Industrial Weed Control

Category 7C

K·STATE
Research and Extension

IPM
INTEGRATED PEST MANAGEMENT
& PESTICIDE SAFETY EDUCATION

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

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Using this Manual

This is a self-teaching manual. At the end of each major section is a list of study questions to check your understanding of the subject matter. These questions represent the type that are on the certification examination. By studying this manual and answering the study questions, you should be able to gain sufficient knowledge to pass the Kansas Commercial Pesticide Applicators Certification examination. Correct answers appear on page 72.

Why Control Vegetation

The nation's rights-of-way and industrial areas provide for the flow of goods and services vital to the American economy. They include lands set aside across the country for roadside, electric utility, railroad, storage yards, and pipelines totaling more than 20 million acres. Because rights-of-way enable people to access supplies and services, most right-of-way and industrial acres are located in heavily populated areas in the eastern U.S.

Reliability and public safety across all rights-of-way and industrial areas are major concerns that call for controlling selected types of vegetation. Management enables workers to perform their jobs without hazards for those who use or depend on rights-of-way. Visibility along roadways and railroads, maintenance of road surfaces and railroad tracks, and the proper functioning of utility substations and drainage ditch banks all depend on proper vegetation management. Common objectives include motorist and worker safety, reduced fire hazards, and the ability to perform inspections though there are many other issues unique to the situation.

Most rights-of-way and industrial weed managers have to contend with noxious weeds. Many states declare certain plants to be noxious weeds because of detrimental effects on public health, agricultural crops, natural ecosystem function, or animal production. In many cases, state law requires control. If the agency or company responsible for the property does not control these weeds, local governments can hire an outside group to do the work and charge the negligent party. If a state has established a list of noxious weeds, applicators should know and be able to identify these weeds at various stages of growth.

Roadsides

Maintainence of the the areas between the edge of the pavement and the outside boundary of roadside rights-of-way improves safety for motorists. These areas may be natural or installed to improve safety such as the median strips on multilane highways and interchange areas. Roadside vegetation control addresses safety concerns, road structure maintenance, and appearance or beauty (aesthetics). Safety requirements ensure a safe recovery or clear zone, sign visibility, and sight distance. Vegetation control improves drainage and snowdrift control, slows roadbed degradation, reduces erosion and fire hazard, and extends the life of roadside hardware. Vegetation control enhances the beauty of roadsides.

Safety Recovery Zone

When vehicles accidentally leave the road, they need a place to stop. This area is called the safety recovery zone or clear zone. Roads designed for travel at higher speeds and greater traffic density need wider safety recovery zones than roads designed for travel at slower speeds and less traffic. Slopes that are excavated or cut out (cut slopes) require narrower safety recovery zones than flat areas. Steep slopes created by filling (steep fills) require the widest safety recovery zones (Figure 1). A clear area beyond the edge of the slope is desirable as vehicles may continue to the bottom of a steep slope after leaving the road. Likewise, a wider recovery zone is needed at curves where cars are likely to leave the road at a sharper angle.

Figure 1. The safety recovery zone is an integral part of highway design.

Trees in the safety recovery zone are a major concern because they are the greatest cause of fatalities when vehicles leave the road and collide with fixed objects. Regulations on the size and height of trees permitted in the recovery zone differ by state, ranging from no trees at all to trees less than 4 inches in diameter at 1 foot above the ground. Shrubs that do not block visibility usually are acceptable. A vehicle can be funneled along the ditch bottom or onto the backslope after leaving the roadway, so there should be no trees in or near the bottom of a ditch or on the backslope near the ditch.

Sign Visibility

Signs along roadsides must be visible at all times of the day and during all seasons or weather conditions (Figure 2). Signs convey warnings, guidance, and information. They are an important part of road safety and can prevent accidents and driver confusion. Hidden signs that obscure the message can create a safety hazard. Vegetation near the sign or between the sign and the point on the road where the driver should see it is undesirable.

Figure 2. Signs should be visible for traffic safety and driving convenience. Photo: Michelle Wiesbrook

Sight Distance

Sight distance describes how much of the road ahead is visible to the driver. Clear sight distance is necessary for stopping and making decisions about turning, changing lanes, passing, and entering the roadway. As speed increases, greater sight distance is needed. Vegetation has the greatest effect on sight distance on two-lane, rural highways. Sight distance is often limited by hills and curves, and can be blocked by vegetation at intersections and nearing curves (Figure 3). During snow and ice storms, overhanging limbs become heavier, reducing sight distance more than usual.

Figure 3. Trees obstructing the view of the roadway.

Many drivers have difficulty with depth perception on the right side of the vehicle. Vegetation encroaching from the shoulders often forces or directs drivers toward the center of the road on two-lane highways and can reduce driver safety. Encroaching vegetation has the greatest effect on driver behavior when weeds occur in short, isolated sections as compared to long, continuous stretches. Tall vegetation and overgrown shrubs should be kept far enough from the roadside to keep them from influencing driver behavior.

Drainage

Vegetation growing on the road shoulder and in ditches may prevent water from draining off the road rapidly (Figure 4). Water on the road surface can cause automobile hydroplaning and ice patches to form in the winter. Water speeds breakdown of pavement and road surfaces by softening subgrades and shoulders, which lose their ability to support the road, and depositing sediment in ditches and drainage structures. Plant material left behind after mowing can block drainage inlets, particularly during heavy rains when drainage is most critical. Weeds growing around or over inlets can slow drainage. These areas should be kept free of weeds.

Figure 4. Control of tall weeds along the roadside helps move water off the highway.

Tall and thick stands of plants such as trees, ragweeds, and cattails reduce water flow in drainage ditches by catching and holding debris. Low-growing grass is desirable because it controls erosion with minimal interference of flowing water. Grass buffers act as biofilters by trapping sediment. Vegetation control promotes rapid drainage and often improves the appearance of the ditch. Shoulders should be kept free of weeds to prevent drainage problems and damage to the roadway pavement as a result of shoulder deterioration. Weeds in the shoulder restrict subgrade drainage, softening the soil. The internal pumping action of the drainage causes sorting of the aggregate or base, and the road loses its weight-bearing capability. The gravel shoulder should be kept free of weeds, so it is clearly defined for the motorist.

Surface Degradation

Weeds can destroy paved shoulders by growing through cracks and speeding deterioration. Once established in the crack where the shoulder meets the road surface, roots or creeping rhizomes can pierce the road surface. Shaded road surfaces dry slower, and ice and snow take longer to melt. Water reduces the life of the surface, especially asphalt.

Snow Drift Control

Snowdrifts occur on the downwind side of any obstacle that slows the wind. Tall vegetation, either trees or weeds, can cause drifts as the snow piles up behind the vegetation. Fences, barriers, median plantings, and guide rails clogged with weeds or overgrown vines can cause snow to drift. Narrow bands of vegetation upwind from the road and downwind from wide-open spaces increase the amount of snow on the road. In areas susceptible to drifting snow, it is important to control vegetation some distance from the roadside because the vegetation can impact the roadway and contribute to snow drifts 15 to 20 times its height.

Fire Hazard Reduction

Fires can occur when vehicles pull off the road. Hot catalytic converters and mufflers can ignite dry vegetation. In regions where plants complete their life cycle at the onset of drought — particularly annual grasses such as wild oats and cheatgrass in the western U.S. — weed-free areas wider than normal road shoulders should be maintained to allow vehicles to pull off the road without igniting a fire (Figure 5).

Figure 5. Roadside fires can cause serious problems in dry areas. Photo: Brice Gibson

Erosion Control

Soil stability is important to the maintenance of roadbeds and surfaces. Dense vegetation is effective in reducing erosion. However, vegetation growing at the road's edge can prevent water from draining off the road after a rain. Water that does not run off the road often collects or flows on the pavement. The flowing water gains force and eventually breaks over the edge with the increased water pressure causing erosion of the shoulder. Weed dams can be a problem, particularly under guide rails where machine grading is not possible.

Roadside Hardware

Controlling weeds around roadside hardware such as guide rails, posts, delineators, metal inlets, and drains extends the hardware's usefulness. Weeds growing over and around roadside hardware hold moisture that causes rust and deterioration.

Appearance

Roadsides are highly visible to the public. Vegetation management enhances the appearance of the roadside and delineates the road for motorists (Figure 6). The appearance of the roadside varies — from rough turf to manicured lawns, and from planted flowers to native vegetation. Although there is a cost associated with the establishment of native wildflowers, the presence of native plants can reduce other maintenance costs and increases the aesthetic value for the motoring public. Managing roadsides to meet the requirements of native vegetation helps to maintain their dominance. When roadside vegetation management meets the functional requirements for transportation (safety recovery, sight distance, sign visibility) the improved appearance is an extra, low-cost benefit.

Figure 6. Vegetation management improves appearance and road delineation. Photo: Frannie Miller

Electric Utility

Electric utilities control vegetation to keep electricity flowing through the conductors, allow inspection of the infrastructure, to ensure emergency access and maintain equipment operation.

Conductor Clearance

Tall growing trees, such as oaks and maples, may interfere with electric transmission and distribution. Trees that touch the electrical conductors create a safety hazard for the public, especially for children who could encounter the conductors by climbing the trees, or people working to remove the tree (Figure 7).

When trees touch the conductors, electricity is rerouted into the ground causing temporary power outages. These interruptions may cause household electrical appliances to malfunction. When a tree or limb breaks and falls on electrical wires, prolonged outages can occur. Vines that climb poles and guy wires can cause outages and may pose a risk to public safety.

Figure 7. Trees and people should not touch electric conductors. Photo: Cheryl Irwin

Structures

Both wooden and steel structures should be free of vegetation so structures and conductors can be inspected for preventive maintenance (Figure 8). Inspections can be performed from the air (helicopter) or the ground. Vegetation should be cleared from structures to allow for maintenance and repair.

Figure 8. Structural inspection and maintenance is made easier with vegetation control.

Emergency Line Service

Electrical rights-of-way and industrial areas need to be free of large vegetation to provide access to crews performing emergency line service. Lines free of overhanging vegetation are less likely to be taken down during storms because the limbs do not fall on the transmission and distribution lines.

Substations and Storage Yards

Total weed control is important in substations and storage yards to prevent short circuits (when trees touch conductors) and prolonged outages, which can occur when broken limbs fall on electrical wires (Figure 9). Vegetation poses a fire hazard, harbors insect pests and rodents, disrupts the equipment in substations, and creates an aesthetic problem. These areas should be kept weed-free to prevent employees from tripping and falling while working with the electrified equipment.

Figure 9. Substations are maintained and free of weeds for safety and aesthetics. Photo: Frannie Miller

Railroads

Railroad vegetation requires control for similar reasons as electric utilities and roadsides. The areas that need to be controlled fall into five broad groups: yards, bridges, line-of-road, road crossings, and brush.

Yards

In rail yards, weed control provides a safe work place and is required by the Federal Railroad Administration (FRA) specifically to: prevent fires around buildings, outside storage, and the general yard area; prevent wheel slippage; facilitate maintenance and inspection; and improve appearance (Figure 10).

Figure 10. Vegetation in yards presents a hazard to railroad employees.

Bridges

Vegetation control is necessary around bridges, especially wooden bridges, to reduce fire hazard and to facilitate structural inspection and maintenance (Figure 11).

Figure 11. Vegetation around wooden bridges can be a serious fire hazard. Photo: Frannie Miller

Line-of-Road

Vegetation control along rights-of-ways protects the roadbed. It helps maintain proper drainage, allows for track inspection, improves visibility of signals, switches, signs, and crossings, and reduces the fire hazard.

In railroad vegetation control, line-of-road refers to management of areas along the main lines and branch lines. This represents the greatest number of treated acres compared to other phases of railroad vegetation management (Figure 12).

