY	SY	NY	SY	SY	SY	SY	NY	SY	SY	NY	SY	SY	SY	SY	NY	NY	NY
Extreme	4	18	4	18	18	8.5[8]	18	NR	18	40B	NR	NR	18[9]/ 40B	40B	2	NR	18	40B	18	9.5	18[9]/ 40B	18	26	4	4	3
Facet L	24B	10	24B	10	10	10	NR	10	10	10	10	24B	24B	10	10	10	10	10	10	24B	24B	10	24B	10	10	NR
Fierce/ Fierce EZ	10	18	18	1-2[1]	18	0.25-1[1]	18	11	18	18	4	11	18	18	11	NR	11-12[1]	18	18	12	18	18	4	11-12[1]	11-12[1]	1-2[1]
Fierce XLT[1]	18	18-30	18	18-30	18-30	10-18	18	18-30	18-30	18-30	18-30	18-30	18-30	18-30	18-30	NR	18-30	18-30	18-30	18[9]	18[9]	18-30	18-30	18	18	4
Finesse Cereal and Fallow (0.4 oz)	B	B	B	18	B	18	4-18[1]	B	B	B	B	B	B	B	B	18[14]	10	B	B	B	B	B	10	10-16[1]	0-4[1]	0-4[1]
FirstRate	9	18	18	9	18	9	9	9	18	18	9	9	18	18	9	NR	9	18	18	18[15]	18	18	18	12	18	4
Flexstar/ Flexstar GT	18	18	18	NR	12	10	18	4	12	18	10	4	10[9]/12	10	NR	NR	18	12	10	18	10[9] /12	10	NR	4	4	4
FulTime/ Keystone	15	SY	SY	NY	SY	NR	NY	SY	SY	SY	SY	15	SY	SY	SY	NY	15	SY	NR	15	SY	SY	15	15	15	15
Fusilade/ Fusion	2	2	2	NR	2	2	2	2	2	NR	NR	1	1	1	1	NR	2	2	2	2	2	2	2	2	2	2

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Glyphosate products	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	1	NR	NR	NR	NR	NR	NR
Goal/Goal Tender	2	1	2	0.25	2	10	10	1-2	2-3[1]	4[1]	2	2	1[9]	2	2	0.25	10	3	10	2	1[9]	1-2[1]	2	10	10	10
Gramoxone/paraquat	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
GrazonNext HL	24B	24B	24B	24B	24B	12	24B	24B	24B	24B	24B	24B	24B	24B	24B	24B	12	24B	12	24B	24B	24B	24B	12	12	12
Grazon P+D	B	B	B	B	B	B	8	B	B	B	B	B	B	B	B	B	8	B	B	B	B	B	B	2	2	2
Halex GT	10	18	18	10	18	NR	NR[10]	18	18	18	10	10[1]	18	18	10[1]	10	4.5	18	NR	10	18	18	10	4.5	4.5	4.5
Harmony Extra SG	1.5	1.5	1.5	0.5	1.5	0.5	0.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	NR	1.5	NR
Harmony SG	1.5	1.5	1.5	0.25	1.5	NR	NR	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	NR	NR	1.5	1.5	1.5	1.5	1.5	1.5	NR	1.5	NR
Harness	9	SY	9	NS	SY	NR	NR[10]	SY	SY	SY	NY	NS	SY	SY	NS	NS	NS	SY	NR	NS	SY	SY	NS	NS	NS	4
Harness Max	10	18	18	10	18	NR	NR[10]	18	18	18	18	18	18	18	18	10	NY	18	18	18	18	18	18	NY	NY	4
Harness Xtra	SY	SY	SY	NS	SY	NR	NS	SY	SY	SY	SY	SY	SY	SY	SY	NS	SY	SY	NR	SY	SY	SY	SY	SY	SY	SY
Hornet WDG	10.5[1]	26B	26B	18	26B	NR	12	10.5[1]	26B	26B	18	18[16]	26B	26B	18[16]	10.5	4	26B	18[16]	18	26B	26B	18	4	4	4
Huskie	4[1]	1	1	1	1	4	0.25	1	1	9[1]	1	9	1	1	9	4	1	1	1	1	1	1	9	0.25	1	0.25

