Introduction to
Weeds and Herbicides
There are numerous definitions of a weed. Some common definitions include:

- a plant that is out of place and not intentionally sown
- 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 since 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 may 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, while nature breeds plants for survival.

**Characteristics of Weeds**

There are approximately 250,000 species of plants worldwide; of those, about 3 percent, or 8,000 species, behave as weeds. Of those 8,000, only 200 to 250 are major problems in worldwide cropping systems. A plant is considered a weed if it has certain characteristics that set it apart from other plant species. Weeds possess one or more of the following characteristics that allow them to survive and increase in nature:

- abundant seed production
- rapid population establishment
- seed dormancy
- long-term survival of buried seed
- adaptation for spread
- presence of vegetative reproductive structures
- ability to occupy sites disturbed by humans

**Abundant Seed Production**

Weeds can produce tens or hundreds of thousands of seeds per plant, while most crop plants only produce several hundred seeds per plant. The following are some examples of approximate numbers of seeds produced per weed:

- giant foxtail—10,000
- common ragweed—15,000
- purslane—52,000
- lambsquarters—72,000
- pigweed—117,000

Some weeds, such as pigweed, can produce several hundred thousand seeds per plant under optimal growing conditions.
Since most weeds deposit their seeds back to the soil, seed numbers in the soil increase rapidly from year to year if the weeds are not managed. Despite that many weed seeds are either not viable, eaten by animals or insects, or decompose within several months after they are deposited, hundreds of millions of viable weed seeds per acre can still be present and waiting to germinate.

**Rapid Population Establishment**

Most weeds can germinate and become established relatively quickly. They also produce viable seeds even under environmental and soil conditions that are not favorable for most crop plants. Under ideal conditions, dense weed populations can thrive and easily outcompete a crop if left unchecked. Under poor conditions, certain weeds can adapt and produce some viable seeds in a relatively short time period (6 to 8 weeks).

**Seed Dormancy**

Dormancy is basically a resting stage or a temporary state in which the weed seeds do not germinate because of certain factors. Dormancy is a survival mechanism that prevents germination when conditions for survival are poor. For example, seeds of summer annual weeds will generally not germinate in the fall, preventing them from being killed by cold winter conditions. The various factors that affect dormancy are temperature, moisture, oxygen, light, the presence of chemical inhibitors, tough seed coat, and immature embryos. There are several kinds of dormancy, but the most commonly used terms to describe dormancy are innate, induced, and enforced.

**Induced dormancy** is a temporary dormancy that occurs when a seed is exposed to hot or cold temperatures. It continues after temperatures change and prevents germination during the wrong time of year. The dormancy is broken by temperatures opposite of those that induced it.

Summer heat induces dormancy in summer annual weeds such as yellow foxtail and pigweed, preventing germination in the fall. Cold temperatures in fall and winter break this dormancy (usually by mid-winter), and the seeds germinate in spring when conditions are right. In winter annual weeds, the process is reversed.

Dormancy can be induced in many weed seeds when a crop canopy filters sunlight, shading the ground and reducing germination. Dormancy can be induced over and over again for as long as the seeds remain viable.

**Enforced dormancy** takes place when environmental conditions—cold temperatures, lack of moisture or oxygen, and occasionally a high salt concentration in the soil—are unfavorable. When limitations are removed, seeds germinate freely. Summer annual weed seeds lose their induced dormancy by mid-winter and, if not for the cold temperatures, would germinate at that time.

Seeds of different weed species have various temperature requirements for germination. Common chickweed can germinate under snow cover, while common purslane will not germinate until the soil temperature reaches 70 to 75°F. Crop seeds are generally planted at or near the optimum soil temperature needed for quick germination—a temperature that is also ideal for some weed seeds.

Seeds require water for germination. Seeds in dry soils may remain dormant even when all other factors promoting germination are favorable.

Oxygen availability also influences a seed’s ability to germinate. Water may fill soil pores and exclude air, limiting germination in very wet soils. Soil compaction also may reduce the oxygen supply and prevent seeds from germinating. Deep plowing, tillage, or hoeing can bring buried seeds to the surface, where they readily germinate upon exposure to oxygen.

**Long-Term Survival of Buried Seed**

If conditions are adequate, buried weed seeds have the potential to remain viable for 40 years or more. Broadleaf weed seeds tend to last longer in the soil than grassy weed seeds because they usually have tougher seed coats. In most cases, the majority of seeds only exist in the soil for a few years due to germination, decomposition, predator feeding, or other factors. However, with the large number of seeds produced, a small percentage may remain viable for long-term survival.

**Adaptation for Spread**

Weeds have certain mechanisms for easy dispersal of seeds. Most seeds or seed pods have special structures that allow them to cling, fly, or float. Common cocklebur and burdock seed pods have hooks that attach to animal fur or feathers; curly dock seeds have bladder-like structures that allow them to float; and milkweed, dandelion, and thistle seeds have a feathery pappus that allows them to be carried by the wind. Other weeds, such as jewelweed or snapweed, have pods that “explode” when the seeds are mature, projecting them several feet from the parent plant. Weeds can also be spread when animals or birds eat their fruit and deposit the seeds with their droppings. Weed seeds can be widely spread through crop seeds, grains, feed hay, and straw. These and other human activities probably account for the long-distance spreading of weeds.
Vegetative Reproductive Structures

Most perennial weeds possess special vegetative structures that allow them to reproduce asexually and survive. These perennial structures contain carbohydrates (food reserves, sugars), have numerous buds in which new plants can arise, and include the following:

- **stolons**—aboveground, horizontal stems that root at the nodes (e.g., crabgrass, bermudagrass, ground ivy)
- **rhizomes**—belowground, thickened stems that grow horizontally in the upper soil layers (e.g., quackgrass, johnsongrass, wirestem muhly, Canada thistle)
- **tubers**—enlarged rhizomes with compressed internodes located at the ends of rhizomes (e.g., yellow nutsedge, Jerusalem artichoke, potato)
- **bulbs**—modified leaf tissues for carbohydrate storage that are located at the base of the stem or below the soil line (e.g., wild garlic, onion)
- **budding roots**—modified roots that can store carbohydrates and grow both vertically and horizontally (e.g., hemp dogbane, Canada thistle)

Despite these vegetative reproductive structures, many perennials also reproduce by seed. Some depend heavily on reproduction by seed (e.g., dandelion), while for others it is less important (e.g., yellow nutsedge).

Ability to Occupy Disturbed Sites

Weeds are very opportunistic. When conditions are adequate, weed seeds germinate and colonize if left unchecked. When a site is disturbed, weeds are usually the first to emerge. If a weed becomes established first, it has the competitive advantage over crop plants or desirable vegetation.