Figure 12. Vegetation control in railroad ballasts preserves ties and track stability. Photo: Frannie Miller

Road Crossings

Road crossing treatments are applied to the areas on either side of highway grade crossings. Weed control at road crossings is needed to comply with legal requirements and to improve visibility for the driver of the automobile and the train engineer (Figure 13).

Figure 13. At railroad crossings, both the train and the traffic must be visible.

Brush Control

Brush control prevents fouling of communication and signal lines and maintains visibility around signs, signals, switches, and crossings. Brush control keeps woody plants from encroaching on the tracks and becoming an obstacle, or striking railcars or employees as they pass.

Pipelines

Vegetation management issues for pipelines parallel electric utilities in many respects. Vegetation control allows for inspection, access, and safety measures on the pipeline right-of-way. Brush-free industrial areas can be inspected to spot warning signs of leaks (Figure 14). Open rights-of-way and industrial areas enable crews to perform maintenance and emergency repairs. Total vegetation control around pumping stations and storage tanks reduces fire hazard.

Figure 14. Vegetation control allows for pipeline inspection and maintenance. Photo: Frannie Miller

Other Areas

Additional industrial sites may need to be kept free of vegetation for aesthetics, to protect hardware, or to improve access to sidewalks or parking lots. Soil sterilants are commonly used in these situations to provide more long-term control. Industrial areas include

- sidewalks
- fence lines
- parking lots
- driveways
- gravel areas
- airport runways
- drive-in theater lots
- public paths (hiking, bicycle, trails)

Summary

Rights-of-way and industrial vegetation management is necessary for improved highway safety, infrastructure maintenance, preservation and enhancement of scenic resources, and improved appearance. Vegetation management contributes to safe and reliable operations. Vegetation management performed for fire prevention, employee and public safety, facilities inspection and wildlife habitat, and compliance with noxious weed law, is important for all rights-of-way. The goals are the same for all — to protect people, move goods and services, and protect the environment.

Study Questions

1. Compared to a flat roadside, the safety recovery zone will be wider for:
   a. Fill slopes
   b. Cut slopes
   c. Curves
   d. Both A and C

2. The most problematic weeds in the safety recovery zone are:
   a. Wildflowers
   b. Trees
   c. Tall grasses
   d. Shrubs

3. The single greatest cause of fatalities resulting from vehicles hitting fixed objects is:
   a. Bridge abutments
   b. Parked autos
   c. Telephone poles
   d. Trees

4. Since an obstacle slows the wind for a distance of _______ times its height, vegetation some distance from the roadside may require control to prevent snowdrifts.
   a. 2
   b. 5
   c. 10
   d. 15-20

5. Total vegetation control is important in:
   a. Railroad yards
   b. Pumping stations
   c. Electric substations
   d. All of the above

6. Brush control, road crossings, yards, and line-of-road are components of vegetation control for:
   a. Roadsides
   b. Electric lines
   c. Railroads
   d. Pipelines

7. Structure inspection, conductor clearance, and emergency service are reasons for controlling vegetation on:
   a. Roadsides
   b. Electric lines
   c. Railroads
   d. Pipelines

8. Aesthetics, drainage enhancement, sign visibility and sight distance are reasons for controlling vegetation on:
   a. Roadsides
   b. Electric lines
   c. Railroads
   d. Pipelines

9. Noxious weeds:
   a. Vary from state to state
   b. Do not have showy flowers
   c. May require control
   d. Both A and C

10. Right-of-way vegetation control is generally required to provide:
   a. System reliability
   b. Public safety
   c. Noxious weed control
   d. All the above

Plant Biology and Vegetation Management

Although weeds are only one of several types of pests, they are the most important pest problem in rights-of-way and industrial areas. Therefore, it is important to have a basic understanding of plant biology, and how it influences weed management practices.

A plant is considered a weed when it grows where it is not wanted or is a plant with more undesirable qualities than desirable ones in a given site. It is a plant that interferes with the intended use or safety of the area. Plants may be considered weeds in these areas if they

- Compete with desirable vegetation for moisture, nutrients, light and growing space.
- Negatively affect the desired appearance of a site or prevent inspections.
- Obscure views of signals, signs, crossroads, and other vehicles.
- Provide a source of weed seeds for nearby crop areas.
- Harbor insects or diseases that affect desirable plants.
- Pose a fire hazard.
- Restrict drainage in ballasts, ditches, or channels.
- Have been legally declared as noxious.
- Cause hay fever, skin rash, or other allergic reactions.

There are many methods of classifying plants. Most place the plants into larger groups, for example annual vs. perennial or grass vs. broadleaf. Being able to classify and identify plants is important for the industrial weed applicator. For instance, some herbicides will kill broadleaf plants but have no effect on grasses. It is essential to understand that some weeds share the same life cycle and growing environments as desirable species. Selectivity of an herbicide may not apply to broad categories of plants. For example, a product may be effective on some tree species, but not all.

Growth Stages

Nearly all plants have four stages of development (Figure 1):

- seedling
- vegetative
- reproductive
- mature (senescent).

In the seedling stage, seed leaves (cotyledons) may be present, along with the first true leaves. At this stage, plants are small and easily controlled. In the vegetative stage, rapid growth of stems, roots, and foliage occurs. This corresponds with rapid uptake of water and nutrients, movement of water and nutrients

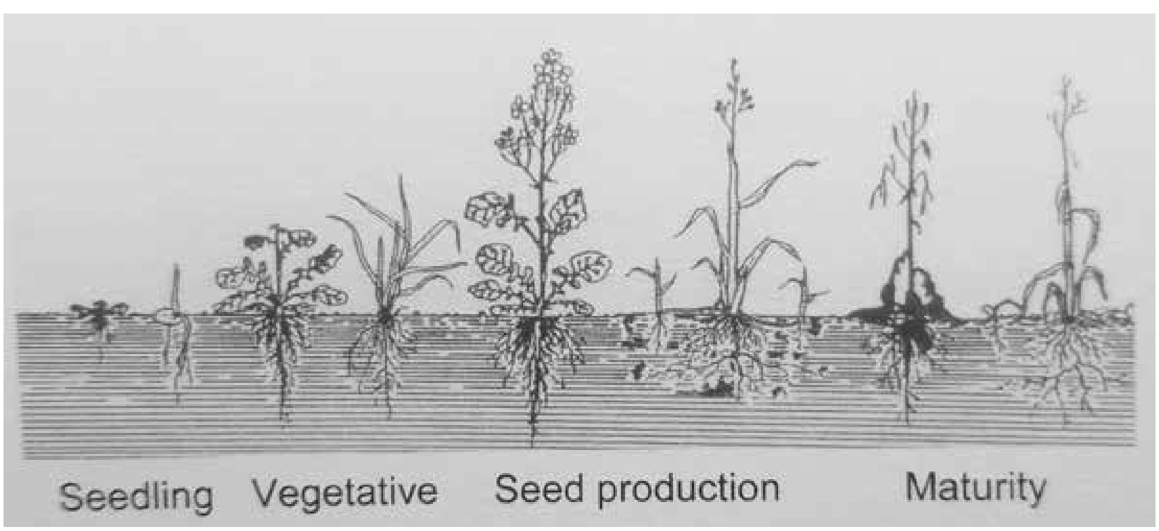


Figure 1. The four stages of weed development.

throughout the plant, and the production of plant nutrients (sugar) through photosynthesis. These activities make many herbicides much more effective in controlling the plant. Flowering and seed production or fruit-set occurs during the reproductive stage. Growth is limited, and uptake of water and nutrients is slowed. Movement (translocation) of water and plant food (nutrients and sugars) is directed to reproductive parts, flowers, fruits, and seeds. Movement of plant food and herbicides to the roots is reduced. In the mature stage, there is little to no growth. Movement of water, nutrients, and herbicides in plants is slow. At this stage, perennial plants translocate sugars to the roots for winter storage. Application of translocated herbicide in perennials may be most effective at this time.

Plants are easily controlled with herbicides in the seedling stage before the waxy coating and surface hairs fully develop on plant leaves and make them more difficult to penetrate. The roots of younger plants are small and near the soil surface. Small plants require less herbicide for control and do not create unsightly patches of dead weeds. As plants grow larger, the leaves become more difficult to penetrate, and roots are deeper and store more food. Product labels provide information on the best time for an application or when plants are at the most susceptible stage of growth for control.

Plant Life Cycles

Plants can be grouped by their life cycles:

- annuals (summer and winter)
- biennials
- perennials

Annuals

Annual plants have a one-year life cycle. Plants grow from seed, produce seed for the next generation, and mature in one year or less. They are also relatively easy to control. Annual weeds thrive where the soil has been disturbed, or stands of perennial plants are spotty or poor.

Summer annuals

Summer annuals are plants that arise from seeds in the spring. The seeds were in the ground over the winter. They grow, produce seed, mature and die before the winter. Examples include annual morning glory, barnyard grass, common cocklebur, crabgrass, foxtails (green, yellow, and giant), kochia, lambsquarter, pigweed, ragweed (common and giant), and Russian thistle (Figure 2).

Figure 2. Cocklebur is an example of a summer annual weed. Photo: Phil Westra, Colorado State University, www.bugwood.org

Winter annuals

Winter annuals grow from seeds that germinate in the fall, overwinter as young plants, set seed, mature, and die in the spring and early summer. Examples include common chickweed, henbit, shepherd's purse, cheat, downy brome, wild mustard, wild oats, and wild rye (Figure 3).

In milder climates, the line between winter and summer annuals is less distinct. Because the root systems of annual plants do not persist from year to year, defoliation of these plants usually controls them. Treating annual plants after seed set usually is not recommended. Knowing the growing habits of annuals is useful in planning how and when to control them.

Figure 3. Henbit is an example of a winter annual because it flowers in the spring. Photo: Frannie Miller

Biennials

Biennials complete the life cycle in two years (Figure 4). During the first season, they grow from seed, develop a root system, and a compact cluster of leaves called a rosette forms on the soil surface. The plant overwinters, and in the second growing season, flowers form, seeds are produced, and the plant dies. There are no grasses with a biennial life cycle. Biennial broadleaved plants include bull thistle, burdock, common mullein, musk thistle, sweetclover, teasel, wild carrot (Queen Anne's lace), and wild parsnip.

Biennial weeds usually grow in areas that are not mowed or disturbed, such as fencerows, pastures, and abandoned fields. Control should be implemented at the rosette stage. After the plant produces the seedhead, which is often the most visible part of the plant, the plant begins to senesce and die. Controlling annual and biennial plants with herbicides after flowering and seed production is of little or no benefit. It may be more practical to cut the plant to reduce the height of the flower stalk.

Figure 4. Biennial plants are rosettes of leaves at the end of the first year. Photo: Frannie Miller

Perennials

Perennial plants live for two or more years and can be either herbaceous (die down each winter) or woody (with persistent stems). Most perennials propagate from seed, but many can also reproduce vegetatively by way of rhizomes, bulbs, tubers, stolons, or runners. Perennial weed problems are common in areas with minimal soil disturbance, such as pastures, woodlots, abandoned fields, riparian strips, and fencerows. Perennials can be quite variable but can be grouped into three broad categories based on root characteristics: simple, bulbous or tuberous, and creeping.

Simple perennials

Simple perennials will spread by seed and root segments. These plants have persistent root systems but do not usually spread by root segments unless they are broken into parts by mechanical methods. Common simple perennials include broomsedge, plantain (buckhorn and broadleaf), chicory, curly dock, dandelion, goldenrod, spiderwort, white heath aster, and most trees and shrubs (Figure 5).