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Impact Core	9	18	18	10	18	NR	9	18	18	18	10	18	18	18	18	10	9	18	NR	18	18	18	10	9	9	4
Instigate	18	18	18	10	18	NR	10	18	18	18	10	10[1]	18	18	10[1]	10	9	18	10	10	18	18	10	4	4	4
Karmex	24	24	24	NR	24	NY	NY	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Kerb[1]	NR	3-6	NR	3-5	3-6	12	12	3	3-6	3-6	12	3-4	3-6	3-6	3-4	3-4	12	3-6	12	12	3-6	3-6	3	12	12	12
Keystone NXT	SY	18	SY	NY	18	NR	NY	SY	18	18	SY	SY	18	18	18	NY	SY	18	NR	SY	18	18	SY	15	15	15
Laudis	10	18	18	10	18	NR	10	18	18	8[1]	11	10	18	18	10	8	4	18	NR	12	10	18	10	4	4	4
LeadOff (1.5 oz)	10	18	10[1]	1	10	NR	10	18	18	18	1.5	10	18	18	10	1[1]	9	18	10	1.5	1	18	1	3	3	3
Lexar/Lexar EZ	18	18	18	NY	18	NR	NR[10]	18	18	18	NY	18	18	18	18	NY	NY	18	NR	18	18	18	18	NY	NY	NY
Liberty	6	2.3	6	NR	6	NR	6	6	6	2.3	6	6	6	6	6	NR	2.3	6	NR	6	6	18	2.3	2.3	2.3	2.3
Lightning	9.5	40B	40B	9.5[1]	40B	8.5[8]	18	9.5	40B	40B	9.5	9.5	40B	40B	9.5	9	18	40B	18	9.5	40B	40B	26	9.5	4	4
Lorox/ Linex	4	4	4	4	4	NR[1]	NR[1]	4	4	4	4	4	4	4	4	NR[1]	4	4	4	4	4	4	NR[1]	12	4	4
Lumax/ Lumax EZ	18	18	18	NY	18	NR	NR[10]	18	18	18	NY	18	18	18	18	NY	NY	18	NR	18	18	18	18	4.5	4.5	4.5
Marvel	18	18	18	NR	18	10	18	18	18	18	10	10	4[9]	18	NR	NR	4	18	18	18	4[9]	18	NR	4	4	4
Matrix	4	12	18	10	10	NR	18	10	18	10	18	8	12	12	10	4	9	18	10	18	NR	12	NR	12	12	4
Metribuzin products	4	18	18	18	18	4	18	18	18	18	18	8	18	18	18	4	18	18	4	18	4	18	12	4[1]	18	4[1]

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Milestone	24B	24B	24B	24B	24B	12	24B	24B	24B	24B	24B	24B	24B	24B	24B	24B	12	24B	24B	24B	24B	24B	24B	12	12	12
Optill[1]	4	40B	4	18	18	8.5[8]	18	4	40B	40B	4	4	18	40B	4	0-1	18	40B	18	9.5	18	40B	26	9.5	4-18	4[8]
Osprey	10	10	10	3	10	3	3	10	10	10	3	3	10	10	10	3	10	10	10	10	10	10	10	1	10	0.25
Outlook[1]	4-6	6-9	6-9	4	6-9	NR	NR[10]	6-9	6-9	6-9	NR	4	6-9	6-9	6-9	NR	4	6-9	NR	6-9	6-9	6-9	6-9	4	4	4
Outrider	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	NR
Overdrive	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Pasture-Gard HL	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	4	NI	NI	NI	NI	NI	NI	4	NI	4
Peak (0.25 oz)[1]	22	22	22	10	22	1[8]	1	22	22	22	10	10	22	22	10	10	NR	22	10	10	22	22	22	NR	NR	NR
Permit	9	15	9	4	2	1[8]	2	NI	9	18	6	9	10	9	2	9[1]	2	9	3	36	2	9	9	2	2	2
Permit Plus	9	15	9	4	2	1	2	NI	9	18	6	9	10	9	2	9[1,14]	2	9	3	36	2[9]	9	9	2	2	2
Perpetuo	10	18	18	2-4	18	NR	6-8[1]	11	18	18	2-4[1]	9-11[1]	18	18	11	NR	18	18	8	18	18	18	4	18	18	1-4
Poast	NR	NR	NR	NR	NR	30	30	NR	NR	NR	NR	NR	NR	NR	NR	NR	30	NR	30[7]	NR	NR	NR	NR	30	30	30
PowerFlex HL	9	12	12	3[1]	12	9	9	12	12	12	9	9	12	12	12	3[1]	9	12	9	12	12	12	9	9	12	1
Prefar[1]	4	NR	4	4	NR	4	4	4	NR	NR	4	4	NR	NR	4	4	4	NR	4	4	NR	NR	4	4	4	4
Prefix	18	18	18	1	12	10	18	4	12	18	4	4	10[9]	10	NR	NR	4.5	12	10	18	10[9]	10	1	4.5	4.5	4.5
Princep 4L	SY	SY	SY	NY	SY	NR	NY	SY	SY	SY	NY	SY	SY	SY	SY	NY[17]	SY	SY	NY	SY	SY	SY	SY	NY	NY	NY