Problems with Weeds

Weeds are troublesome in many ways. Primarily, they reduce crop yield by competing for:

- water
- light
- soil nutrients
- space
- CO₂

The following are other problems associated with weeds:

- reducing crop quality by contaminating the commodity
- interfering with harvest
- serving as hosts for crop diseases or providing shelter for insects to overwinter
- limiting the choice of crop rotation sequences and cultural practices
- producing chemical substances that can be allergens or toxins to humans, animals, or crop plants (allelopathy)
- producing thorns and woody stems that cause irritations and abrasions to skin, mouths, or hooves of livestock
- being unsightly, dominant, aggressive, or unattractive
- obstructing visibility along roadways, interfering with delivery of public utilities (power lines, telephone wires), obstructing the flow of water in water ways, and creating fire hazards
- accelerating deterioration of recreational areas, parking lots, buildings, and equipment
- invading exotic weed species that can displace native species in stabilized natural areas

Quackgrass reproduces primarily by shoots from underground rhizomes, but it can also reproduce by seeds.
Costs of Weeds

Weeds are common on all 485 million acres of U.S. cropland and almost one billion acres of range and pasture. Since weeds are so common, people generally do not understand their economic impact on crop losses and control costs. In 2003, it was estimated that the nonuse of herbicides and the likely substitution of alternatives (i.e., cultivation, hand-weeding) would result in a loss of $13.3 billion in food and fiber production. The total impact of herbicide nonuse would be an income loss of $21 billion, which includes $7.7 billion in increased costs for weed control and $13.3 billion in yield losses. In the early 1990s, the estimated average annual monetary loss caused by weeds, with current control strategies in the 46 crops grown in the United States, was over $4 billion. If herbicides were not used, this loss was estimated to be $20 billion. Losses in field crops accounted for over 80 percent of this total. Other sources estimate that U.S. farmers annually spend over $3.5 billion on chemical weed control and over $2.5 billion for cultural and other methods of control. The total cost of weeds in the United States could approach $15 to $20 billion. Weed control and other input costs (e.g., seed, fertilizer, other pesticides, fuel) vary with the crop. For example, in the mid-1990s, herbicides for soybeans cost about $30 per acre, or about half of the total per-acre purchased input. For corn, the cost was about $32 per acre, or about a quarter of the total per-acre purchased input. Weed control costs for wheat are about $6 per acre, or about 5 percent of the total per-acre purchased inputs. A decade later, these costs are about the same. However, in most situations, herbicide use is still the most economical means to control weeds. The USDA estimates that weed control costs for organic vegetable growers in California can be $1,000 per acre in comparison to $50 per acre that conventional growers spend on herbicides. Several factors help determine the relative costs of herbicides from one crop to another, including the competitive ability of the crop, the weeds present, the contribution of nonchemical control practices, the tillage method, management decisions, the type of crop seed used (e.g., normal versus resistant GMO variety), and the value of the crop. Weeds not only cause losses in crops, but also can affect livestock production if poisonous weeds are present or weeds invade and render the pasture useless.

Benefits of Weeds

Despite the negative impacts of weeds, some plants usually thought of as weeds may actually provide some benefits, such as:

- stabilizing and adding organic matter to soils
- providing habitat and feed for wildlife
- providing nectar for bees
- offering aesthetic qualities
- serving as a genetic reservoir for improved crops
- providing products for human consumption and medicinal use
- creating employment opportunities

Weeds have a controversial nature. But to the agriculturist, they are plants that need to be managed in an economical and practical way in order to produce food, feed, and fiber for humans and animals. In this context, the negative impacts of weeds indirectly affect all living beings.
Origins of Weeds

Weeds are found throughout the world. However, all are not common in every region. Since weeds can be easily spread, more and more are being disseminated to places where they were not originally found. Only about 40 percent of the weeds found in the United States are native, while the remaining 60 percent are considered exotic or imported. The following are some examples of weeds and their origins:

- **United States**—common and giant ragweed, common milkweed, fall panicum, common cocklebur, poison ivy, marestail (horseweed), nightshade, wild or common sunflower, and wild onion
- **South America**—pigweed species and prickly sida
- **Europe**—quackgrass, chickweed, Canada thistle, common lambsquarters, common purslane, wild garlic, and yellow foxtail
- **Asia or Africa**—Johnsongrass, wild carrot, giant foxtail, velvetleaf, kudzu, and witchweed

Questions and Answers Regarding Concerns about Nonnative, Invasive Plants


What Are Native Species?

A native species occurs naturally in a particular place without human intervention. Species native to North America are generally recognized as those occurring on the continent prior to European settlement. Nonnative plants are species that have been introduced to an area by people from other continents, states, ecosystems, and habitats. Many non

What Are Invasive Plants?

Invasive plants reproduce rapidly, spread over large areas of the landscape, and have few, if any, natural controls, such as herbivores and diseases, to keep them in check. Many invasive plants share some important characteristics that allow them to grow out of control: (1) spreading aggressively by runners or rhizomes; (2) producing large numbers of seeds that survive to germinate; and (3) dispersing seeds away from the parent plant through various means such as wind, water, wildlife, and people.
How Are Invasive Plants Introduced?

People introduce exotic plants to new areas, on purpose and by accident, through a variety of means. Some species (e.g., kudzu, kochia, multiflora rose, Japanese knotweed, and Johnsongrass) are introduced for use in gardening and landscaping or for erosion control, forage, and other purposes. Others come in unknowingly on various imported products or in soil, water, and other materials used for ship ballast. Many invasive aquatic plants are introduced by dumping unwanted aquarium plants into waterways. Once established in a new environment, some exotic species proliferate and expand over large areas, becoming invasive pests.

How Do Invasive Plants Spread?

Invasive plants spread by seed, vegetative growth (producing new plants from rhizomes, shoots, tubers, etc.), or both. Seeds, roots, and other plant fragments are often dispersed by wind, water, and wildlife. Animals spread invasive plants by consuming fruits and depositing seeds on their feet and fur. People also help spread invasive plants by carrying seeds and other plant parts on shoes, clothing, and equipment and by using contaminated fill dirt and mulch. Invasive aquatic plants are often spread when plant parts attach to boat anchors and propellers.

Why Are Invasive Plants a Problem in Natural Areas?

Like an invading army, invasive plants are taking over and degrading natural ecosystems. Invasive plants disrupt the intricate web of life for plants, animals, and microorganisms and compete for limited natural resources. Invasive plants impact nature in many ways, including growing and spreading rapidly over large areas, displacing native plants (including some very rare species), reducing food and shelter for native wildlife, eliminating host plants of native insects, and competing for native plant pollinators. Some invasives spread so rapidly that they displace most other plants, changing a forest, meadow, or wetland into a landscape dominated by one species. Such “monocultures” (stands of a single plant species) have little ecological value and greatly reduce the natural biological diversity of an area.

Invasive plants also affect the type of recreational activities that we can enjoy in natural areas, such as boating, bird watching, fishing, and exploring. Some invasives become so thick that accessing waterways, forests, and other areas is impossible. Once established, invasive plants require enormous amounts of time, labor, and money to control or eliminate. Invasive species cost the United States an estimated $34.7 billion each year in control efforts and agricultural losses.

How to Prevent Spread of Invasive Plants

Become familiar with invasive plant species in your area (Table 1). When selecting plants for landscaping, avoid using known invasive species and those exotic species exhibiting invasive qualities. Ask for native plant alternatives at your nursery. Obtain a list of plants native to your state from your native plant society, state natural resources agency, or the U.S. Fish and Wildlife Service. If you have already planted invasives on your property, consider removing them and replacing them with native species.