Figure 5. Curly dock is an example of a simple perennial found in Kansas. Photo: Frannie Miller

Bulbous or tuberous perennials

Some perennials reproduce vegetatively from underground bulbs or tubers, as well as by seed. Bulbs are swollen underground leaf stems. Perennials that reproduce from bulbs include wild garlic and wild onions. Tubers are also swollen underground stems. They contain many buds, whereas bulbs have a single shoot. Examples of perennials with tubers include Jerusalem artichoke, and yellow and purple nutsedge (Figure 6). Bulbs and tubers can spread by soil disturbance and can resprout when the parent plant is controlled.

Figure 6. Nutsedge reproduces vegetatively from underground bulbs. Photo: Frannie Miller

Creeping perennials

Creeping perennials spread vegetatively from stolons (horizontal stems running along the soil surface and usually rooting at the joints) (Figure 7), by rhizomes (underground horizontal stems modified for food storage and asexual reproduction) (Figure 8), or by seed. Creeping perennials usually occur as a patch that enlarges every year. Roots of creeping perennials can be located off the right-of-way, while the spreading stems or vines continue to reinvade the treated area and may make the herbicide treatment seem ineffective. Repeated treatments with a translocated herbicide may be necessary. Examples of creeping perennials include bermudagrass, blackberries, Canada thistle, common milkweed, field bindweed, horsenettle, Johnsongrass, leafy spurge, multiflora rose, quackgrass, poison ivy, trumpet-creeper, Virgina creeper and honeysuckle (Figure 9 and 10).

Figure 7. Aboveground stolons enable some plants to spread vegetatively. Photo: John M. Randall, The Nature Conservancy, www.bugwood.org

Figure 8. Some perennial plants spread by rhizomes.

Figure 9. Bindweed is an example of a creeping perennial, which has persistent roots and stems. Photo: Frannie Miller

Figure 10. Johnsongrass beginning to grow from root pieces. Photo: Frannie Miller

Perennial plants are also best controlled while seedlings. Mature perennials are difficult to control because their persistent roots and stems enable the plants to resprout. Defoliating perennial plants provides only temporary growth suppression by killing the aboveground plant without killing the root, bulb, tuber or rhizome. Herbicides that move through the plant (translocate) are most effective if applied after rapid growth has stopped and the plant has begun to store food reserves in its roots. This situation occurs in woody perennials after the leaves have fully expanded in late spring, and in herbaceous perennials when plants are in the bud-to-bloom stage. It is important to have the herbicide move to the roots and underground stems when trying to control perennial plants.

Weed Classification

Pest plants can be grouped into the following broad categories according to their growth form:

- Grasses
- Sedges
- Broadleaves (forbs)
- Vines
- Brush and trees
- Ferns and their allies

It is not important to learn the names of all the different plant features. Instead, become familiar with different plant characteristics so you can identify a plant specimen by comparing it with a photograph, sketch, or description in a reference book.

Grasses

Grasses are monocotyledons, meaning there is only one cotyledon and only one leaf at germination. Grass leaves are generally narrow and upright with parallel veins. All annual grasses have fibrous root systems, and many perennial grasses have rhizomes or stolons with fibrous roots attached. The growing point of the seedling grass is located at or below the soil surface (Figure 11). Grasses can be distinguished from each other by their vegetative and reproductive structures. Examples of annual grasses include barnyardgrass, crabgrass, downy brome, foxtail, fall panicum, and shattercane. Examples of perennial grasses include bluestem, Johnsongrass, and quackgrass.

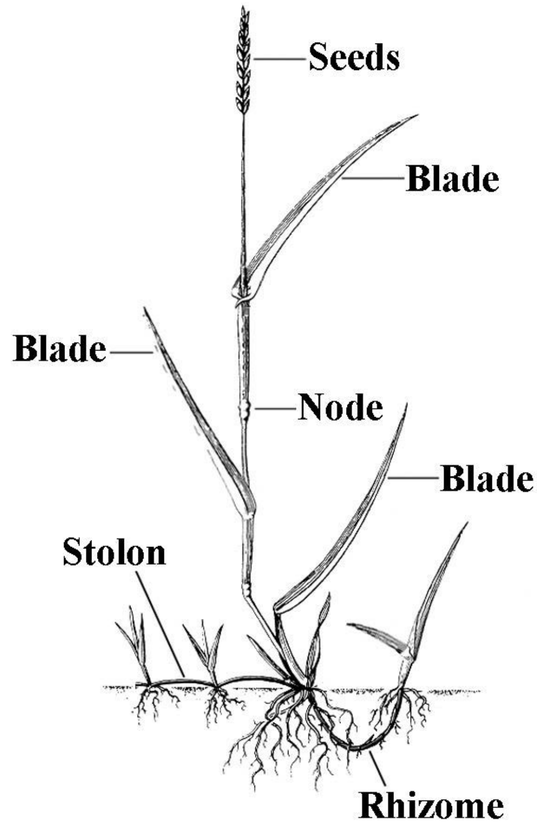


Figure 11. Parts of a grass plant. Source: Jim Converse, The Scotts Company, Marysville, Ohio

Sedges

Sedges have a grass-like appearance and may be confused with grasses. One characteristic used to distinguish them from grasses is the arrangement of the leaves around the stem. Most sedges have triangular stems and three rows of leaves, but others can have round stems. Most sedges are found in wet places but can occur in fertile, well-drained soils. Some of the most problematic sedges, including yellow and purple nutsedge, are perennial weeds that produce rhizomes and tubers.

Broadleaves (Forbs)

Broadleaf seedlings have two conspicuous leaf-like structures as they emerge from the soil (dicotyledon). These plants have broad leaves with net-like veins (Figure 12). Leaf type, leaf arrangement on the stem, leaf shape, leaf margins, cotyledon shape, color of stems and leaves, type of inflorescence, flower, and root systems can all help identify these plants. Broadleaves usually have a taproot and a relatively coarse root system. All actively growing broadleaf plants have exposed growing points on root tips, at the end of each stem, and in each leaf axil. Perennial broadleaf plants may also have growing points on stolons or other vegetative reproductive structures as well as aboveground stems. Herbaceous plants do not develop persistent aboveground woody tissue. Broadleaves contain species with annual, biennial, and perennial life cycles. Examples of annuals include kochia, pigweed, ragweeds, Russian thistle, sweetclover, and wild sunflower. Biennials include bull thistle, common mullein, musk thistle, wild carrot, and wild parsnip. Broadleaf perennials include Canada thistle, curly dock, dandelion, field bindweed, ironweed, leafy spurge, plantains, and purple loosestrife.

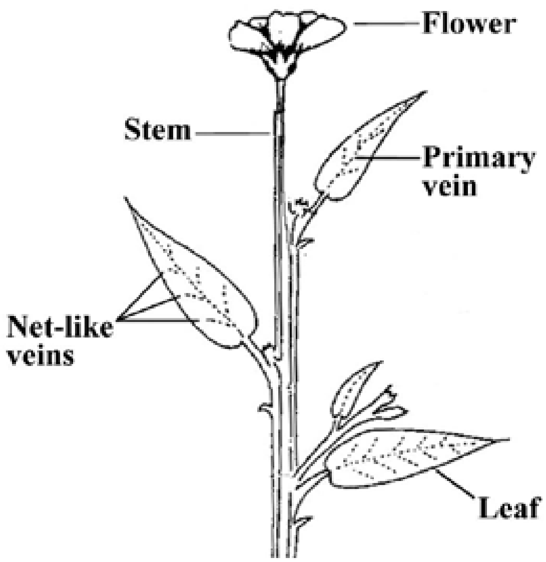


Figure 12. Broadleaf plant structures. Source: Oklahoma Cooperative Extension Service

Vines

Woody and herbaceous vines are also broadleaves with many similar characteristics, but vines often have persistent woody stems. Vines invade treated weed-free areas from the surrounding untreated area, climbing poles, signs, signals, guy wires, fence posts, and other vegetation (Figure 13). Although some vines are annuals, including annual morningglory and wild buckwheat, most are perennials that sprout vigorously from underground vegetative reproductive structures. Examples of perennial vines include blackberry, field bindweed, Japanese honeysuckle, kudzu, poison ivy, and trumpet creeper.

Figure 13. Woody and herbaceous vines can persist along the edge of the right-of-way and impact signs. Photo: Dan Wixted, Cornell University

Woody Plants

Woody plants are those that form secondary tissues from the vascular cambium (wood). These include brush, shrubs, and trees. Brush and shrubs are woody plants that have several stems and are typically less than 10 feet tall. Trees are woody plants that usually have a single stem (trunk) and grow over 10 feet tall. These perennial plants may reproduce by seed or from sprouting roots. Stem, bud, and bark characteristics are the main ways to identify woody plants after their leaves have fallen. Trees are subdivided into two broad groups: deciduous and evergreen, which includes conifers. Deciduous trees usually shed their leaves in the fall with a few exceptions. Examples include ash, black locust, boxelder, cottonwood, dogwoods, elms, hickories, maples, mulberries, oaks, redbud, sumac, sweetgum, tree-of-heaven, wild cherry, and willows. Most conifers keep their needles year-round (evergreens). The needles are shed after 2-3 years, depending on species, but there is always newer green foliage present. Examples include Douglas fir, eastern redcedar, hemlocks, junipers, Ponderosa pine, Scots pine, and white pine. Larch and bald cypress are also conifers, but they shed their needles each fall.

Ferns and their Allies

These perennial plants do not produce seed but reproduce by spores and creeping rhizomes. They prefer moist soils. Examples include bracken fern, common horsetail or jointgrass, scouringrush, and swordfern.

Plant Transport Systems

Two groups of tissues, the xylem and phloem, facilitate movement of herbicides, water, nutrients, sugars, and naturally occurring growth regulators in plants. Xylem tissue moves water and nutrients from the roots to the leaves. Typically, soil-applied herbicides move upward in this tissue. Phloem transports manufactured plant food (sugars) from the leaves to points of active growth, including root tips, reproductive tissues, and storage organs. In grasses and broadleaf forbs, the two tissue types are grouped together into vascular bundles, which are evident in the veins.

In woody plants, the inner and outer bark is composed of phloem tissue (Figure 14). The wood, sapwood, and heartwood is xylem tissue. The inner and outer bark is separated by the cambium, the living tissue responsible for tree growth. This is the part of the tree that should be treated during a fresh cut stump application. Girdling a tree by removing a ring of bark from around the trunk prevents plant food from reaching the roots. The major portion of the wood in the tree provides structural support. Living tissues are on the outer edge of the wood and on the inner edge of the trunk. The rest of the bark is nonliving tissue that protects the tree from injury.

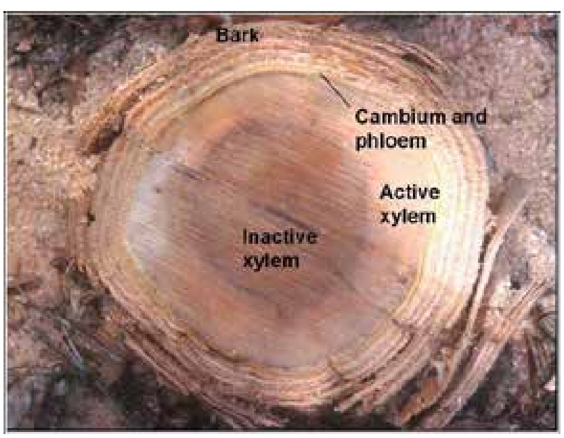


Figure 14. In woody plants xylem and phloem tissues are separated by the cambium. Photo: Ken Langeland, retired UF/IFAS

Some herbicides move only in xylem tissue. Others are translocated in both the xylem and phloem. Most soil-applied herbicides primarily move in the xylem. In contrast, most foliar-applied herbicides move primarily in the phloem. The product label indicates where, when, and how the herbicide should be applied to place the material in the best position for plant uptake to ensure maximum control.