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Prowl H2O	6[1]	NY	NY	NR	NY	NR[18]	NY	NR	NR	NY	NR	NR	NR[1]	NY	NR	NR	NY	NR	NR[18]	NR[1]	NR[1]	NR	NR[1]	4[1]	NY	4[1]
Pursuit[1]	4	18	4	18[19]	18	8.5[8]	18	NR	18	18	NR	NR	18[9]	40B	2	NR	18	40B	18	9.5	18[9]	18	18[1]	4[1]	4	4
Python	4	26B	26B	18	26B	NR	12	4	26B	26B	4	4	26B	26B	4[1]	NR	4	26B	18[1]	9	26B	26B	12	4	4	4
Raptor	3	9	18	9	9	8.5[8]	9	NR	9	9	9	NR	9	9	NR	NR	9	9	8.5	9	9	9	9[1]	9[1]	4	3
Realm Q	10	18	18[1]	10	18	NR	10	18	18	18	10	10[1]	18	18	10[1]	10	9	18	10	10	18	18	10	4	4	4
Reflex	18	18	18	NR	12	10	18	4	12	18	4	4	10[9]	10	NR	NR	4	12	10	18	10[9]	10	NR	4	4	4
Remedy Ultra[30]	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
Resicore	10.5[28]	18	18	12	18	NR[28]	10.5[28]	18	18	18	18	18	18	18	18	10.5[28]	10.5[28]	18	10.5	18	18	18	18	10.5[28]	10.5[28]	4
Resolve SG (1 oz)	10	18	10[1]	10	10	NR	10	18	18	18	18	10	18	18	10	10[14]	9	18	10	18	1	18	NR	18	18	3
Resolve Q (1.25 oz)	10	18	10[1]	1	10	NR	10	18	18	18	1.5	10	18	18	10	2[1]	9	18	10	1.5	1	18	NR	3	3	3
Resource	1	1	1	1	1	NR	1	1	1	1	1	1	1	1	1	NR	1	1	1	1	1	1	1	1	1	1
Revulin Q	10[1]	18	18	10	18	NR	10[1]	18	18	18	18	18	18	18	18	10	8	18	10[20]	18	18	18	10[1]	4	4	4
Ro-Neet	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH
Sandea	9	15	9	4	2	1[8]	2	36	9	18	6	9	10	9	2	9[1]	2	9	3	36	2	9	9	2	2	2
Scepter[1]	18	18	18	18	18	9.5[13]	11	11	18	18	11	18	18	18	11	NR	11	18	18	9.5	18	18	18	11	18	3
Select/Select Max	NR	NR	NR	NR	NR	0.2	1	NR	NR	NR	NR	NR	NR	NR	NR	NR	1	NR	1	1	NR	NR	NR	1	1	1

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Sentrallas	4	4	4	4	4	NR	NR	4	4	4	4	4	4	4	4	4[1]	NR	4	4	4	4	4	4	NR	4	NR
Sequence	4	NY	9	NR	NI	NR	NR	NR	NI	NI	NI	NR	NY	NI	NR	NR	4.5	NI	NI	NY	61	NI	NY	4.5	4.5	4.5
Sharpen (1 oz)[1]	4	4	4	1.5	4	NR	NR	4	4	4	4	NR	4	4	4	0–1	NR	4	0.5	4	4	4	4	NR	NR	NR
Shieldex	9	9	12	9	9	NR	9	12	9	12	9	9	12	9	9	9	3	9	NR	12	9	9	9	3	3	3
Sierra[1]	24	24	24	24	24	11	24	24	24	24	24	11	24	24	24	9[14]	24	24	24	24	24	24	9	9	24	NR
Sinate	9	18	18	9	18	NR	9	18	18	18	9	9–18[1]	18	18	9–18[1]	9	3	18	NR	18	18	18	9	3	3	3
Sinbar	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Solicam	16	24B	24B	1–16[1]	24B	24B	24B	24B	24B	24B	1–16[1]	24B	24B	24B	24B	1.5–16[1]	24B	24B	24B	24B	24B	24B	24B	24B	24B	24B
Sonalan	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	NR	AH	AH	AH	AH	NR	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH
Spartan	12	NR	12B	18	12B	10	10[1]	NR	12B	12B	12B	12B	12B	12B	12B	NR	12	12B	18	NR	NR[9]	12B	12B	4	4	4
Spartan Charge	12	NR[9]	12B	12–18[1]	12B	4	10[1]	12B[1]	12B	12B	NR	12B	12B	12B	12B	NR	12	12B	12	NR	NR[9]	12B	4	4	4	4
Spin-Aid	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	4	AH	AH	AH	AH	AH	AH	4	4	4
Spirit	18	10	18	10	18	1[8]	10	18	18	18	18	10	18	18	10	10	3	18	8	10	10	18	10	3	3	3
Spur	10.5	NR	10.5B	10.5–18B	10.5–18B	NR	10.5	10.5B	10.5–18B	10.5	10.5B	18B	10.5B	10.5–18B	10.5B	10.5–18	NR	10.5B	NR	10.5B	10.5B	10.5–18B	18B	NR	10.5B	NR
Starane Ultra	4	4	4	4	4	NR	NR	4	4	4	4	4	4	4	4	4[31]	NR	4	NR	4	4	4	4	NR	NR	NR
Status	1[5]	4	4	1[5]	4	0.25	1[5]	4	4	4	4	4	4	4	4	1[5]	1[5]	4	4	4	4	4	4	1[5]	1[5]	1[5]