Table 1. List of selected invasive plant species common to the Northeast. For additional information about these and other invasive plants refer to www.invasive.org/eastern/midatlantic.

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<tr>
<th>Aquatic Plants</th>
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<tr>
<td>Eurasian watermilfoil (Myriophyllum spicatum)</td>
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<td>Hydrilla (Hydrilla verticillata)</td>
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<td>Water chestnut (Trapa natans)</td>
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<th>Herbaceous Plants</th>
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<td>Garlic mustard (Allaria petiolata)</td>
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<td>Japanese knotweed (Polygonum cuspidatum)</td>
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<td>Japanese stiltgrass (Microstegium vimineum)</td>
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<td>Purple loosestrife (Lythrum salicaria)</td>
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<td>Giant hogweed (Heracleum mantegazzianum)</td>
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<tr>
<td>Bamboos, exotic (Bambusa, Phyllostachys, and Pseudosasa species)</td>
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<td>Spotted knapweed (Centaurea biebersteinii)</td>
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<th>Shrubs</th>
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<td>Autumn olive (Elaeagnus umbellata)</td>
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<td>Bush honeysuckles, exotic (Lonicera species)</td>
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<td>Japanese barberry (Berberis thunbergii)</td>
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<td>Multiflora rose (Rosa multiflora)</td>
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<td>Privets (Ligustrum species)</td>
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<td>Winged burning bush (Euonymus alata)</td>
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<td>Butterfly bush (Buddleja species)</td>
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<th>Trees</th>
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<tr>
<td>Bradford pear (Pyrus calleryana ‘Bradford’)</td>
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<td>Norway maple (Acer platanoides)</td>
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<td>Tree of Heaven (Ailanthus altissima)</td>
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<th>Vines</th>
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<td>Kudzu (Pueraria montana v. lobata)</td>
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<td>Mile-a-minute (Polygonum perfoliatum)</td>
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<td>Oriental bittersweet (Celastrus orbiculatus)</td>
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<tr>
<td>Porcelainberry (Amelopsis brevipedunculata)</td>
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<tr>
<td>Japanese honeysuckle (Lonicera japonica)</td>
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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. Weeds are also classified by various means. In general, they can be classified by their structure and appearance (for example, 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 annuals 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, downy brome, and annual bluegrass. (Some annual bluegrass subspecies can occasionally function as a perennial.)

Biennials

Biennial weeds grow from seed anytime during the growing season. They normally produce a rosette of leaves close to the soil surface the first year, 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.

Biennials, such as wild carrot, are controlled more easily during their first year of growth.

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, and common pokeweed. Creeping perennials may be either herbaceous or woody and can spread by both vegetative structures as well as by seed. Some common herbaceous perennials include Canada thistle, common milkweed, hemp dogbane, creeping buttercup, slender speedwell, ground ivy, quackgrass, and yellow nutsedge. Some examples of 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 is not as dependent upon seed as the other two weed groups.

For perennial weed control, the best time to either mow or apply an effective herbicide is during the bud to bloom growth stage and/or in the fall.

Common chickweed can be a problem in field crops, gardens, lawns, and many other areas.
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.

**Weed Management Techniques**

**Prevention**

Preventative methods are used to stop the spread of weeds. Preventing the introduction of weeds is usually easier than controlling them after establishment. Preventative practices include cleaning tillage and harvesting equipment of weed seeds and vegetative structures; planting certified, weed-free crop seed; and controlling weeds in barnyards, around structures, and along fencerows, roadways, and ditch banks.

**Cultural**

Cultural and crop management techniques provide a healthy crop to best compete with weeds. Crop competition 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 crop varieties; planting dense crop populations at the proper timing; scouting fields regularly for weeds, insects, and diseases and controlling them when necessary; and including crop rotations 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 unharmed and can germinate if spread back onto the land.

Preventing weed spread includes controlling weeds around barns and along fences, roads, ditches, and woodlands.
Mechanical

Mechanical or physical techniques either destroy weeds or make the environment less favorable for seed germination and weed survival. These techniques include hand-pulling, hoeing, mowing, plowing, diskng, cultivating, and digging. Mulching (straw, wood chips, gravel, plastic, etc.) can also be considered a mechanical control means since it uses a physical barrier to block light and impede weed growth.

Biological

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 that it is a long-term undertaking, its effects are neither immediate nor always adequate, only certain weeds are potential candidates, and the rate of failure for past biological control efforts has been fairly high. There have been a few success stories of weed species being managed with insect or disease biocontrol agents. Herbivores such as sheep and goats can provide successful control of some common pasture weeds. Research continues in this area of weed management.

Chemical

Herbicides can be defined as crop-protecting chemicals used to kill weedy plants or interrupt normal plant growth. Herbicides provide a convenient, economical, and effective way to help manage weeds. 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 one 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.
Herbicides can be classified several ways, including by 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.

Contact herbicides kill only the plant parts contacted by the chemical, whereas systemic herbicides are absorbed by the roots or foliage and translocated (moved) throughout the plant. Herbicide activity can be either selective or non-selective. Selective herbicides are used to kill weeds without significant damage to desirable plants. Nonselective herbicides kill or injure all plants present if applied at an adequate rate.

**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 an 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 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 thus can be grouped into “classes.” Table 2 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 2.
Table 2. Important herbicide groups and examples for agronomic and horticultural crops, turf, forestry, and industrial areas in Pennsylvania.

<table>
<thead>
<tr>
<th>Mode of Action (Class)</th>
<th>Site of Action</th>
<th>WSSA Group</th>
<th>Family</th>
<th>Active Ingredient</th>
<th>Trade Name(s)*</th>
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<tr>
<td>Plant growth regulators (PGR)</td>
<td>IAA like</td>
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<td>phenoxy</td>
<td>2-4-D</td>
<td>Banvel, Clarity, Status, Vanquish</td>
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<td></td>
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<td>2,4-DB</td>
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<td>MCPA</td>
<td>various</td>
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<td>Stinger, Lontrel, Transline</td>
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<td>MCPP (mecoprop)</td>
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<td>benzoic acid</td>
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<td>carboxylic acid (pyridines)</td>
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<td>aminopyralid</td>
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<td>triclopyr</td>
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<td>Garlon, Remedy</td>
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<td>auxin transport inhibitors</td>
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<td>naptalam</td>
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<th>Active Ingredient</th>
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<th>Active Ingredient</th>
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<td>Pigment inhibitors (bleaching)</td>
<td>diterpenes (carotenoid biosynthesis)</td>
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<td>4-HPPD enzyme</td>
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<td>isoxaflutole, mesotrione, tembotrione, topramezone</td>
<td>Balance, Callisto, Laudis, Impact</td>
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<td>Basamid, Aquathol, Krenite, Vapam, Scythe, Matran</td>
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*Only selected trade names appear. Certain active ingredients may have other trade names or be contained in prepackaged mixtures.
**Plant Growth Regulators (PGRs)**

These herbicides 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, strap-like 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 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 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.

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**Amino Acid Biosynthesis Inhibitors**

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. The effect is like that of an assembly line worker not doing his or her job. 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.