Factors Affecting Plant Growth

Water

Water carries dissolved nutrients up to the leaves, and sugars (sap) to the roots. Nutrients in the soil and soil-applied herbicides must be dissolved in water and taken up by the roots of the plant. Water is also a necessary part of photosynthesis — the manufacturing of sugar from water and carbon dioxide in the presence of green chlorophyll with sunlight as the energy source. The effects of the herbicides are reduced under drought conditions, as is photosynthesis.

Rainfall must be sufficient to reach the root zone. Light rain in hot, dry weather will have little effect on soil moisture because the water quickly evaporates without reaching the plant roots. Short, heavy rains may have little effect on soil moisture because of excessive and rapid run-off.

During drought periods, plants undergo growth stress conditions and produce thick waxy layers on the leaves. They may close their stomates (small pores in the leaf surface) and reduce their metabolic rate to protect against excessive moisture loss. Because photosynthesis, and consequently sugar production, are slowed, translocation of nutrients and herbicides will also be greatly reduced. Under these conditions, herbicides do not penetrate the leaf surfaces or move through the plant easily, so control may be reduced, and their use is questionable. Plants growing in dry (arid) environments adapt to these conditions. For example, they may have small, thick leathery leaves, a thick waxy layer on the leaf surface, or ability to grow and flower rapidly when it rains.

Temperature

Temperature influences all plant activities — absorption of water, transpiration (the evaporation of water from plants), respiration (plant food is used to produce energy), germination, growth, and reproduction. Temperature is one of the most important environmental factors affecting evaporation. Evaporation cools the leaf, so its temperature is not as high as the surrounding air. Plant growth tends to increase when temperature rises, and it declines when temperature falls. Most plant growth occurs between 50-100 degrees F (10-38 degrees C). Temperature is also a factor in determining how far north or south a specific plant will grow because temperature extremes determine the length of the growing season or frost-free period.

Relative humidity

At high relative humidity, plant leaves are more succulent, may have less of a waxy layer, and a thinner cuticle. In addition, the cuticle accumulates water. As relative humidity increases, transpiration decreases. High relative humidity and optimum temperatures usually enhance plant growth.

Liquid sprays more easily penetrate leaf surfaces as relative humidity increases. This increases penetration because spray droplets do not evaporate as fast on the leaf surface. This allows more time for the herbicide to enter the leaf.

Light

Light affects photosynthesis, plant growth, and flowering. Light is the energy source that drives photosynthesis. The rate of photosynthesis increases with increased light (up to about one-third of full sunlight). Plants growing in moderate shade tend to be taller and have larger leaves than the same species growing in full sunlight. Leaves in the sun usually are thicker, smaller, with more cuticle than plants in the shade. Some plants require high light intensity. Shade-intolerant plants often establish first on disturbed sites because they grow well only in a lot of sunlight. On the other hand, shade-tolerant plants become established later because they have the capacity to survive and grow in the shade of other plants.

Summary

Although plants come in numerous shapes and sizes, they can be grouped by several similarities for vegetation management purposes. All plants, including grasses, broadleaves, or woody plants, go through similar growth stages and have specific life cycles. In general, they respond similarly to environmental influences, although some plants may be more adapted to environmental extremes than others. Herbicides work best when plants are actively growing. Any conditions that make it difficult for plants to grow will reduce the effect of herbicides used to control them. Slow growth means the movement of water, nutrients, and herbicides is greatly reduced. Understanding the biology of weeds can help in planning effective management programs, regardless of whether you are trying to prevent, suppress or release them.

Study Questions

1. What type of plants is characterized by narrow upright leaves, parallel veins running the length of the leaf, one leaf at germination, and a fibrous root system?
   a. Trees
   b. Broadleaf forbs
   c. Grasses
   d. Ferns

2. What type of plants are characterized by leaves with net-like veins, two leaves at germination, a taproot or coarse root system, buds in each leaf axil, and not woody?
   a. Trees
   b. Grasses
   c. Broadleaf forbs
   d. Ferns

3. Seedling weeds are more easily controlled because:
   a. Wax and cuticle are less thick
   b. There are generally fewer and shorter hairs
   c. They are smaller in size
   d. All of the above

4. Perennial weeds are difficult to control because they have:
   a. High seed viability
   b. Thick leaf cuticle
   c. Persistent root system
   d. All the above

5. Plants that complete their life cycle in one year are called:
   a. Winter annuals
   b. Summer annuals
   c. Biennials
   d. Both A and B

6. Perennial weeds are those that live:
   a. One year
   b. Two years
   c. More than two years
   d. None of the above

7. Plants with a two-year life cycle are called:
   a. Annuals
   b. Biennials
   c. Perennials
   d. None of the above

8. Soil-applied herbicides move upward in what plant tissue?
   a. Cambium
   b. Xylem
   c. Stomata
   d. Phloem

9. The manufacturing of sugar from water and carbon dioxide in the presence of green chlorophyll with sunlight as the energy source is termed:
   a. Assimilation
   b. Respiration
   c. Transpiration
   d. Photosynthesis

10. The correct sequence of plant growth stages is:
    a. Seedling, vegetative, mature, reproductive
    b. Seedling, reproductive, vegetative, mature
    c. Seedling, mature, vegetative, reproductive
    d. Seedling, vegetative, reproductive, mature

Vegetation Control Options

Managers have many control options for reducing undesirable weed species in rights-of-way and industrial areas. Vegetation control methods either try to stress the unwanted weeds or improve environment for desired plants. This can be done using biological, cultural (preventive), manual, mechanical, and chemical controls. Because no single method is effective in every situation, a large-scale vegetation management program may use a combination of control measures. An integrated approach allows managers to maintain safe and reliable rights-of-way and industrial areas at a reasonable cost by selecting the best control method for a situation.

Biological Controls

Biological control uses living organisms such as insects, animals, or plant pathogens to control undesired vegetation. The organism is introduced for controlling specific plant species. State and federal agencies normally release insects, animals, and plant disease organisms for long-term control. For instance, they may try to reduce certain weed species by grazing goats on areas where it is difficult to use large mowing equipment, or by releasing an insect that burrows into the seed head or feeds on plant roots.

Insects have been introduced to manage populations of musk thistle, purple loosestrife, and leafy spurge (Figure 1). Insect numbers increase over time and continue to reduce the number of weeds. Use of plant pathogens is limited at present. Although biological controls are inexpensive to maintain, populations lag behind those of weeds and are slow to show results. Biological controls usually do not eliminate a weed population, but rather reduce its severity.

Biological controls are weed-specific, and their inability to adequately control a variety of weeds in a timely manner limits their effectiveness as management tools. Biological controls typically are used for regional programs targeting specific weed populations with rights-of-way and industrial areas as incidental beneficiaries.

Figure 1. Musk thistle head weevil is an example of a biological control. Photo: Phil Sloderbeck, Kansas State University, www.bugwood.org

Cultural Controls

Weed prevention should begin early using cultural control methods to manage weeds indirectly. For example, revegetation with native plant materials such as wildflowers or perennial grasses prevents undesired weeds from becoming established by setting up a competition between plants for important resources such as nutrients, moisture, and light. Allelopathy is another cultural control mechanism by which one plant species releases one or more chemicals that inhibits the establishment and growth of neighboring species. Both competition and allelopathy are likely at play in shaping the plant communities found on various rights-of-way and industrial areas. Plants living and growing in groups or communities typically compete throughout their life cycles. Taller plants shade shorter ones. Dense sod prevents seeds from germinating and establishing other plants.

Cultural control includes plant selection, for example, selecting salt-tolerant grass species along highways treated with salt during the winter months. Or when drought-resistant grass species, native grasses, and wildflowers are selected for site conditions to keep the ground covered to prevent weeds from taking over. Planting of native wildflowers provides an attractive display of colors while preventing or slowing undesirable weed invasions (Figure 2).

Figure 2. Wildflowers add beauty while providing competition for invading weeds.

Other forms of cultural control encourage growth and development of desired vegetation but do not involve mechanical or chemical control. Examples include treatment timing, cutting height, fertilizers, lime, mulches, and fire. Fertilization is effective in the production of dense grass cover to prevent the growth of weeds and woody plants. Liming soils to reduce acidity or increase pH can inhibit the establishment and growth of plants such as broomsedge.

Mulch and gravel can keep weed pressure down by eliminating bare soil, but they are not a permanent solution for weeds, which eventually invade. Although mulches are useful in established landscape plantings, fertilizers, mulch, and compost can significantly increase the density of desirable vegetative species on rights-of-way by improving the texture and fertility of soil.

In some situations, fire can be used to promote desired vegetation, prairie plants in particular. But it is difficult to confine fire to the right-of-way, and dense smoke creates a safety hazard (Figure 3). Fire may be used to control limited infestations of annual or biennial weeds, but is seldom effective against herbaceous perennial weeds or brush species because it only destroys the plant parts above the ground. Many states have laws restricting the use of fire and open burning.

Figure 3. Fire suppresses weeds but only temporarily. Photo: USDA Forest Service Southern Research Station, USDA Forest Service, SRS, www.bugwood.org

Manual Controls

Manual control involves the use of string trimmers, chain saws, brush hooks, machetes, hoes, and shovels, which are sharp and require special safety equipment during use. Protection for eyes, ears, legs, hands and feet is required when using these tools. In addition to the hazards associated with manual equipment, operators are more exposed to the hazards of road traffic and walking across uneven ground, which may result in trips and falls.

Manual control methods are commonly used for small areas and for treating areas where obstacles prohibit the use of other methods. Manual weed control is labor intensive and costly when compared to other methods as cut debris may have to be removed from the site. In addition, cut plants may not be killed and often resprout. An operator can be more selective in controlling specific weeds when using small, rather than larger, equipment. Using a chain saw to cut unwanted trees only is much less disruptive than using a large mower to cut down everything.

Mechanical Controls

Mechanical control involves the use of machines or physical barriers to control weeds. Mowers are the most common method of mechanical control used on rights-of-way and industrial areas. Mowers cut all aboveground vegetation but do not injure the roots of plants. Consequently, many plants resprout in greater numbers, especially perennials, including broadleaf woody species. Mowing can be used to prevent flowering and seeding of annual or biennial weeds or to remove brush and woody plants. Cutting grasses too short encourages broadleaf weed invasion, and close cutting and sod scalping can cause erosion. Problems may occur when cut material smothers desirable grasses, becomes a fire hazard, or blocks culverts and drains during heavy rains.

Several types of cutting heads can be used. They include flail, reel, sicklebar, and rotary blades ranging in size from 4 to 6 feet wide for two-lane local and county roads, to 12 to 24 feet wide for large-scale interstate highway mowing operations (Figure 4). There is a risk of flying debris during a mowing operation especially along a roadside. Brush cutting is usually done with machines that are larger and heavier versions of rotary or flail mowers such as Hydro-Ax and Kershaw.

Flexible geotextile mats or polymer barriers, as well as radiant heat, hot water, and steam occasionally are used to prevent the spread of weeds, reduce an infestation, or sufficiently alter the environment to suppress weed populations. These alternative methods are not suitable for large-scale clearing or maintenance.

Figure 4. Mechanized equipment used to remove large trees on the right-of-way. Photo: David M. Moehring, Mississippi State University, www.bugwood.org

Chemical Controls

Chemical control methods utilize herbicides or plant growth regulators (Figure 5). Use of herbicides is often more complex, difficult, and requires more precision than other forms of weed control. The applicator must consider major factors when using herbicides, including application equipment, herbicide strengths and weaknesses, targeted weed(s), and management goals. No single herbicide can meet the needs of every weed situation on an industrial site. Each herbicide controls a spectrum of weeds. By selecting the proper herbicide, application method and rate, and timing, it is possible to selectively control broadleaf plants, grasses, or trees without injuring other desirable plants.