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Steadfast Q	10[1]	18	10[1]	10	10-18	NR	10-18	10-18	10-18	10-18	10-18	10	10-18	10-18	10	0.5	8	10-18	10[20]	10-18	10-18	10-18	10[1]	4	4	4
Stinger	10.5	NR	18	18B	18B	NR	10.5	18B	18B	10.5	18B	18B	18B	18B	18B	10.5[1]	NR	18B	NR	18B	18B	18B	18B	NR	NR	NR
Storm	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	NR	3.3	3.3	3.3	3.3	NR	1.5	3.3	3.3	3.3	3.3	3.3	3.3	1.5	1.5	1.5
Stout	10[1]	18	10[1]	10	18	NR	10	18	18	18	18	10	18	18	10	0.5	8	18	10[20]	18	18	18	10[1]	4	4	4
SureStart/ Triple FLEX	NY[1]	26B	NY[1]	26B	26B	NR	12	26B	26B	26B	26B	NY	26B	26B	26B	NY[1]	NY	26B	18[1]	18	26B	26B	18	NY	NY	4
Surpass NXT	9	NI	9	NY	NI	NR	NR[10]	NY	NI	NI	NI	NY	NI	NI	NY	NY	NY	NI	NR	NY	NY	NI	NY	NY	NY	4
Surveil	10	30B	30B	9	30B	9	9	9	30B	30B	9	9	30B	30B	9	NR	9	30B	18	10[21]	30B	30B	18	30B	30B	3
Synchrony XP[1]	12	18	12	9	18	9	9	30	30	30	15	9	30	18	9	NR	3	30	18	9[9]	9[9]	18	30	3	3	3
Targa	4	4	4	NR	4	4	4	4	4	4	4	NR	4	4	NR	NR	4	4	4	4	4	4	4	NR	4	NR
Tavium	6	6	9	1.4[1]	12	4	6	6	12	6	6	6	6	6	6	1[1]	4.5	12	4	NY	6	12	6	4.5	4.5	4.5
Treflan	NR	NR	5	NR	5	12-14[33]	12- 14	NR	5	5	NR	NR	NR[9]	5	NR	NR	12-14[33]	5	12-14[33]	5	NR	5	NR	NR	NR	NR
Trivence	10	18	18	18	18	10[1]	18	30	30	30	18	12	30	18	30	NR	18	30	18	18[9]	12[9]	18	30	4	30	4
Ultra Blazer	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	NR	3.3	3.3	3.3	3.3	NR	1.3	3.3	3.3	3.3	3.3	3.3	3.3	1.3	1.3	1.3
Valor SX/ Valor EZ (up to 3 oz)	5[11]	6-12B	5[11]	2[11]	6-12B	0.5-1[1]	1	6-12B	6-12B	6-12B	NR	4	6-12B	6-12B	4	NR	5[11]	12	4	2[11]	6-12B	6-12B	5[11]	4	4	2[11]
Valor XLT[22]	12	18	12	10	18	10	10	18	18	18	18	12	18	18	12	NR	18	18	18	10[9]	12-18[9]	18[1]	18	4	4	4