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**Fatty Acid (Lipid) Biosynthesis Inhibitors**

These herbicides are rapidly absorbed by grasses and are 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 such as quackgrass, annual and perennial ryegrass, orchardgrass, timothy, and small grains are not as sensitive as the warm-season grasses. Some of these herbicides are weaker on perennial species than other products. They are frequently referred to as “post-grass” 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 pulled out of the whorl. Sensitive grasses commonly turn a purplish color before dying.
Seedling Growth Inhibitors (Root and Shoot)

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 tap-rooted plants, such as soybeans and alfalfa, are usually not affected, nor are established plants with roots more than a couple of 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)

Herbicides in this class are most effective on annual grasses and yellow nutsedge. They are sometimes referred to as “pre-grass” herbicides. 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. Then follows 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, not free flapping (flag like). The leaves of broad-leaved plants turn dark green, become wrinkled, and fail to unfold from the bud. The roots become shortened, thickened, brittle, and club like.

Photosynthesis Inhibitors (Mobile)

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.

Selective herbicides control weeds without causing injury to the crop or other desirable plants.
**Photosynthesis Inhibitors (Nonmobile; “Rapid-Acting”)**

Herbicides in this group have activity on primarily 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**

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. Effected 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**

These herbicides provide control of many annual broadleaves and some grasses. These products are referred to as “bleachers” since they inhibit carotenoid biosynthesis or the HPPD enzyme by interfering with normal chlorophyll formation.

**Injury Symptoms**

Symptoms are very evident and easy to identify. Effected 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**

This herbicide 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; there, 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), a fatty-acid herbicide, 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.
Herbicide Resistance

A number of weed species that were once 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 repeatedly using a certain type of herbicide on the same land, many different species of weeds have developed resistance to these chemicals. Currently, about 225 weed species (more than 400 weed biotypes) worldwide are resistant to about ten different herbicide families. 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 outnumbers the susceptible type. Depending on the herbicide family and weed species, resistance can occur within 5 to 20 years. Certain precautions, such as tank-mixing, crop rotations, and a combination of weed management techniques, must be taken to prevent resistance.

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 (WSSA) developed a grouping system to help with this process. Herbicides that are classified as the same WSSA group number kill weeds using the same mode of action. WSSA group numbers can be found on many herbicide product labels and can be used as a tool to choose herbicides in different mode of action groups so mixtures or rotations of active ingredients can be planned to better manage weeds and reduce the potential for resistant species. Refer to Table 2 (pp. 12–14) for WSSA mode of action group numbers and corresponding herbicides.

Times of Application

The following terms describe herbicides based on when they are applied:

- **Preplant incorporated**: applied to soil and mechanically incorporated into the top 2 to 3 inches of soil before the crop is planted
- **Preplant**: applied to soil before the crop is planted
- **Preemergence**: applied after the crop is planted but before it emerges
- **Postemergence**: applied after crop emergence

Although these terms normally refer to application in relation to crops, they may also imply application in relation to weeds. Always be certain whether reference is being made to the crop or to the weed. In no-till situations, it is possible for an herbicide application to be preplant or preemergence to the crop but postemergence to weeds. Some herbicides must be preplant or preemergence to the weed for maximum activity.

Methods of Application

The following terms refer to the ways herbicides can be applied:

- **Broadcast**: applied over the entire field
- **Band**: applied to a narrow strip over the crop row
- **Directed**: applied between the rows of crop plants with little or no herbicide applied to the crop foliage
- **Spot treatment**: applied to small, weed-infested areas within a field

Product Formulations

Herbicides are not sold as pure chemicals, but as mixtures or formulations of one or more herbicides with various additives. Adjuvants (surfactants, emulsifiers, wetting agents, etc.) or various diluents may increase the effectiveness of a pure herbicide. The type of formulation determines toxicity to plants, uniformity of plant coverage, and stability in storage. Herbicides are formulated to permit uniform and easy application as liquid sprays or dry granules.

Some everyday household products are formulated similarly to herbicide products. These similarities will be noted in the sections below.

**Emulsifiable concentrates (EC or E)** are liquid formulations with an active ingredient that is dissolved in one or more petroleum-based solvents. An emulsifier is added to cause oil to form tiny globules that disperse in water. The formulation then will mix readily with water for proper application. Emulsifiable concentrates usually contain between 2 and 8 pounds of active ingredient per gallon. Dual II Magnum, Pennant, Acclaim, and Prowl are generally emulsifiable herbicide formulations. (Household product with similar formulation—Pine-Sol.)

**Emulsifiable gels (EG or GL)** are herbicides that traditionally are emulsifiable liquids formulated as gels. The gels typically are packaged in water-soluble bags (WSB) and are stable at temperatures ranging from –20 to 50°C. In addition, the gelling process reduces the need for nonaqueous solvents, compared to standard nonaqueous EC-type formulation processes. Currently, few herbicides are formulated as gels.

**Wettable powders (WP or W)** are finely ground, dry particles that may be dispersed and suspended in water. They contain from 25 to 80 percent active ingredient. Suspensions of wettable powders appear cloudy. Wettable powders are nearly insoluble and require agitation to remain in suspension. Atrazine, Kerb, and Dacthal are formulated as wettable powders. (Household products...
Most herbicides are sold in a liquid or dry formulations.

with similar formulation—cocoa mix and flour.)

Soluble liquid (S) and soluble powders (SP) dissolve in water to form a true solution. Once the soluble liquid or powder is dissolved, the spray mixture requires no additional mixing or agitation. Few herbicides are available as solubles because most active ingredients of herbicides are not very soluble in water. 2,4-D amine and Roundup are examples of soluble liquid herbicide formulations. (Household products with similar formulation—grape juice concentrate and Kool-Aid mix.)

Dry flowables (DF), also called water-dispersible granules (WDG or WG) or dispersible granules (DG) are wettable powders formed into prills so they pour easily into the sprayer tank without clumping or producing a cloud of dust. Nearly insoluble, they require agitation to remain in suspension. Many herbicides are now formulated in this fashion. Atrazine, Accent, Gallery, and Pendulum are examples of products formulated as water-dispersible granules. (Household products with similar formulation—grits and dry milk.)

Flowables (F or FL), suspension concentrates (SC), and aqueous suspension (AS) are finely ground, wettable powders or solids already suspended in a liquid carrier so they can be poured or pumped from one tank to another. They usually contain at least 4 pounds of active ingredient per gallon of formulation. Flowables are nearly insoluble in water and require agitation to remain in suspension. Suspension (SE) is a combination formulation of an SC and an oil-based emulsion (E). Atrazine, Princep, and Callisto are formulated as flowables or SCs. (Household products with similar formulation—Pepto-Bismol and V8 vegetable juice.)

Microencapsulated (ME or MT) and capsule suspension (CS) herbicides are encased in extremely small capsules that can be suspended in a liquid carrier and pumped and applied with normal equipment. Microencapsulated formulations are nearly insoluble in water and require agitation to remain in suspension. Micro-Tech, Prowl H2O, and Command are formulated in microcapsules, allowing the active ingredient to be slowly released over a period of time. This extends the soil activity and improves weed control. (Household product with similar formulation—older versions of Contac cold capsules.)