Herbicides enable the control of all vegetation for short or long time periods, suppress grass seedhead production, and reduce the growth of plant stems and foliage. Proper use of chemicals and application equipment is important to avoid injury to desirable plants on or off industrial areas. Chemical control methods often are less labor intensive and time consuming, more economical, and present fewer hazards to the operators than mechanical and manual vegetation control methods.

Figure 5. Herbicides have a lasting effect on the vegetation occurring on a right-of-way. Photo: James H. Miller, USDA Forest Service, www.bugwood.org

Summary

Industrial vegetation management is necessary for public safety and system reliability. Managing industrial vegetation requires a variety of weed control methods. Each method offers advantages and disadvantages, and no single method can be used for all weed control problems. The most economical and effective program with the least environmental disturbance can be developed through the integration of several control methods.

Study Questions

1. Flail mowers are an example of which weed control option?
   a. Manual control
   b. Chemical control
   c. Mechanical control
   d. Biological control

2. Plants resprouting in greater numbers, especially trees, closecutting, and sod scalping can be associated with which type of control?
   a. Manual control
   b. Chemical control
   c. Mechanical control
   d. Biological control

3. Use of the herbicide 2,4-D to control broadleaf weeds is an example of:
   a. Manual control
   b. Chemical control
   c. Mechanical control
   d. Biological control

4. Weed eaters, string trimmers, and chain saws are examples of:
   a. Manual control
   b. Chemical control
   c. Mechanical control
   d. Biological control

5. When one plant produces chemicals that inhibit the establishment and growth of another plant, this is called:
   a. Synergism
   b. Competition
   c. Allelopathy
   d. Antagonism

6. Use of insects to control specific weeds is an example of:
   a. Manual control
   b. Chemical control
   c. Mechanical control
   d. Biological control

7. Integrated Vegetation Management (IVM) means the weed control program:
   a. Depends mainly on manual methods
   b. Uses only chemical methods
   c. Is dependent on biological control methods
   d. Uses a combination of the best control method(s).

8. The control method that is weed-species specific, but inexpensive to maintain, is:
   a. Biological control
   b. Manual control
   c. Chemical control
   d. Mechanical control

9. Fertilizers, mulches, height of cutting, and fire are examples of
   a. Biological control
   b. Manual control
   c. Cultural control
   d. Mechanical control

10. Of the various control methods, the one most highly regulated is:
    a. Biological control
    b. Manual control
    c. Chemical control
    d. Mechanical control

Characteristics of Herbicides Used to Manage Vegetation

Herbicides are pesticides used to control unwanted vegetation (weeds). Weeds along industrial areas include those considered to be a safety hazard or a nuisance, or unsightly to the traveling public. Right-of-way and industrial weeds also include plants that impede road use and maintenance, injure workers, interrupt electricity or communications, or are declared noxious under state law. These weeds may crowd out desired native plants, damage structures and ballast, reduce crop yields, or injure livestock.

Methods used to control plants in industrial areas should be part of a sound weed management program that is sensitive to the environment. Herbicide application is one of the tools available to rights-of-way managers. This chapter presents general information on the use of herbicides for rights-of-way and industrial vegetation control and is not meant to be an in-depth discussion.

Herbicide Terminology

In weed management, effective use of herbicides requires knowledge of the active ingredient and how it works. Herbicides can be classified according to the following criteria:

- how they are absorbed by plants (through plant foliage or the roots);
- the type of activity or the ability to translocate (contact vs. systemic);
- type of plants controlled (selective vs. nonselective);
- how long the herbicide remains effective (persistent vs. nonpersistent); and
- the herbicide's mode of action.

Effective weed control considers the characteristics of individual herbicides, ensuring no incompatibility or label restrictions exist, and weed biology.

Foliage vs. Root-Absorbed

Foliage-absorbed herbicides enter the plant through the leaves and are known as post-emergent products because spray applications are not effective until after the weeds have emerged from the soil. Root-absorbed herbicides enter the plant through the roots and are most effective when applied before weeds emerge from the soil. These products are called pre-emergents. Some herbicides are absorbed by both the foliage and roots (Table 1).

Herbicide formulation, application method, and adjuvants, or substances added to a spray mix to improve the application, can influence which part of the plant absorbs the herbicide. Examples of foliage-absorbed herbicides include 2,4-D, diquat, fosamine (Krenite), glyphosate, and triclopyr (Garlon). Root-absorbed herbicides include bromacil (Hyvar), diuron, oryzalin (Surflan), and tebuthiuron (Spike). Herbicides that can be absorbed by either the leaves or roots include clopyralid (Transline), hexazinone (Velpar), imazapyr (Arsenal), picloram (Tordon), and sulfometuron (Oust).

Selective vs. Nonselective

Selective herbicides control only certain types of plants. When applied to mixed vegetation, some plant types or species will not be affected or show minimal signs of injury. Selectivity may be physiological. For example, grasses are naturally tolerant to the herbicide 2,4-D, whereas dandelions and ragweeds are susceptible. The rate, timing, and method of application, and plant characteristics also determine selectivity (Table 2).

Nonselective herbicides control most plants and are used where complete vegetation control is desired. Nonselective herbicides include bromacil (Hyvar), glyphosate, and tebuthiuron (Spike). Some herbicides such as diuron, hexazinone (Velpar), imazapyr (Arsenal), and

Table 1. Characteristics of herbicides used for industrial weed control

Active Ingredient	Trade Name	MOA Group	Pre/ Postemergent	Selective/ Nonselective	Limited Mobility	Foliar/Root Translocated	Persistent/ Nonpersistent
2,4-D	several	Group 4	Post	Selective	No	Foliar	Nonpersistent
bromacil	Hyvar X	Group 5	Pre	Nonselective	No	Root	Persistent
chlorsulfuron	Telar	Group 2	Both	Selective	No	Foliar	Persistent
clopyralid	Transline	Group 4	Both	Selective	No	Foliar	Persistent
dicamba	several	Group 4	Post	Selective	No	Foliar	Nonpersistent
diquat	Reward	Group 22	Post	Both	Yes	Foliar	Nonpersistent
diuron	several	Group 7	Pre	Nonselective	No	Root	Persistent
fluazifop	Fusilade	Group 1	Post	Selective	No	Foliar	Nonpersistent
fluroxypyr	Vista	Group 4	Post	Selective	No	Foliar	Nonpersistent
fosamine	Krenite	Group 26	Post	Selective	Yes	Foliar	Nonpersistent
glufosinate	Finale	Group 10	Post	Nonselective	Yes	Foliar	Nonpersistent
glyphosate	several	Group 9	Post	Nonselective	No	Foliar	Nonpersistent
hexazinone	Velpar	Group 5	Both	Nonselective	No	Root	Persistent
imazapic	Plateau	Group 2	Both	Selective	No	Root	Persistent
imazapyr	Arsenal	Group 2	Both	Nonselective	No	Root	Persistent
metsulfuron	Escort	Group 2	Both	Selective	No	Root	Persistent
MSMA	several	Group 17	Post	Nonselective	Yes	Foliar	Nonpersistent
norflurazon	Solicam	Group 12	Pre	Nonselective	No	Foliar	Persistent
oryzalin	Oryzalin 4 Pro	Group 3	Pre	Selective	Yes	Foliar	Persistent
pendimethalin	Pendulum	Group 3	Pre	Selective	Yes	Foliar	Persistent
picloram	Tordon, Pathway	Group 4	Both	Selective	No	Root	Persistent
prodiamine	Evade	Group 3	Pre	Selective	Yes	Foliar	Persistent
prometon	Pramitol	Group 5	Pre	Nonselective	No	Root	Persistent
sethoxydim	Poast	Group 1	Post	Selective	No	Foliar	Nonpersistent
sulfometuron	Oust	Group 2	Both	Both	No	Root	Persistent
sulfosulfuron	Outrider	Group 2	Both	Selective	No	Root	X Persistent
tebuthiuron	Spike	Group 7	Pre	Nonselective	No	Root	Persistent
triclopyr	Garlon, Pathfinder	Group 4	Post	Selective	No	Foliar	Nonpersistent

Table 2. Selectively of herbicides commonly used in industrial weed control

Herbicide	Plants Not Controlled
2,4-D	Grasses
Chlorsulfuron (Telar)	Perennial and many annual grasses
Clopyrslid (Transline)	Grasses, many broadleaves
Dicamba	Grasses
Fosamine (Krenite)	Non-woody plants
Metsulfuron (Escort)	Grasses
Oryzalin (Surflan)	Most broadleaves
Pendimethalin (Pendulum)	Many broadleaves
Picloram (Tordon)	Grasses
Prodiamine (Endurance)	Most broadleaves
Sulfosulfuron (Outrider)	Bermudagrass and bahiagrass
Triclopyr (Garlon)	Grasses

sulfometuron (Oust) have selective uses in certain crops and forest situations but at higher rates are considered to be nonselective herbicides when used for rights-of-way vegetation management (Table 1).

Contact vs. Translocated (Systemic)

A contact herbicide generally kills only the green portion of the plant it touches. These compounds act quickly, and little herbicide moves (translocates) in the plant. Consequently, good coverage is necessary. Contact herbicides are most effective in the control of annual plants. While contact herbicides may destroy the top growth of perennial weeds, they only suppress perennial weeds that resprout from underground root or rhizome systems.

On the other hand, translocated (systemic) herbicides move throughout the plant, whether they are taken in by the foliage and translocate downward to the roots or enter through the roots and translocate upward to the leaves (Table 1). Foliage-applied herbicides that translocate are useful in controlling perennial weeds because the herbicide moves to and destroys the growing points in the roots, leaves, and shoots.

Nearly all herbicides used for rights-of-way vegetation control translocate within the plants and include 2,4-D, bromacil (Hyvar), dicamba, diuron, glyphosate, imazapyr (Arsenal), picloram (Tordon), sulfometuron (Oust), and triclopyr (Garlon). The few contact herbicides used on rights-of-way include glufosinate (Finale) and paraquat.

Persistent vs. Nonpersistent

Persistent herbicides remain active in the environment for an extended time period (Table 1). The ability of the herbicide molecule to persist depends on its ability to resist microbial and chemical degradation in the soil. Herbicides vary greatly in their resistance to breakdown. Nonpersistent herbicides are short-lived in the environment. They are easily broken down by soil microorganisms or become tightly bound to soil particles and are not available to plants.

Persistence is an important herbicide characteristic when long-term (residual) weed control is desired, for instance, around a guide/guard rail, median barrier, substation, or rail yard. Persistence allows for control of shallow-rooted annual weeds that grow among deep-rooted established perennial plantings.

Persistence is an undesirable characteristic for herbicides used in reseeding or plant release programs because it may hinder or delay the growth of desirable plants. Herbicide persistence usually increases with cold temperatures, dry, compacted, or clay soils, and high application rates. Conversely, warm temperatures, frequent rainfall, low usage rates, sandy soils, and high organic soils reduce persistence.

Herbicides generally considered to be persistent include bromacil (Hyvar), diuron, imazapyr (Arsenal), picloram (Tordon), sulfometuron (Oust), and tebuthiuron (Spike). Nonpersistent herbicides include 2,4-D, fosamine (Krenite), glufosinate (Finale), glyphosate, and triclopyr (Garlon).

Herbicide Characteristics

Herbicides can be grouped broadly by chemical family, plant response to the herbicide, and type, or mode of action of the active ingredient (Table 3).