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Varisto	3	9	18	9	9	8.5[29]	9	NR	9	9	9	NR	9	9	NR	NR	9	9	8.5	9	9	9	9[29]	9[29]	4	3[29]
Verdict	7	7	7	6	7	NR	NR	7	7	7	7	4	7	7	7	NR	4	7	NR	7	7	7	7	4	4	4
Vida	1	1 day	1	NR	1 day	NR	1 day	1 day	1 day	1 day	1	1 day	1 day	1 day	1 day	NR	1 day	1 day	1	1	1 day	1 day	NR	1 day	1 day	NR
Warrant	9	NI	9	NR	NI	NR	NR[10]	NY	NI	NI	NR	SY	NI	NI	NY	NR	NY	NI	NY	NY	NI	NI	NY	NY	NY	4
Warrant Ultra	18	NI	18	1	NI	10	18	NY	NI	NI	10	10	NI	NI	NY	NR	4	NI	10	NI	NI	NI	NI	4	4	4
XtendiMax[1]	4	4	4	1[1]	4	NR	0.5[1]	4	4	4	4	4	4	4	4	1	1	4	4	4	4	4	4	1	1	1
Yukon	9	15	9	4	9	1[8]	2	NI	9	18	6	9	10	9	2	9[1]	2	9	3	NI	2[9]	9	9	2	2	2
Zeus XC	12	NR[9]	12B	18	12B	10	10[1]	12B	12B	12B	4	12B	12B	12B	12B	NR	12	12B	18	NR	NR[9]	12B	12B	4	4	4
Zidua/ Zidua SC (3 oz or 5 fl oz)[1]	10	18	18	4	18	NR	10	11	18	18	4	11	18	18	11	NR	11	18	NR	18	18	18	4	11	11	4
Zone Defense	12	4[34]	4[34]	18	12	10	10	4[34]	4[34]	12	NR	4[34]	12	12	12	NR	12	12	18	1	4[9,34]	4[34]	4[34]	4	4	4

[1] Read the label for additional restrictions due to application rate, timing, geographical region, rainfall, soil pH, tillage, variety, or supplemental labeling.

[2] Eighteen months with a soil pH > 6.5. At rates greater than 2.1 oz/A, a rotation interval of 30 months and a successful field bioassay are required.

[3] Rotation interval for lima bean is 18 months if Armezon PRO is applied at greater than 20 fl oz/A. Rotation interval for pea and snap bean is extended to 18 months if Armezon PRO is applied at greater than 25 fl oz/A.

[4] Cotton can be planted after 12 months where Authority Elite/BroadAxe was applied at rates less than 36 oz/A, Authority MTZ DF at rates less than 17 oz/A, or Authority First/Sonic at rates less than 5 oz/A and the following conditions are met: medium and fine soils, pH < 7.2, and rainfall or irrigation must exceed 15 inches after herbicide application and prior to planting cotton.

[5] Following application of Clarity and a minimum of 1 inch of rainfall or overhead irrigation, a waiting interval of 21 days is required per 8 fl oz/A applied prior to planting cotton, 30 days per pint restriction for soybean, and 20 days per pint restriction for small grains. If less than 1 inch of rainfall or irrigation is received after

application and Status is applied at greater than 5 oz/A, the rotation interval is 4 months.

[6] If Basis rate is 0.33-0.5 oz/A or Basis Blend rate is 1.25 oz/A, alfalfa, sorghum, pea = 18 months; soybean, snap bean = 10 months; STS soybean = 1 month; spring oat = 9 months. If Basis rate is greater than 0.5 oz/A or Basis Blend rate is 2.5oz/A, cotton = 10 months and 18 months if less than 15 inches of rainfall or irrigation occur after application and before the rotational crop is planted. STS soybean = 4 months. If Basis rate is 0.33 oz/A or Basis Blend rate is 0.825, soybean = 0.5 month.

[7] NR for Poast Protected corn hybrids.

[8] NR for IMI (IR/IT) or Clearfield (CL) varieties.

[9] Transplanted.

[10] Use safener with seed.

[11] Cotton may be planted no-till or strip-till after 14 or 21 days when applied at 1 oz/A or 1.5-2 oz/A, respectively. For winter wheat, at rates up to 2 oz/A, the rotation interval is 7 days for no-till or minimum-till wheat and 30 days for conventional-till wheat. At least 1 inch of rainfall/irrigation must occur between application and cotton, field corn, grain sorghum, tobacco, or wheat planting, or crop injury may occur. For alfalfa, clover, potato, and spring oats, the rotation interval is 5 months if the soil is tilled prior to planting or 10 months if no tillage is preformed prior to planting. At lower rates of Valor/Rowel/Chateau, rotation interval for many crops is reduced. Chateau may be applied to potato following hilling at a rate of 1.5 oz/A. Consult labels for more specific information.

[12] Command may be applied preemergence to cotton only if Di-Syston or Thimet insecticides are applied in furrow with the seed at planting.

[13] Corn hybrids that are classified as IMI-corn or as tolerant (IT) or resistant (IR) may be planted in the spring of the year following regardless of rainfall or time interval from chemical treatment to corn planting. Rotation interval varies by tillage type and use rate. Consult the label for specific rotation intervals.

[14] Rotation interval is shorter for STS soybean.

[15] Transplanted tobacco = 10 months if ≤0.3 oz/A.

[16] If Hornet WDG rate is <4 oz/A, snap beans, peas, and some varieties of sweet corn = 10.5 months.

[17] If no more than 2 lb ai applied the previous year.