Granules (G) are formulated with a premixed carrier that contains a low percentage of active ingredient. The carrier may be fertilizer, clay, lime, vermiculite, or ground corn cobs. These herbicides are applied directly (dry) to the soil without further dilution. The performance of granulated herbicides compared with that of sprayable formulations varies with the herbicide. Granular forms generally require more rainfall for activation than do sprayable formulations. Granule herbicides are used often in turf and ornamental settings. Some examples include Balan and Ronstar. (Household products with similar formulation—cat litter and Grape-Nuts cereal.)

Pellets (P) are like granules but are compressed into larger cylinders about ¼ inch long. Herbicides formulated as pellets usually contain from 5 to 20 percent active material and are hand-applied to control clumps of brush. They also may be applied with cyclone-type spinner spreaders mounted on helicopters or aircraft to control brush in forests or permanent pastures. Pellets gradually break down from rainfall and leach into the soil for root uptake. Spike is an example of a pelleted herbicide. (Household product with similar formulation—guinea pig/ rabbit pellets.)

Premixes are not formulations, but two or more herbicide active ingredients mixed into one product by the manufacturer. The actual formulation can be any of those discussed above and commonly combines 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.

Trade Name and Formulation Notations

In certain publications, many herbicides are listed by trade name (or product name) and formulation (for example, Roundup 4S or Accent 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. Accent is formulated as a water-dispersible granule with each granule (or certain unit) containing 75 percent active ingredient (nicosulfuron). 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 on the product’s label and MSDS sheet.

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. More than 70 percent of all herbicides recommend using 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 by decreasing photodegradation. These include surfactants (i.e., "surface active agents"), crop oil concentrates, vegetable oil concentrates, wetting agents, stickers-spreaders, N-fertilizers, penetrants, and others. Commonly used surfactants are nonionic surfactants and organosilicones and are typically used at a rate of 1 quart per 100 gallons (0.25 percent v/v) of spray mixture. Crop oil concentrates are 80 to 85 percent petroleum based plus 15 to 20 percent 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 percent v/v) 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/or reduce problems with hard water. Many blended adjuvants are available that include various combinations of special purpose adjuvants and/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.

**Mixing and Applying**

Be aware that improper sprayer calibration, nonuniform application, calculation errors, or use of the wrong chemicals can cause herbicide injury to the crop.

Apply only the recommended amount of herbicide. Slight increases in rates could result in crop injury or leave residues that might injure succeeding crops.

Recalibrate sprayers frequently to adjust for increased output resulting from normal nozzle wear. Be sure there is sufficient agitation in the sprayer tank to prevent settling of wettable powders, dry flowables, or flowables.

Do not stop in the field with the sprayer on, spill herbicide when loading, or dump unused herbicides into anything except a holding tank.

Take the following steps when mixing herbicides:

- Always be sure the sprayer has been calibrated properly for application at recommended rates.
- Calculate the amount of herbicide to add to the sprayer tank based on the active material in each gallon of herbicide concentrate or the percentage of active ingredient of dry herbicide formulation.
- Read and follow the instructions on the manufacturer’s label pertaining to personal hazards in handling.

**Effect of a surfactant on the spread and penetration of spray solution across and through the leaf surface.**

- Fill the sprayer tank with at least half the volume of water or fertilizer solution you will ultimately need.
- Start with moderate agitation and keep it going.
- Add compatibility agents, ammonium sulfate, or other mixing adjuvants, if needed. For maximum benefit, they must be in the solution before herbicides are added. (To determine pesticide compatibility, see the next section.)
- If tank-mixing different types of herbicide formulations and adjuvants, be sure to add them in the following order:
  1. Add, mix, and disperse dry herbicides (wettable powders, dry flowables, or water-dispersible granules). These formulations contain wetting and dispersing agents that aid in mixing.
  2. Add liquid flowables and mix thoroughly. Liquid flowables also contain wetting and dispersing agents.
  3. Add emulsifiable concentrates or microencapsulated herbicides and mix thoroughly.
  4. Finish by adding water-soluble formulations (2,4-D amine, etc.).
  5. Add any adjuvants (surfactants, crop oil concentrates, drift inhibitors, etc.) last. Crop oils, especially, do not mix and disperse well if added first.
  6. Add the remainder of water or liquid fertilizer and maintain agitation through spraying procedure until tank is empty.

**Caution:** Never mix concentrated herbicides in an empty tank. Never allow a sprayer containing mixed chemicals to stand without agitation because heavy wettable powders may clog nozzles or settle into corners of the sprayer tank where they are difficult to remove.
Compatibility

Pesticides are not always compatible with one another or with the water or liquid fertilizer carrier. Lack of compatibility may result in the formation of a gel, precipitate, or sludge that plugs up screens and nozzles. However, extreme incompatibility may produce a settling out of material that can harden like concrete in the bottom of the tank and in hoses, pumps, and other internal parts of the sprayer. The result may be total loss of the pesticide and use of the sprayer.

Herbicides may be combined with liquid fertilizers to minimize trips over the field. However, little information exists concerning the compatibility of herbicides with specific fertilizer solutions. Herbicide-fertilizer solution combinations may form a gel or precipitate that settles to the bottom of the sprayer tank or will not flow through the sprayer equipment. Incompatibility of tank mixtures is more common with suspensions of fertilizers and pesticides.

Tank-mixing several pesticides, although convenient, may create other problems. Foliar activity may be enhanced and could result in crop leaf burn or the reduction in activity of one or more of the pesticides (“antagonism”).

To prevent the main water tank or liquid fertilizer measuring tank from becoming contaminated, commercial applicators may want to mix the herbicides and other ingredients in a separate holding tank. The herbicide mixture is then sucked into the main line as the truck tank is being filled, and thorough mixing is provided by the truck’s agitation system. Compatibility problems are more likely to result when concentrated herbicides are mixed together, so a compatibility test should be done before new mixtures are tried.

Use only labeled tank mixtures or mixtures recommended by experienced scientists whose recommendations are backed by research. For all unlabeled tank mixtures, a jar test for compatibility is strongly recommended. The compatibility of herbicide-fertilizer combinations should be tested before large batches are mixed. In some cases, adding a compatibility agent (Blendex, Combine, Unite, or comparable adjuvant) may aid in maintaining component dispersion.

The following “two-jar test” procedure may be used to test the compatibility of herbicides with one another, or herbicides and other pesticides with liquid fertilizers. Should the herbicide-carrier mixture prove compatible in this test procedure, it may be applied to the field. The following test assumes a spray volume of 25 gallons per acre. For other spray volumes, make appropriate changes to the ingredients.

1. Add 1 pint of carrier (water or liquid fertilizer) to each of two one-quart jars. (Note: Use the same source of water that will be used for the tank mix and conduct the test at the same temperature the spray mixture will be applied.)

2. To one of the jars, add 0.25 teaspoon (1.2 ml) of compatibility agent. To both jars, add the appropriate amount of pesticide(s), in their relative proportions, based on recommended label rates. If more than one pesticide is used, add them separately with dry formulations first, flowables next, and emulsifiable concentrates last. After each addition, shake or stir gently to thoroughly mix.