Growth Regulators

Growth regulator herbicides affect the auxin receptors and mimic different naturally occurring growth hormone compounds. These include 2,4-D, dicamba, clopyralid (Transline), fluroxypyr (Vista), picloram (Tordon, Pathway), and triclopyr (Garlon, Pathfinder).

Table 3. Common noncrop herbicides classified by mode of action

Photosynthetic inhibitor herbicides
- Benzonitriles
  - bromoxynil (many) **(Group 6)**
- Bipyridyliums
  - paraquat (Gramoxone SL) **(Group 22)**
  - diquat (Reward) **(Group 22)**
- Triazines
  - atrazine (many) **(Group 5)**
  - hexazinone (Velpar) **(Group 5)**
  - prometon (Pramitol) **(Group 5)**
- Uracils
  - bromacil (Hyvar, Krovar) **(Group 5)**
- Ureas
  - diuron (Karmex, Krovar) **(Group 7)**
  - tebuthiuron (Spike) **(Group 7)**

Growth Hormone herbicides
- Phenoxy acids
  - 2,4-D (many) **(Group 4)**
- Benzoic, Carboxylic, Picolinic and other acids
  - aminocyclopyrachlor (Perspective) **(Group 4)**
  - aminopyralid (Milestone) **(Group 4)**
  - clopyralid (Transline, others) **(Group 4)**
  - fluroxypyr (Vista, Starane) **(Group 4)**
  - picloram (Tordon) **(Group 4)**
  - triclopyr (Garlon, Pathfinder II) **(Group 4)**

Meristematic inhibitor herbicides
- Foliar-applied
  - Phosphono amino acid derivatives
    - fosamine (Krenite) **(Group 26)**
    - glufosinate (Finale, Rely, Cheetah) **(Group 10)**
    - glyphosate (Roundup, others) **(Group 9)**
  - ACCase inhibitors
    - fluazifop-P-butyl (Fusilade) **(Group 1)**
    - sethoxydim (Poast) **(Group 1)**
- Soil-or-foliar applied
  - ALS enzyme inhibitors
    - chlorsulfuron (Telar) **(Group 2)**
    - imazapic (Plateau, Panoramic) **(Group 2)**
    - imazapyr (Arsensal, Chopper, others) **(Group 2)**
    - metsulfuron (Escort, MSM Turf) **(Group 2)**
    - sulfometuron-methyl (Oust, Landmark) **(Group 2)**
    - sulfosulfuron (Outrider, others) **(Group 2)**
- Soil-applied
  - Dinitroanalines
    - oryzalin (Surflan, Oryzalin 4 Pro) **(Group 3)**
    - pendimethalin (Pendulum, others) **(Group 3)**
    - prodiamine (Evade, others) **(Group 3)**

Others
- difluenzopyr (Overdrive) **(Group 19)**
- dicamba (Banvel, Clarity, Vanquish) **(Group 4)**
- indaziflam (Esplanade) **(Group 29)**
- topramezone (Frequency) **(Group 27)**
- norflurazon (Solicam) **(Group 12)**

Table 4. Examples of premix industrial weed control products

Product Premix Trade Names	Active Ingredients
Tordon 101M, Pathway	2,4-D + picloram
Krovar I, Weed Blast 4G	Bromacil + Diuron
Sahara, Imazuron, Mojave, Topsite 2.5G	Imazpyr + Diuron
Viewpoint	Imazapyr + Aminocyclopyraclor + Metsulfuron
Streamline	Aminocyclopyrchlor + Metasulfuron
Perspective (Method & Telar)	Aminocyclopyrchlor + Chlorsulfuron
Plainview SC	Indaziflam + Aminocyclopyrchlor + Imazapyr
Landmark XP	Sulfometuron + Chlorsulfuron
Esplanade EZ	Indaziflam + Diquat + Glyphosate
Piper	Flumioxazin + Pyroxasulfone
Opensight	Aminopyralid + Metsulfuron
Capstone	Aminopyralid + Triclopyr
Oust Extra, SFM Extra, Spyder Extra	Sulfometuron + Metsulfuron
SpraKil S-13, SpraKil S-26	Tebuthiuron + diuron

Note: It is important to realize there are many options for bare ground treatments and different pre-mixes, so this is not intended to be an inclusive list. It is also not intended as an endorsement of any product.

Auxin growth regulators are more active than natural growth regulators because they are applied at much higher rates. The plant dies, in part, because of uncontrolled growth and cell division that chokes the vascular tissues. One common symptom of these herbicides is distorted growth, which includes twisting and curling (epinasty).

Growth regulator herbicides:

- Translocate throughout the plant and are usually applied to the foliage, but coverage is still important to get enough product into the plant. Low-volume sprays can provide effective control of many species.
- Result in a variety of growth abnormalities even at low rates. Drift to susceptible crops, such as cotton, grapes, soybeans, sugar beets, tobacco, and tomatoes, is a concern.
- Move downward in the soil as a result of water solubility. Picloram is persistent in the soil and is sometimes used for residual weed control. Some products containing picloram are classified as Restricted Use Pesticides.
- Are available in emulsifiable concentrates (EC) as water-soluble salts (amine and mineral salts) and ester forms. The water-soluble formulations are usually applied to leaves and fresh-cut stumps, or they can be injected into woody stems. The EC formulations are best for control of woody plants and can be applied to young green stems or leaves of trees.
- Effectively control many broadleaf weeds and trees but may not control grasses when applied at labeled rates.

Amino Acid Synthesis Inhibitors, EPSP Synthase

Glyphosate is a nonpersistent herbicide that prevents the plant from making important amino acids (amino acid inhibiting). Glyphosate is a nonselective compound that must be absorbed by the leaves but can be used selectively in some situations, for example, when applied at low rates, with directed application targeted to specific plants, and/or when desired plant species are not actively growing. Glyphosate translocates throughout the plant, with plant symptoms occurring slowly, taking a week or more to appear. Rapid foliage desiccation (brown out) does not occur, even with concentrated sprays. Injury symptoms include slow chlorosis (yellowing) followed by necrosis (death of tissue) beginning at the growing points. There is essentially no activity in the soil at normal use rates because the spray particles adsorb to the soil.

Amino Acid Synthesis Inhibitors, ALS Inhibitors

Chlorsulfuron (Telar), metsulfuron (Escort), sulfometuron (Oust), sulfosulfuron (Outrider), imazapic (Plateau, Panoramic) and imazapyr (Arsenal, Stalker) prevent plants from making important branched-chain amino acids. Unlike glyphosate, these herbicides have residual soil activity and are taken in through the leaves and roots and translocated throughout the plant. Imazapyr and sulfometuron control many grasses and broadleaf weeds. Chlorsulfuron, metsulfuron and imazapic are less effective on grasses. Although symptoms may not appear for several days, plant growth stops soon after application. These herbicides are used at low rates, usually ounces or pints per acre.

Photosynthesis Inhibitors

The herbicides hexazinone (Velpar), diuron, prometon (Pramitol), tebuthiuron (Spike), and bromacil (Hyvar) block photosynthesis in susceptible plants, which is the process by which water and carbon dioxide combine to produce oxygen and sugar in the presence of sunlight. These herbicides have no direct effect on root growth although they primarily enter and are taken up through the roots. Leaves can take up these herbicides under the right conditions with the help of certain adjuvants. All photosynthetic inhibitors persist in the soil and provide residual weed control.The length of persistence varies according to the herbicide, the amount applied, soil type, and climate.

Pigment Inhibitor

The herbicide norflurazon (Solicam) inhibits the production of carotenoids, leading to the destruction of the green chlorophyll and causing new foliage to turn white. The leaves are unable to produce food and the plants die. Norflurazon is applied as a preemergent and has limited soil mobility. It is a nonselective herbicide, but it does not leach deep enough into the soil to damage deep-rooted or established plants.

Cell Membrane Disruptors

The herbicides diquat (Reward) and glufosinate (Finale) disrupt cell membranes. Both are nonselective contact herbicides. Diquat injury may be visible a few hours following application. Chlorosis, or yellowing due to a loss of green pigment, occurs within 2-5 days for glufosinate. Good coverage is required as plants can recover from incomplete spray coverage.

Seedling Root Development Inhibitors

Herbicides that prevent seedling root development — oryzalin (Surflan), pendimethalin (Pendulum), prodiamine (Evade) — stop the growth of roots and shoots of germinating seeds or small seedlings by disrupting cell division. Because these herbicides translocate in plants to a limited degree, they seldom control established weeds and are primarily used for grass control and usually do not leach in soils. Effective control depends on sufficient rainfall soon after application or soil incorporation.

Bud Development Inhibitor

Fosamine (Krenite) inhibits bud development when applied to woody plants late in the growing season, but before leaves start changing colors. Except for pines, plants show little or no visible effects (brownout) until the following spring when susceptible woody plants do not resume growth. Uniform plant coverage is necessary because fosamine only moves from the leaves to the buds. Fosamine has no activity in the soil and does not injure grasses at normal usage rates.

Grass-Specific Herbicides

The herbicides fluazifop-p-butyl (Fusilade) and sethoxydim (Poast) are similar in that their activity is limited almost entirely to postemergent control of annual and perennial grasses. Nearly all non-grass species are highly tolerant of these products. The herbicides are absorbed by the leaves with little or no soil activity. They are most effective when applied to unstressed, rapidly growing grasses. It takes a week or more for susceptible species to die. Crop oil concentrates, nonionic surfactants, and nitrogen solutions increase their effectiveness. Antagonism has been observed when these products are tank mixed with auxin/growth regulator herbicides such as 2,4-D. Many grassy weed species have developed resistance to this group of herbicides.

Tank Mixes

An herbicide mixture or combination allows an applicator to combine the strengths of several products. Instead of using a single product, applicators would use a lower rate of multiple products. The target plant is affected in multiple ways increasing the probability of control when multiple active ingredients are used. The use of tank mixes minimizes the amount applied, while maintaining the necessary level of control. A variety of herbicide pre-mixes are available for industrial weed control applications (Table 4). Or an applicator can create one by mixing several compatible products. The key to effective and economic control of vegetation is to match the capabilities of the herbicides to the needs of the industrial site.

Adjuvant Use

Some herbicides require the addition of adjuvants to improve performance. It is important to check the herbicide label before mixing these products to determine which, if any, adjuvants are required. Below are the most common adjuvants used in industrial herbicide applications:

- surfactants that reduce the surface tension between the spray droplet and the leaf surface and improve the spreading and sticking of the herbicide
- drift retardants that increase the size of spray droplets
- penetrating oils for cut stump and basal bark applications
- crop oil concentrates that increase herbicide penetration and reduce surface tension
- nitrogen fertilizers that enhance adsorption
- ammonium sulfate (AMS) used with glyphosate in hard water, and
- antifoaming agents to minimize foaming during tank fill.

Indicator Dyes

In industrial weed control, indicator dyes mark where the herbicide has been sprayed. The indicator dye turns the liquid in the tank to dark blue or green. In addition to making sprayed areas easier to see, marking dyes can help identify defective or worn spray nozzles. The indicator spray can stain items not targeted, so test the product where it is not noticeable.

Herbicide Resistance

It is important to become familiar with an herbicide's mode of action and to understand how this relates to the development of herbicide-resistant weeds. The resistant plant is a biotype of that species that is no longer susceptible to the herbicide. Herbicide-resistant populations develop through repeated exposure to an herbicide or herbicides with the same mode of action. Tolerance implies that the species has never been susceptible to the herbicide. Resistant weeds can be challenging for rights-of-way vegetation managers, and frequently spread to cropland where they become a bigger issue. By understanding the components of herbicide resistance and taking them into consideration in developing weed-control programs, vegetation managers can help reduce the number of herbicide-resistant weeds.