[18] Regardless of tillage, be sure to plant corn at least 1.5 inches deep and completely cover with soil.

[19] Cotton may be planted 9.5 months following Pursuit if all of the following criteria are met: Pursuit is applied to peanuts only, soil texture is sandy loam or loamy sand only, and greater than 16 inches of rainfall/irrigation is received following application of Pursuit through October of the application year.

[20] The rotation interval for the sweet corn varieties 'Merit', 'Carnival', and 'Sweet Success' is 15 months.

[21] Transplanted tobacco may be planted 10 months after application of 2.1 oz/A of Surveil. Tobacco in seeded nurseries may be planted 18 months after application of 2.1 oz/A of Surveil and following a successful field bioassay. At rates greater than 2.1 oz/A, a rotation interval of 30 months and a successful field bioassay are required.

[22] Rotation intervals based on soil pH < 7.0. In Pennsylvania, rotation interval for clover, lima bean, muskmelon, onion, pepper, spring oat, squash, and white potato is 18, 30, 30, 30, 30, 30, 30, and 30 months, respectively. Consult seed corn agronomist regarding inbred sensitivity to Valor XLT/Rowel FX prior to planting inbred seed corn lines.

[23] If applied after June 1, rotating to crops other than corn (all types) may result in crop injury.

[24] For BOLT or non-BOLT soybean and minimum- or no-till field corn, if Afforia is used on coarse-textured soils such as sands and loamy sands, or on high-pH soils (>7.9), extend time to planting by 7 additional days. For minimum- or no-till wheat in the states of Delaware, Maryland, New Jersey, or Virginia, Afforia may be applied at a minimum of 7 days before planting. Do not use on Durum wheat and do not irrigate between emergence and spike. Wheat must be planted at least 1 inch deep. Do no graze until wheat has reached 5 inches in height. For conventional-till field corn, grain sorghum, cotton, and wheat, at least 1 inch of rainfall/irrigation must occur between application and planting, or crop injury may occur. For alfalfa, cabbage, clover, cucumber, lima bean, muskmelon, onion, pepper, pumpkin, spring oat, squash, sweet corn, tobacco, tomato, watermelon, and white potato, the rotation interval is 4 months if the soil is tilled prior to planting. If no tillage is performed prior to planting these crops, the rotation interval is extended to 8 months.

[25] Rotation interval for spring oat or winter barley at 5.7 oz/A or greater rates is extended to 18 months. For winter wheat, at 5.7 oz/A or greater rates the rotation interval is extended to 6 months.

[26] Seed corn inbred lines vary in sensitivity to herbicides; therefore, users should seek advice from a seed corn agronomist regarding inbred sensitivity to Canopy Blend prior to planting inbred seed corn.

[27] For onion, the rotation interval for irrigated and nonirrigated is 8 and 18 months, respectively.

[28] For corn, if the original corn crop is lost, do not make a second application. Injury may occur to soybean planted the year following application on soils having a calcareous subsurface layer if products containing atrazine were used at rates greater than 0.75 lb/ai atrazine/A in tank mixtures and/or sequentially with Resicore. If Resicore is applied after June 1, rotating to crops other than corn or grain sorghum the next spring may result in crop injury.

[29] NR for Clearfield corn (field and seed). For wheat, planting non-Clearfield cultivars in areas receiving less than 10 inches of precipitation from time of application up until wheat planting may result in wheat injury. Injury potential increases if less than normal precipitation occurs in the 2 months just after Varisto application. For barley, the rotation interval at pH > 6.2 and >18 inches of rainfall/irrigation is 9 months, at pH < 6.2 and <18 inches of rainfall/irrigation and with moldboard plowing the rotation interval is 9 months, and at pH < 6.2 and < 18 inches rainfall/irrigation and without moldboard plowing the rotation interval is 18 months. For potato, the rotation interval at pH > 6.2 and >18 inches of rainfall/irrigation is 9 months and 18 months at pH < 6.2 and <18 inches of rainfall/irrigation.

[30] Rotation information is unknown for this product. Contact manufacturer for recommendations.

[31] In Delaware and Virginia, a Special Local Needs Label 24(c) has approved a 3-month plant-back restriction for soybean after an application to winter wheat.

[32] NR for Enlist varieties.

[33] In areas receiving 20 inches of rainfall or irrigation, 12 months after a spring application or 14 months after a fall application of Treflan 4L or 4EC. Labeled for these crops or after crop plants have emerged.

[34] Rotation is 8 months in no-till.