3. When all ingredients are added, put lids on and shake both jars for 15 seconds and let stand for 30 minutes or more. Then inspect the mixture for flakes, sludge, gels, heavy oil films, or other signs of incompatibility.

- If, after standing for 30 minutes, the components in the jar containing no compatibility agent are dispersed, the herbicides are compatible and no compatibility agent is needed.

- If the components are dispersed only in the jar containing the compatibility agent, the herbicide is compatible only if a compatibility agent is added.
**Herbicide Selectivity**

Were it 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, herbicides would be of little value. Most of the herbicides labeled for use today will selectively remove most of the weeds without injuring the crop. Selectivity is accomplished primarily by two methods: selectivity by placement and true selectivity.

**Selectivity by Placement**

Selectivity accomplished by avoiding or minimizing contact between the herbicide and the desired crop is called selectivity by placement. 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 also is 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.

**True Selectivity**

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 crop injury.

Morphological differences include plant characteristics such as size and orientation of the leaf, waxiness or hairiness of the leaf surface, location of the growing point, and rooting depth. Generally, the more waxy or hairy the leaf surface, the more difficult it is for a foliar-applied herbicide to penetrate. The more protected the growing point (as in grasses), the less likely it is that foliar herbicides will reach the growing point. The more deeply rooted the crop is, the more difficult it is to get a soil applied herbicide to the crop roots and the less likely that there will be sufficient uptake for injury.

Physiological differences can include various processes that affect the activity and/or the breakdown of the herbicide. In certain situations, herbicides may be transported differently across the plasma lemma,

- translocated differently within the plant,
- combined with some component within the cell wall,
- integrated with something in the cell cytoplasm, or
- channeled into “sinks” where the herbicide will have no effect.

These factors all can contribute to tolerance, but any one factor will seldom provide tolerance by itself.

Metabolic factors include genetic insensitivity due to an altered site of herbicide action that prevents herbicide activity. For example, Roundup Ready soybeans produce an excess of the enzyme that glyphosate (Roundup) normally inhibits, so Roundup Ready soybeans are not affected, even though normal amounts of the herbicide are absorbed by the crop plant. Corn plants metabolize and convert atrazine to an innocuous metabolite so rapidly that the herbicide does not have time to inhibit photosynthesis, which provides crop tolerance as long as the metabolic system is not overwhelmed by an excess of the pesticide or a combination of pesticides. In the case of corn treated with an organophosphate insecticide and followed with a post treatment of Accent, Beacon, or some other ALS-inhibiting herbicide, both the insecticide and herbicide are being metabolized by the same pathway. This pathway is unable to rapidly metabolize both the herbicide and insecticide, so corn injury may result. Metabolic insensitivity and/or the ability to metabolize the herbicide usually are the best types of true tolerance.

**Safe Herbicide Use**

Use herbicides only when necessary, only at recommended rates and times of application, and only for those crops and uses listed on the label. Correct use is essential to ensure that chemical residues on crops do not exceed the limits set by law. Recommended herbicides do not generally injure people, livestock, wildlife, or crops if used properly and if recommended precautions are observed. However, any herbicide is potentially dangerous if improperly handled or used.

Follow these basic pesticide safety procedures:

- Make sure that you are familiar with current federal and state pesticide laws and regulations and that you have a license, if required.
- Avoid drift of spray or dust that may endanger other crops or animals. Cover feed pans, troughs, and watering tanks in livestock areas; protect beehives.
- To protect yourself and others, follow all safety precautions on the label. Know and observe the general rules for safe pesticide use, and record the date, time, location, and amount of each pesticide used.
- Wear protective clothing and use protective equipment according to instructions on the pesticide label.
- Never eat, drink, or smoke while applying pesticides.
- Avoid spilling spray materials on skin or clothing. If such an accident occurs, wash immediately with soap and water.
Bathe after applying pesticides and change into freshly laundered clothing. Wash clothing after applying pesticides, keeping in mind that, until laundered, such clothing must be handled according to the same precautions as the pesticide itself. Wash pesticide-contaminated clothing apart from other laundry, and take care in disposing of the wash water.

Store pesticides in their original containers in a locked, properly marked cabinet or storeroom, away from food or feed.

Do not store herbicides with other pesticides; avoid the danger of cross-contamination.

Be sure to triple-rinse all empty containers before recycling (in a special recycling program only through the Pa. Dept. of Agriculture; this is different from typical household curbside recycling programs) or disposing of them in an approved landfill.

If you suspect poisoning, contact your nearest Poison Control Center, hospital emergency room, or physician. Take the pesticide label and, if possible, the MSDS sheet with you and give it to the attending physician.

Livestock
When used properly and in accordance with the use restrictions on the product’s label, herbicides sprayed on plants usually are not toxic to livestock. Animals can be poisoned by consuming unused herbicides left in open containers or by drinking water contaminated with herbicides.

Certain unpalatable or poisonous plants treated with herbicides may become more attractive as forage to livestock. Make sure livestock cannot get to poisonous plants that have been sprayed with herbicides.

The nitrate content of several kinds of weeds may increase after they have been sprayed with 2,4-D, Clarity, or similar herbicides. Livestock grazing on these treated plants may become ill. Remove all animals from sprayed areas for several days, or until it has rained or the weeds have died.

Game and Fish
Controlled spraying may benefit wildlife by maintaining desirable cover. Herbicides recommended for control of aquatic weeds usually have beneficial results for fish populations. Be sure to properly apply these herbicides. Do not drain or flush equipment where chemicals may wash into ponds or streams, and do not leave open containers where curious animals might find them.

Crop Safety
Farmers are occasionally concerned about possible herbicide injury to crops. Most injuries of this kind are caused by misuse, contaminated equipment, or drift. Unfavorable weather conditions combined with herbicide residues from a previous crop planting can potentially injure crops.

Cleaning Contaminated Equipment
Sprayer cleanout is necessary to prevent crop injury from spray contamination and to preserve the life of the sprayer. Cleaning is very important, especially when using a sprayer in different types of crops. Many herbicides, even at low concentrations, may have the potential to injure crops for which they are not labeled. Sprayers used to apply 2,4-D-type herbicides can be used to apply other chemicals before crops are planted or before crop plants emerge, but this equipment must be thoroughly cleaned before applications are made on emerged crops (except grasses). Ester formulations are harder to remove than amine or salt formulations.

The following cleaning procedure is recommended for all herbicides unless the label specifies a different cleaning procedure:

1. Add one-half tank of fresh water and flush tanks, lines, booms, and nozzles for at least 5 minutes using a combination of agitation and spraying. Rinsate sprayed through the booms is best sprayed onto croplands to avoid accumulation of pesticide-contaminated rinsate. Thoroughly rinse the inside surfaces of the tank, paying particular attention to crevices and plumbing fixtures.