The best approach for minimizing herbicide-resistant weeds is to prevent them from developing by using the following integrated weed management practices:

- Scout regularly, especially after an herbicide application, to identify resistant weeds. Respond quickly to changes in weed populations to restrict the spread of plants that may have developed resistance.
- Rotate herbicides with different modes of action. Do not make more than two consecutive applications of herbicides with the same site of action against the same weed unless other effective control practices are included in the management system. Consecutive applications can be single applications in two years or two applications in the same year.
- Apply herbicides in tank-mixed, prepackaged, or sequential mixtures that include multiple sites of action. The Weed Science Society of America has developed an herbicide mode of action numbering system (Table 3) that is included on most herbicide labels to help users determine whether herbicide products have different or multiple modes of action. Multiple herbicides in a mixture must effectively control the target weed(s) in order to reduce the risk of herbicide resistance.
- Combine mechanical and other non-chemical control practices with herbicide treatments for a near-total weed control program.
- Clean equipment before moving from areas infested with resistant weeds to areas that are not infested.

Plant Growth Regulators

Plant growth regulators (PGR) do not kill plants, but rather reduce their growth. Growth regulators are most often used for seedhead suppression in roadside grasses to reduce mowing and regrowth after trimming to clear lines on electric rights-of-way.

Cell Division Inhibitor

The plant growth regulator mefluidide (Embark) inhibits cell division. It reduces growth and suppresses seedhead formation of various turfgrass species. It does not readily translocate out of the applied leaf. Mefluidide does not persist in the soil, but it has been shown to injure some desirable plant species.

Amino Acid Inhibitors

Characteristics of the herbicides glyphosate, imazapyr (Arsenal), chlorsulfuron (Telar), metsulfuron (Escort), and sulfometuron (Oust) have been discussed previously, but when used as growth regulators, the application rate is important. At very low rates, some of these herbicides can suppress seedhead production of certain grasses or allow growth of desirable grasses not injured by low application rates.

Gibberellin Synthesis Inhibitor

Paclobutrazol (Profile 2C, Cambistat) is a tree growth regulator that inhibits the biosynthesis of gibberellins, plant growth substances that stimulate cell division and cell elongation. Inhibition of cell division and elongation limits tree growth, especially re-sprouting stimulated by pruning. Growth may be inhibited for 2-4 years. Paclobutrazol also inhibits stem cambial growth of some tree species when injected into the soil or applied as a drench around the base of the tree.

Other Factors

Having explored the chemical nature of herbicides, the following information focuses on plant characteristics and environmental conditions that influence the effects of an herbicide on plants.

Plant Characteristics

Location of Growing Points

A characteristic of seedling grasses is having a growing point at or below the soil surface. Postemergent control is difficult when growing points are protected and the herbicide does not not move in the phloem. If an herbicide does not reach the growing point, the plant will continue to grow. Creeping perennial grasses have buds that are protected below the soil surface. Many seedling broadleaf weeds have growing points exposed at the top of the young plant and in the leaf axils. Perennial broadleaf plants are more difficult to control because buds on the creeping roots and stems are protected by the soil. Herbicides that translocate to the protected growing points are required for effective control.

Leaf Shape

The shape of the leaf can affect herbicide effectiveness. Droplets of spray solution tend to bounce or run off when applied to a plant with narrow vertical leaves. A vertical leaf can direct the chemical downward into the growing point. A plant with horizontal, flat, wide leaves more easily retains the spray solution. The plant's ability to retain the spray solution is critical to the effectiveness of contact herbicides that must be absorbed through the foliage.

Hairs

Some weeds lack hairs on their leaves and stems, while others have many. A dense layer of leaf hairs can keep the herbicide droplets away from the leaf surface, reducing chemical absorption into the plant. But a thin layer of leaf hairs may cause the chemical to stay on the leaf surface longer than normal, allowing more chemical to be absorbed into the plant. Surfactants facilitate the spread and penetration of the herbicide solution through a dense hair layer. Generally, seedling weeds have fewer and shorter hairs as compared to those in the later growth stages. This is one reason seedlings are easier to control than mature plants.

Size

Smaller plants, regardless of their stage of growth, are usually easier to control than larger plants. The same is true of seedling and small annual weeds, which are easier to control than larger or established weeds. Chemicals can be applied at lower rates on seedling weeds, but more chemical is required as the plants grow larger. Contact herbicides can effectively control biennial or perennial weeds if applied to seedlings before root systems have become established.

Environmental Factors

Precipitation

Soil moisture and rainfall affect herbicide efficacy. They also influence how long herbicides persist in soil and on plant surfaces. Herbicides work best with moderate soil moisture. Excessive soil moisture may increase leaching through the soil. Some rain is beneficial after application of soil-applied herbicides because it moves the herbicide into the soil and into the seed germination and root zone. Rain during or soon after foliar applications may wash herbicides off the leaves and reduce uptake and effectiveness.

Plants become stressed during drought periods, slowing their growth and causing most translocated herbicides to perform poorly. Even contact herbicides do not perform well under drought conditions because plants often produce heavy wax or corky layers of tissue on leaves or stems to protect against excessive moisture loss from transpiration. During dry periods herbicides remain on the soil surface until moisture is received to carry them into the soil. Effectiveness may be reduced if herbicides remain on the soil surface for a long period of time (several days) before rainfall.

Temperature

Temperature generally does not affect final weed control. It may, however, affect the amount of time required for the herbicide to kill the weed. As temperature increases, the herbicide effects occur more quickly. In cold weather, the action of herbicides may be slowed. High temperatures can enhance herbicide volatility (change from a liquid to a gas or vapor). Warm temperatures increase soil temperature, which increases microbial activity. This can reduce the persistence, hence effectiveness, of residual, soil-active herbicides.

Light

Sunlight is necessary for photosynthesis and growth. Light can break down some herbicides while they are on the soil or plant surface for a long time. This process, known as photodegradation, can be avoided by incorporating light-sensitive herbicides, such as pendimethalin, into the soil. Light-sensitive herbicides should not be used on rights-of-way where soil incorporation is not possible.

Summary

To summarize, herbicides registered for use on industrial areas can be used to control almost all plant species or to selectively manage certain groups of plants. Most vegetation management programs rely on only a small number of available products. Other products are mixtures of the active ingredients of the herbicides mentioned above. Premixed and tank-mixed herbicide combinations offer convenience, help with resistance management, and utilize the desired characteristics of each component. Each product has advantages, and some products may not be suited for a specific weed control operation. Before applying any herbicide, read the label for information on use.

Study Questions

1. Herbicide selectivity can be influenced by:
   a. Time of application
   b. Rate of application
   c. Method of application
   d. All the above

2. Herbicides that move in a plant are termed:
   a. Selective
   b. Contact
   c. Translocated (systemic)
   d. Persistent

3. Herbicides that injure some plants and not others are known as __________ herbicides:
   a. Contact
   b. Selective
   c. Volatile
   d. Nonpersistent

4. Herbicides that remain active in the soil for a large part of the growing season are called
   a. Translocated
   b. Nonselective
   c. Persistent
   d. Selective

5. Herbicide that kills or injures a broad spectrum of plants is referred to as:
   a. Nonselective
   b. Persistent
   c. Translocated
   d. Postemergent

6. A __________________ herbicide is applied before the weeds emerge.:
   a. Selective
   b. Nonpersistent
   c. Contact
   d. Preemergent

7. A ______________ herbicide kills only the green portion of the plant where it lands.
   a. Selective
   b. Nonpersistent
   c. Contact
   d. Postemergent

8. Herbicides that are applied after the weeds have emerged through the soil are referred to as:
   a. Selective
   b. Postemergent
   c. Contact
   d. Nonpersistent

9. Herbicides that do not remain active in the environment for very long are:
   a. Nonselective
   b. Leachable
   c. Preemergent
   d. Nonpersistent

10. Conversion of the active ingredient from a solid or liquid phase to a vapor form is:
    a. Solubility
    b. Volatility
    c. Drift
    d. Leaching

Weed Control Programs

A vegetation management program can be nonselective or selective. Nonselective control means controlling all vegetation, while selective control means some plants are left to grow as a result of the treatment method chosen. Each has its place in industrial vegetation management. Some methods can provide both nonselective and selective control depending on the situation. For example, fire usually is thought of as nonselective because all vegetation is affected, but fire controls plants selectively when, for example, perennial plants resprout but annual plants do not. Mechanical control methods such as mowing are nonselective when all vegetation is cut. Use of this same method can be selective when perennials are allowed to resprout or shorter plants that are not cut are released to grow.

Nonselective Vegetation Control Programs

In the context of herbicide and plant growth regulator use, nonselective vegetation control usually means the control of all vegetation by chemicals. Nonselective treatments usually involve some period of bare ground. This period of residual weed control can be short-lived or it can last throughout the growing season depending on the plants growing and the herbicide used. Nonselective control can be achieved in a number of different ways.

1. After weeds have emerged, total control can be obtained with nonselective, postemergence herbicides that do not have residual soil activity. If rainfall occurs throughout the growing season, this control lasts only a short time. New plants or weeds become established and start to grow soon after treatment. When favorable conditions such as rain do not occur after treatment and new vegetation does not germinate, bare ground can be obtained even though the herbicide treatment does not have residual soil activity.

2. Total control can be obtained with soil-active herbicides applied before weeds emerge. These types of herbicides depend on rain to move them into the upper soil layer where weed seeds begin to grow. For maximum effectiveness, herbicides should be applied before weeds emerge and preceding a rainfall event that moves the herbicide into the soil. For much of the U.S., an early spring application is common. In arid conditions, applications may occur in the fall or winter to take advantage of the winter rain or snow.

3. If weeds are already present, nonselective herbicides, which are taken up by the leaves, can be combined with herbicides that have residual soil activity to obtain total control.

4. Total control also can be obtained using nonselective herbicides that are absorbed by both the roots and the leaves and have residual soil activity.

5. Because no single herbicide will control all plants, tank mixes (combinations of herbicides) are an important tool for nonselective weed control. The actual herbicide treatment or combination will be influenced by site conditions, weed species, herbicide costs, available equipment, climate, and duration of weed control desired.

Guide Rails

Guide rails prevent cars from leaving the road where recovery space is inadequate and provide a visual warning to the motorist. Weeds must be controlled so guide rails remain visible to motorists and can be easily inspected by maintenance personnel (Figure 1). Weeds growing up around the guide rails also hold moisture, causing the guide rails to rust. Guide rails are usually established in asphalt, gravel, or grass. Aggregates and winter-applied abrasives tend to accumulate under the guide rails. These materials hold moisture that degrades the asphalt and promotes weed growth. Weeds also grow in the crevices around the guide-rail support posts that are set in asphalt.

Weed control treatments under and in front of the guide rails usually consist of chemical and/or manual methods. Where the guide rails are anchored in asphalt, treatment of cracks and crevices is necessary for residual weed control. Guide rails can be treated using a variety of techniques, such as a handgun sprayer, short boom with nozzles spraying each side of the guide rail, flood nozzles, or off-center nozzles treating the front side of and underneath the guide rail. Mowing in front of guide rails can be done easily, but mowing behind them usually is difficult.

Figure 1 Guide rails must be kept visible to motorists and maintained.

Median Barriers

Median barriers prevent traffic from crossing into oncoming lanes (Figure 2). Similar to guide rails, median barriers catch and accumulate aggregates and abrasives that support weed growth. Weeds are usually controlled manually or with herbicides using a variety of application methods including handguns, off-center, or straight-stream nozzles. Treatments are commonly spot applications. Because there is usually little soil and surface run-off can be excessive, herbicides with residual soil activity should be used carefully.