Herbicide-Resistant Crops

Herbicide-resistant crops are available for use in crop production systems. Corn, soybean, sorghum, alfalfa, and canola varieties are currently the key agronomic crops with herbicide resistance that can be grown in the Northeast. Herbicide resistance in crops results from two different procedures: tolerance selection and genetic engineering techniques. Tolerance selection involves selecting naturally occurring herbicide-tolerant cells from a particular crop cultivar or cell culture and incorporating them into crop varieties and hybrids using traditional breeding techniques. Genetically engineering herbicide-resistant plants (also called a GMO) involves transferring a gene with a certain trait from one organism to another (e.g., from bacteria to plant) using complex technology. The transferred genetic trait or traits are then incorporated into crop varieties using breeding techniques. (The same genetic engineering technology is used to create crop protection to insect pests [e.g., Bt corn].) Several crop protection chemical companies and seed companies are involved in developing and marketing these crops. Following is a brief summary of the herbicide-resistant crop varieties currently available or soon to be released..

Clearfield (CL) corn is non-GMO that was developed by tolerance selection to be resistant to imidazolinone herbicides (e.g., Pursuit, Scepter). Although these hybrids were initially introduced to help manage herbicide carryover, Pursuit and Pursuit-containing products such as Lightning can be applied directly to the CL corn hybrids as part of the weed management program.

Enlist corn, cotton, and soybean are genetically engineered to resist 2,4-D. In addition to 2,4-D resistance, Enlist corn is resistant to the aryoxyphenoxy-propionate herbicides (FOPs), such as Assure II (quizalofop). Enlist corn and soybean are also stacked with Roundup Ready and LibertyLink traits. A new low-volatility 2,4-D formulation (2,4-D choline or Colex-D) has been developed for use with this technology and is available as Enlist One (2,4-D) and Enlist Duo (2,4-D + glyphosate).

Inzen Z herbicide-tolerant sorghum is a non-GMO trait that provides tolerance to certain Group 2 or ALS-inhibitor herbicides. Zest WDG (nicosulfuron) from Corteva is the product that is co-marketed with Inzen Z sorghum.

LibertyLink (LL) corn and soybean are genetically engineered (GMOs) to allow over-the-top applications of Liberty (glufosinate) herbicide. This program provides broad-spectrum control of annual broadleaves and grasses of low-to-moderate pressure. Sequential applications or tank mixtures may be required for new weed flushes and perennials.

Roundup Ready alfalfa, corn, cotton, canola, and soybean were developed using genetic engineering techniques. They have an altered target site not sensitive to glyphosate and allow postemergence applications of glyphosate directly to alfalfa, corn, canola, and soybean. Glyphosate-resistant weeds are a major and growing issue in Roundup Ready crops.

LibertyLink GT27 soybeans are genetically engineered to resist glyphosate, Liberty (glufosinate), and isoxaflutoe (Alite 27). However, Alite 27 is not registered in the mid-Atlantic region.

The STS and BOLT soybean/herbicide systems enhance crop safety from certain sulfonylurea herbicides such as Harmony (thifensulfuron) and Classic (chlorimuron). STS is a non-GMO, but BOLT also includes the GMO glyphosate-resistant trait. Although these varieties were developed to be used in combination with STS-labeled herbicides, they also provide greater safety from many of the ALS (Group 2) herbicides. The BOLT herbicide-resistance trait provides enhanced resistance to additional herbicides such as Basis Blend (rimsulfuron).

Xtend soybean were introduced for the first time in 2017. These soybean are genetically engineered to allow preemergence and over-the-top application of dicamba. Xtend soybean are also Roundup Ready. Three different dicamba products (Engenia, XtendiMax, and Tavium specially formulated for reduced drift are labeled for Xtend soybean. All other dicamba products are not allowed. In addition, a number of stewardship guidelines are required, including using low-drift nozzles, at least 15 GPA carrier, and making applications only when certain environmental conditions exist to reduce the potential for off-site movement. In the Mid-Atlantic region, this technology is best suited for burndown application in no-till for control of winter annual weeds, including horseweed/marestail. Over-the-top application and use in double-crop soybean is not encouraged due to greater concern for off-target movement.

Xtendflex cotton and soybean allow three herbicides to be used over-the-top: dicamba, Liberty (glufosinate), and glyphosate. Three different dicamba products (Engenia, XtendiMax, and Tavium specially formulated for reduced drift are labeled for Xtendflex crops. All other dicamba products are not allowed. Application, stewardship, and other recommendations made in Xtend soybean apply to Xtendflex crops.

Herbicide-Resistant Weeds

A number of weed species that once were susceptible to and easily managed by certain herbicides have developed resistance. These weeds are no longer controlled by applications of previously effective herbicides. As a result of repeated use of a certain type of herbicide on the same land, many different species of weeds have developed resistance to these chemicals. Globally, resistance has developed in all herbicide modes of action in about 262 weed species, and the number of species continues to increase each year. (**More information about herbicide-resistant weeds and herbicide modes of action can be found at weedscience.org.**) It is believed that within any population of weeds, a few plants have sufficient tolerance to survive any herbicide that is used. Since only the survivors can produce seed, it is only a matter of time until the population of resistant weeds (or biotypes) outnumbers the susceptible type.