2. Fill the tank with fresh water and add one of the cleaning solutions below, or a commercially available tank cleaner, and agitate the solution for 15 minutes. Add one of the following to each 50 gallons of water to make a cleaning solution: (a) 2 quarts of household ammonia (let stand in sprayer overnight for growth regulator herbicides such as 2,4-D and Clarity) or (b) 4 pounds of trisodium phosphate cleaner detergent. Operate the spray booms long enough to ensure that all nozzles and boom lines are filled with the cleaning solution. Let the solution stand in the system for several hours or overnight. Agitate and spray the solution onto an area suitable for the rinsate solution.
3. Add more water and rinse the system again by using a combination of agitation and spraying. Remove nozzles, screens, and strainers and clean separately in a bucket of cleaning agent and water.

4. Rinse and flush the system once again with clean water.

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**Drift**

Drift is the movement of any pesticide through the air to areas not intended for treatment. During application, droplet or particle drift occurs as spray droplets or dust particles are carried by air movement from the application area to other places. Vapor drift takes place after application as herbicides evaporate (volatilize) and yield fumes (gases) are carried on wind currents and deposited on soils or plants in untreated areas.

Drift may injure sensitive crops, ornamentals, gardens, livestock, wildlife, or people and may contaminate streams, lakes, or buildings. It may contaminate crops and cause illegal or intolerable residues. Excessive drift may mean poor performance in the desired spray area because the application rate is lower than expected.

Highly active chemicals present the greatest drift hazard because extremely small amounts can cause severe problems. For example, growth regulator herbicides such as 2,4-D, dicamba, and picloram at a rate of 1 ounce per acre can deform sensitive crops such as tobacco, grapes, or tomatoes.

Vapor drift from Command (clomazone) that has not been incorporated can cause bleaching of chlorophyll in sensitive plants within a quarter mile of application. Vapor drift problems can often be avoided by using nonvolatile formulations. Essentially, no vapor drift hazard is involved in the use of amine formulations of 2,4-D. Soil incorporation of Command and a microencapsulated formulation greatly reduces vapor loss of this herbicide.

Particle drift depends on the size of the particle or droplet, and droplet size depends on pressure and nozzle design. Very small particles of fog or mist present the greatest drift hazard. To minimize particle drift, calibrate equipment to create droplets about the size of light rain. Most nozzles can be adjusted to a pressure that permits droplet formation as a result of surface tension. If nozzles are operated at this pressure, a minimum of mist-sized droplets will be formed. For some nozzles, this pressure may be as little as 15 psi; for others, it may be 30 psi.

The distance particles will drift increases with the height of release. Wind velocities usually are lower close to the ground. Therefore, sprays should be released as close to the soil surface or vegetation as adequate coverage permits.
Drift hazard usually is minimized if prevailing winds are blowing away from sensitive crops, but a sudden shift in wind direction could result in serious damage. If possible, do not apply pesticides when wind speed is greater than 5 mph.

High temperatures increase the loss of volatile herbicides. Esters of 2,4-D rapidly evaporate at temperatures above 800°F. The use of such ester formulations should be restricted to fall, winter, and early spring because sensitive plants are not present and lower temperatures reduce vapor drift hazard.

Drift control should be considered with each pesticide application. You can prevent severe drift problems by
- using sprayer nozzles especially designed for drift reduction;
- using low volatile or nonvolatile formulations;
- using low spray-delivery pressures (15–30 psi) and nozzles with a larger orifice;
- using drift-inhibiting adjuvants in the spray mixture when spraying under less-than-ideal conditions;
- using nozzles that allow for lowered boom height;
- avoiding application of volatile chemicals at high temperatures;
- spraying when wind speed is low (less than 5 mph) or when the wind is blowing away from areas that should not be contaminated;
- spraying during the early morning or evening hours when there is usually less wind;
- leaving border areas unsprayed if they are near sensitive crops.

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**Evaluating Herbicide Injury**

Insects, diseases, severe weather (hail, lightning, drought, flooding), fertilizer burn, and nutrient deficiencies are among the causes of symptoms often attributed to herbicide injury. Cool, wet weather can increase the potential for injury, particularly with preemergence herbicides. When evaluating crop injury, careful consideration of the following will help you diagnose the problem:

1. **What is the pattern in the field of plant injury or uncontrolled weeds?**
   - A pattern of injury that starts on one side of an area and diminishes gradually and uniformly away from that area is typical of application drift.
   - A pattern of injury occurring in irregular patches that follow air drainage could indicate herbicide volatilization and movement of vapors.
   - Strips of injured areas or surviving weeds at predictable intervals indicate possible skipping or overlapping application.
   - Poor control at the edges of a field can result from only half coverage by the last nozzle on the boom and/or more sunlight availability along the edge of the field.
   - Injury limited to the end rows or ends of the field is usually due to overlapping applications or high herbicide rates in the turnaround areas at the ends of the rows.
   - A definite break between the normal or uninjured part of the field and the rest of the field usually indicates some major difference in soil type or pH between the two sides.
   - A pattern of obvious overapplication as indicated by bare ground (both crop and weeds killed), followed by improved crop survival and appearance with good weed control, followed by lack of crop injury or weed control, indicates inadequate or poor agitation in the sprayer tank. The evidence is even stronger if this pattern repeats itself at intervals that correspond to each new load.

2. **What is the history of the problem area—fertility program, cropping sequence, land preparation, soil pH, soil texture and organic matter, and seed source?**

3. **What was the temperature, moisture, rainfall, and prevailing wind at and immediately following herbicide application?**
**Persistence**

The residual life or length of time an herbicide persists in the soil is the length of time it can be expected to control weeds. Residual toxicity, if not considered, may injure the next crop planted in a herbicide-treated field.

Inactivation, breakdown, and disappearance of herbicides are influenced by the following factors.

**Microbial Degradation**

Microorganisms feed on all types of organic matter, including organic herbicides. Microbial degradation is the primary means of herbicide breakdown. Some herbicides are more readily attacked by microorganisms than others, often because of minor differences in chemical structure that permit rapid decomposition in some cases and block decomposition in others. Soil temperature, aeration, pH levels, organic matter, and moisture levels favorable for microbial growth promote rapid herbicide breakdown. Microbial degradation takes place primarily in the top foot of soil, where microbial activity is the greatest.

**Chemical Degradation**

Herbicides may be inactivated upon reaction with salts, acids, and other substances in the soil. These reactions are affected by the same environmental factors that influence microbial breakdown. Chemical degradation can occur anywhere in the soil profile and is the primary process responsible for herbicide dissipation below the top foot of soil, where microbial activity is limited or nonexistent.

**Runoff**

Water moving over the surface of a field or treated area can carry herbicide with it. The greatest loss of herbicide occurs when the herbicide is applied to the soil surface and is washed off by the first rain after application. If the herbicide is incorporated or leached into the soil with light rains or irrigation, most loss occurs only with erosion after the herbicide is adsorbed to soil particles.

**Leaching**

Water carries herbicides into and ultimately out of the root zone. The portion lost to leaching depends on soil texture, herbicide solubility, and amount and intensity of rainfall. As a rule, herbicides leach most from sandy soils and least from clay soils or soils high in organic matter.

**Adsorption**

After application, herbicides may become adsorbed (bound) to clay and organic matter particles. The extent of adsorption increases as the percentage of organic matter and/or clay increases. Adsorption reduces the amount of chemical available to plants and slows leaching. Herbicides are then degraded by various means.

**Volatilization**

Some herbicides may be rapidly lost as vapors after application. Loss as vapor reduces the persistence of dinitroaniline and thiocarbamate herbicides and Command. The rate of vapor loss is influenced by soil moisture, temperature, and adsorption. Evaporation of herbicides increases as sand content, soil moisture, and soil temperature increase. Incorporation into soil immediately after application reduces this kind of loss.

**Photodecomposition**

Sunlight may inactivate herbicides—a factor that may contribute to a decline in effectiveness of unincorporated herbicides such as trifluralin (Treflan) and benefin (Balan). Exposure to light for two or more hours reduces the effectiveness of trifluralin and related herbicides and can be avoided by soil incorporation.
Plant Uptake
Herbicides may be absorbed by plant roots or leaves and inactivated within the plant. This effect generally accounts for a relatively small amount of herbicide removal.

Crop Removal
If a crop is harvested or removed from the treated area before rain has washed the herbicide off the foliage or before the plant has had time to metabolize the residue, the herbicide will be removed with the crop. This seldom happens because herbicides are not commonly used close to harvest. However, if grass clippings are collected shortly after treatment and used to mulch a garden, there may be enough herbicide on the grass to damage the garden plants.

Toxicity
Toxicity usually is measured as LD₅₀ (lethal dose), which is the amount of a toxicant required to kill 50 percent of the test animals. The lower the LD₅₀, the less pesticide it takes to kill the animal. As with any chemical, whether naturally occurring or synthetic, it is “the dose that makes the poison.” Below is a list of the most commonly available herbicides, as well as other commonly used substances, in order of decreasing oral toxicity.

Highly Toxic Herbicides (LD₅₀ < 50 mg/kg)
The probable lethal dose of a highly toxic herbicide for a 150-pound person is a few drops to 1 teaspoon. The label contains the signal words “Danger/Poison” and has a skull and crossbones.

metham (Vapam)
sodium arsenite

Moderately Toxic Herbicides (LD₅₀ = 50 to 500 mg/kg)
The probable lethal dose of a moderately toxic herbicide for a 150-pound person is 1 teaspoon to 1 ounce. The signal word on the label reads “Warning.”

bromoxynil (Buctril)
caffeine
copper sulfate (bluestone)
difenzoquat (Avenge)
diquat
endothall (Aquathol, Des-i-cate)
gasoline
kerosene
nicotine
paraquat (Gramoxone)

Slightly Toxic Herbicides (LD₅₀ = 500 to 5,000 mg/kg)
The probable lethal dose of a slightly toxic herbicide for a 150-pound person is 1 ounce to 1 pint or 1 pound. The signal word on the label reads “Caution.”

aspirin
ethy alcohol
sodium chloride (table salt)
acetochlor (Harness, Topnotch)
acifluorfen (Blazer)
alachlor (Micro-Tech, Lasso)
ametryn (Evik)
atrazine (various)
bensulide (Betasan)
bentazon (Basagran)
butylate (Sutan+)
CAM (various)
clodinafop-propargyl (Discover)
cloazine (Command)
clopyralid (Stinger, Transline)
cloridazon (Pyramin)
cycloate (Ro-Neet)
2,4-D (various)
2,4-DB (Butyric 200, various)
2,4-DP, dichlorprop (various)
dicamba (Banvel, Clarity, Vanquish)
dichlobenil (Casoron)
diclofop-methyl (Hoelon)
dimethenamid (Frontier, Outlook)
diuron (Karmex)
DSMA (various)
EPTC (Eptam, Eradicane)
fenoxaprop-P-ethyl (Acclaim, Puma)
fluazifop-P-butylic (Fusilade)
flufenacet (Define)
glufosinate (Liberty, Finale, Rely)
hexazinone (Velpar)
linuron (Lorox)
MCPA (various)
MCPB (Thistrol)
MCPP, mecoprop (various)
metolachlor (Dual, Pennant)
methribuzin (Sencor, Lexone)
molinate (Ordram)
MSMA (various)
pebulate (Tillam)
pinoxaden (Axial)
prometon (Primatol)
prometryn (Caparol)
propachlor (Ramrod)
propanil (Stam, Stamped)
pyridate (Tough)
quizalofop-P-ethyl (Assure II)
Almost Nontoxic Herbicides
(\(LD_{50} > 5,000\) mg/kg)

The probable lethal dose of an almost nontoxic herbicide for a 150-pound person is more than 1 pint or 1 pound. The signal word on the label reads “Caution.”

Asulam (Asulox)
Benefin (Balan)
Bensulfuron-methyl (Londax)
Bromacil (Hyvar X)
Chlorimuron-ethyl (Classic)
Chlorsulfuron (Glean, Telar)
Clethodim (Select)
DCPA (Dacthal)
Desmedipham (Betanex)
Dithiopyr (Dimension)
Ethalfluralin (Sonalan)
Ethofumesate (Prograss)
Flucarbazone (Everest)
Flumetsulam (Python)
Flumiclorac (Resource)
Flumeturon (Cotoran)
Fomesafen (Flexstar, Reflex)
Foramsulfuron (Option)
Fosamine (Krenite)
Glyphosate (Roundup, Touchdown, Rodeo, various)
Halosulfuron (Permit, Sempra)
Iodosulfuron (Autumn)
Imazamethabenz (Assert)
Imazamox (Raptor)
Imazapic (Cadre, Plateau)
Imazapyr (Arsenal, Chopper)
Imazaquin (Scepter, Image)
Imazethapyr (Pursuit)
Isoxaben (Gallery)
Isoxaflutole (Balance)
Lactofen (Cobra)
Metsulfuron-methyl (Cimarron, Escort)
Mesotrione (Callisto)
Napropamide (Devrinol)
Niclosulfuron (Accent)
Norflurazon (Zorial, Soltam)
Oryzalin (Surflan)
Oxadiazon (Ronstar)
Oxyfluorfen (Goal)
Pendimethalin (Prowl, Pendulum)
Prodiamine (Barracade)
Picolorm (Tordon)
Primisulfuron-methyl (Beacon)
Promamide (Kerb)
Prosulfuron (Peak)
Rimsulfuron (Matrix, Resolve)
Siduron (Tupersan)
Simazine (Princep)
Sodium borated
Sulfometuron-methyl (Oust)
Sulfosulfuron (Maverick)
Thifensulfuron-methyl (Harmony GT)
Triasulfuron (Amber)
Trifluralin (Treflan)
Tribenuron-methyl (Express)

Dermal response:
a. Absorbed and poisonous
b. Causes burns and blisters
c. Moderately irritating
d. Mildly irritating

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An Outreach program of the College of Agricultural Sciences

Penn State College of Agricultural Sciences research and extension programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

This publication is available from the Publications Distribution Center, The Pennsylvania State University, 112 Agricultural Administration Building, University Park, PA 16802. For information telephone 814-865-6713.

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Produced by Ag Communications and Marketing

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Code UC175 Rev5M10/13