Depending on the herbicide family and weed species, resistance can occur within five to 20 years. Reasons or mechanisms for resistance vary depending on the herbicide family. Resistant biotypes may have slight structural or biochemical differences at the cellular level from their susceptible counterparts that make them less sensitive to certain herbicides, and therefore they are not killed. Regardless of the mechanism for resistance, becoming familiar with the herbicide mode of action can help when designing programs that prevent the introduction and spread of herbicide-resistant weeds.

Growers, consultants, and those working with herbicides to manage weeds should know which herbicides are best suited to combat specific resistant weeds. The Weed Science Society of America developed a grouping system to help with this process. Herbicides that are classified as the same WSSA group number kill weeds using the same site of action. Therefore, choose a combination of different herbicide sites of action that each contribute to the control of the target weeds. In other words, make sure to have at least two unique sites of action that are effective against the same weed during the season whether in tank mixtures or sequential applications. Tank mixing multiple, effective sites of action is better than sequential applications/rotation of sites of action. Try to avoid using the same products and herbicide sites of action every year. This practice is especially important on weeds that are typically prone to resistance, such as pigweed species, common lambsquarters and common ragweed, horseweed, and foxtail species (**table 3, page 212**).

WSSA group numbers can be found on many herbicide product labels and used as a tool to choose herbicides in different mode of action groups so mixtures or rotations of active ingredients can be planned to manage weeds and resistant species better. Keep in mind that many products contain similar active ingredients even though the products may have different trade or brand names. Using a different product or brand does not guarantee that you are selecting a different herbicide site of action. Refer to **table 1 (page 175)** for herbicide – or WSSA – site of action group numbers and corresponding herbicides. Other resources, such as university pest guides or recommendations, can provide effectiveness ratings of numerous herbicides on many different weed species to help with this process of developing appropriate weed management programs.

Table 3. Weed species prone to resistance and of concern in the Mid-Atlantic region.

	WSSA site of action number (see table 1, page 175)															
	1	2	3	4	5	6	7	8	9	10	11	13	14	15	22	27
Broadleaf species																
Amaranth, palmer		MA	WW	WW	WW				MA				WW	WW		WW
Chickweed, common		MA		WW	WW											
Horseweed/marestail		MA			WW		WW		MA						MA	
Lambsquarters, common		WW			MA				WW							
Pigweed, redroot/ smooth		MA			MA	WW	WW		WW				WW			
Ragweed, common		MA			WW		WW		MA				MA			
Ragweed, giant		WW							WW							
Waterhemp		WW		WW	WW				WW				WW			WW
Grass species																
Barnyardgrass	WW	WW	WW	WW	MA		WW	WW	WW			WW		WW		
Foxtail, giant	WW	MA			MA											
Goosegrass	WW	WW	WW		WW				WW				MA		WW	
Johnsongrass	MA	MA	WW						WW							
Ryegrass, Italian	MA	MA					WW		WW	WW	WW			WW	WW	
Shattercane		MA														

MA: Species confirmed to be resistant to a particular site of action in the Mid-Atlantic U.S.

WW: Species confirmed to be resistant to a particular site of action worldwide.

Dependence on a single strategy or herbicide site of action for managing weeds will increase the likelihood of additional herbicide resistance problems in the future. Management programs to combat herbicide resistance should emphasize an integrated approach. Some management guidelines for an integrated approach include using herbicide tank mixtures containing more than one effective site of action that are active on similar weeds, shorter residual herbicides, crop rotations that allow for application of different herbicide classes, judicious and noncontinuous use of herbicide-resistant crops in a rotation, nonchemical control measures, and combinations of weed management techniques, such as avoiding spreading resistant weed seed with machinery or in manure, and ensiling to help destroy weed-seed-infested forage.

Reducing the risk for developing herbicide-resistant weed populations requires incorporating a number of guidelines in managing fields, including:

- Spray only when necessary.
- Use alternative methods of control whenever possible, such as mechanical cultivation or delayed planting (row crops), mowing (forage crops), and using weed-free crop seeds.
- Rotate crops and their accompanying herbicides' site of action.
- Limit number of applications of herbicide(s) with same site of action in a given growing season.
- Use mixtures or sequential herbicide treatments having different sites of action that will control the weeds of concern.
- Scout fields after herbicide application to detect weed escapes or shifts.
- Clean equipment before leaving fields infested with or suspected to have resistant weeds.