Figure 2. Weeds grow in median barriers built to prevent vehicles from crossing into oncoming traffic. Photo credit: Frannie Miller

Signposts and Delineators

Like guide rails, signposts and delineators are anchored in soil or asphalt and subject to rusting caused by weeds. Mowing next to these obstructions is not possible. If anchored in asphalt, treatment of cracks and crevices at the base of the posts will be necessary. Application of a nonselective herbicide around posts to enable mowers to be used efficiently usually is done with handguns (Figure 3).

Figure 3. Total vegetation control around delineator posts facilitates mowing. Photo credit: Frannie Miller

Fences

Mowing near fences is difficult. The ideal control is a banded residual weed control treatment (Figure 4), but trees located on and off the right-of-way may be injured if roots pick up residual herbicides that have been applied near the fence. If using a residual herbicide near trees, check the label carefully to ensure it will not harm desirable trees and shrubs. In these situations, an herbicide treatment without residual soil activity may be preferred. Weeds growing near fences are commonly treated with handgun or backpack sprayers.

Figure 4. Weed control under fences reduces maintenance costs. Photo credit: Frannie Miller

Structures, Abutments, Headwalls, and Inlets

Vegetation degrades abutments and headwalls, which are troublesome to mow around. Weeds should be controlled around drain inlets for visibility and to maintain proper drainage. Usually, herbicides are applied with handguns or backpack sprayers. Take care not to spray into the drain itself.

Storage Yards

Weed control in storage yards provides a safe work area, enables workers to find parts and supplies when needed, and reduces equipment deterioration. Herbicides are commonly used for weed control as obstructions make mowing difficult, other than in alleyways. If size permits, broadcast herbicide application equipment can be used in combination with handguns in inaccessible areas. Granular and pelleted formulations are convenient to use in storage yards.

Road Shoulders

Total vegetation control eliminates deterioration from weeds growing through the edge of the asphalt (Figure 5), provides a clear area for motorists to stop, and reduces the risk of fire. Weeds growing through the shoulder loosen the soil. A weed-free shoulder stays compacted, making it safer for vehicles to stop and start. Maintaining a compacted shoulder reduces soil erosion and the need for mechanical grading to smooth and dress the shoulder area. Use of a nonselective herbicide treatment is recommended for maintaining a weed-free zone without disturbing the shoulder. Shoulder treatments usually are applied by a moving vehicle equipped for this purpose.

Figure 5. A road shoulder should be kept free of vegetation. Photo credit: Frannie Miller

Curbs, Gutters, and Median Islands

Curbs, gutters, and median islands feature a variety of surface materials including soil, concrete, asphalt, gravel, or brick. The non-soil surfaces have cracks where weeds can grow (Figure 6). Weeds attract litter and harbor rodents. A residual soil-active herbicide treatment is applied to these cracks and crevices to prevent weed growth, usually with a backpack or handgun.

Figure 6. Cracks and crevices support roadside vegetation. Photo credit: Frannie Miller

Ditches

Roadside drainage ditches are sometimes maintained and kept free of weeds to facilitate rapid water movement after storms, particularly in the western U.S. The presence of vegetation slows the flow of water and traps soil in the ditch. Over time, ditches accumulate soil that must be removed mechanically to maintain the functionality of the ditch. Residual soil-active herbicides are applied along these drainage ditches during dry periods. When selecting an herbicide for ditch work, consider how the water will be used after it leaves the right-of-way.

Railroad Bridges

Residual soil-active herbicides are applied early in the growing season to prevent vegetative growth around the wooden supports of railroad bridges and to achieve vegetation control through the growing season. Bridges can be treated by hand with granular spreaders or sprayed with special "bridge booms" mounted on a hi-rail truck or with regular flat fan nozzles on a fixed boom. Bridge booms usually use two clustered off-center (OC) nozzles that spray in opposite directions and are attached to a flexible boom that can be raised and lowered. A boom is mounted on each side of the hi-rail truck, and equipment travels at a reduced speed while passing over the bridge. During the application, the operator should leave a buffer strip before and after any body of water according to label instructions.

Railroad Yards

Residual soil-active herbicides are applied early in the growing season to prevent weed and grass growth around railyards, switches, buildings, and storage areas (Figure 7) to obtain long-term vegetation control. The equipment is most often a fixed boom sprayer with flat fan or off-center nozzles mounted on a hi-rail truck or railroad car. Off-center (OC) nozzles can supplement the fixed boom to treat adjacent tracks in a single pass. A handheld spray gun may be used to treat areas around buildings or on "stub" tracks and other areas inaccessible to a track-mounted vehicle.

Figure 7. Prevention of weeds and grass in a railroad yard is desirable. Photo credit: Frannie Miller

Line-of-Road

In railroad vegetation control, the line-of-road phase refers to control of vegetation along main lines, branch lines, and around signs and other trackside fixtures. Line-of-road operations usually require a postemergence treatment for short-term weed control. Weeds are present when the treatment is applied, and new weeds may begin to grow before a killing frost. The operation uses the same equipment as for yard treatment — a hi-rail truck or spray train equipped with fixed booms and off-center nozzles (Figure 8).

Figure 8. Trucks with the ability to move on roads or rail are commonly used to treat railroad ballasts. Photo credit: Nic Zimprich

Substations and Pumping Stations

Season-long vegetation control is necessary in substations and pumping stations to reduce fire hazard and ensure facility reliability. Hand-gun applications are the most common around equipment and facilities. Areas with substantial open ground can be treated using short booms mounted on light trucks or ATVs.

Selective Vegetation Control Programs

Many roadside treatments use selective herbicides to control broadleaf weeds and allow desirable grasses to grow. Nonselective herbicides or methods that direct the herbicide to specific target plants are used for special problem areas or problem plants.

Broadleaf Weeds

The presence of tall broadleaf weeds gives the roadside an unkempt appearance. Control of these weeds is the major focus of many vegetation management programs. Historically, this has been accomplished with growth regulator herbicides. More recently, weed management programs have benefited from a wider selection of herbicides to control broadleaf weeds without injuring grasses. As a result, broadleaf weed control can be done throughout the growing season. Results of treatments conducted in the spring when the weeds are small and hidden by the grass will be less noticeable. Fall applications are effective for controlling germinating winter annuals and biennials in the rosette stage.

Herbicides for broadleaf weed control can be combined with plant growth regulators that suppress grass seedhead production in a single application if the timing is appropriate. Herbicides for broadleaf weed control can be applied as spot or broadcast treatments using a variety of methods, including boom and boomless spray equipment. Drift is of concern for the following reasons: 1) treated areas are usually long and can pass by a variety of sensitive crops; 2) a large number of acres are often treated; 3) wide spray swath widths are possible; and 4) roadside traffic is adjacent to spraying operations.

Ditches

Drainage ditches in the eastern U.S. usually are managed in a selective manner, so grass cover is encouraged (Figure 9). Woody plants and other plants that restrict water flow, such as cattails, are the main problem in ditches. However, herbicide labels may restrict product use in or around drainage ditches.

Figure 9. Grasses are encouraged in some ditches to reduce soil erosion.

Special Grass Control

Special grass-control programs include Johnsongrass, fescue, or wild oat control, and Bermudagrass release. One grass species can be controlled in another grass using the following strategies: 1) careful control of application rate or treatment timing, 2) directed application, or by 3) taking advantage of the difference in plant heights. Treatments can be applied by broadcast, spot, or wiping equipment.

Road Crossings

Treat the areas on either side of highway/rail grade crossings to improve visibility. Road crossing treatments should be applied after weeds have emerged, aiming to suppress vegetation on the railroad right-of-way rather than to eliminate it. Treatments vary with conditions on or adjacent to the right-of-way. To reduce drift hazard, crossing treatments are usually applied as higher volume (large droplet) applications. Off-center tips with large orifices, handguns, or specially constructed straight-stream nozzle configurations are used for this purpose.

Crossing treatments can be applied by hi-rail trucks or spray trains. They are frequently done at the same time as line-of-road treatments and usually with a different herbicide mixture. Crossings can also be treated with off-track equipment and herbicides chosen specifically for the problem weed species.

Woody Plant Control

All rights-of-way and industrial weed managers in the eastern U.S. and the Pacific Northwest contend with trees. Trees also occur in other regions of the U.S. but are sparser or slower growing. The objective is to selectively control some trees. Typically, control is directed at the tall woody species to release lower growing vegetation that will occupy the site and hinder tree species establishment. Because of their size, woody plants can be treated individually or collectively.

Cut Stump

Cutting down trees may appear to solve the problem, but regardless of how the tree is cut if it is a deciduous species, there is a high probability that the stump will resprout without herbicide treatment. A water-soluble formulation such as an amine salt can be used to treat the stump soon after cutting. Herbicide should be applied to the cambium area where the bark and wood meet. It is not necessary to treat the entire stump (Figure 10). If the stump has been cut for several days, treat it with an oil-soluble formulation in an oil carrier. The entire stump should be wet with the mixture, not necessarily to run-off. Backpacks and hand sprayers are effective for treating cut stumps.

Figure 10. Only the outer part of a fresh cut stump needs to be treated with a water-soluble, translocated herbicide. Photo: Frannie Miller

Basal

Basal application is a low-volume treatment that uses a high concentration of herbicide and a low amount of oil carrier. Low-volume basal treatments use an herbicide concentration of 20-30% by volume. Treat the lower 12-24 inches of the stem to wet the bark surface, but not to the point of run-off. This treatment can be applied with a backpack sprayer (Figure 11). Basal treatments are effective year-round. This treatment is most effective on small trees or shrubs with green stems or stems lacking well-developed bark.

Figure 11. Basal applications of the herbicide can be applied with a backpack sprayer. Photo: Steve Manning, Invasive Plant Control, www.bugwood.org

Foliage

Foliar applications are an easy way to control dense stands of woody plants. The largest selection of herbicides is available for this method of control. Applications can be made with a hose and handgun for spot or broadcast treatments, or with other broadcast equipment. The brown foliage that results from many herbicide treatments (brownout), particularly for tall trees, may cause public concern. Brown foliage on small trees is not as noticeable. Consider applying brush control treatments in late summer or early fall when brown foliage blends better with natural leaf senescence.

Soil Active Treatments

Some herbicides have enough soil activity to be used for woody plant control. They are applied in spots on the soil surface so that tree roots growing in the treated zone can absorb the herbicide. These treatments can be applied relatively quickly and require little special equipment. Because plants with roots extending into the treated area can also take up the herbicide, off-site injury is possible when the right-of-way runs alongside woods or other desirable plantings. The treatment should not be applied on steep slopes, frozen ground, or water-saturated soils.

Chemical Side Trimming

Side trimming is the removal of part of the tree's crown by treating only that portion of the crown with an herbicide. It is particularly useful on two-lane roads in wooded areas where the tunneling effect is undesired. Herbicides that translocate are generally used at an extremely low rate so that only the sprayed portion of the tree is affected.

Cut Stubble

Cut-stubble treatments involve the application of an herbicide with soil activity at the time of or soon after a brushy area has been mowed. Resprouting stumps are controlled when their roots take up the soil-active herbicide. The right-of-way and industrial areas are not left with large, standing dead trees.

Herbicide Injection

Spaced cuts are made around the stem and small amounts of herbicide are added to the cuts (Figure 12). The cuts do not have to overlap. The cuts, approximately 1-2 inches wide, are applied around the tree at about a 1-inch spacing, edge to edge. A small amount of herbicide, 1-2 milliliters, is added to each cut. The "hack-and-squirt" method using a hatchet and squirt bottle is effective, but there are specialized tools. Tree injection is faster and requires less labor than girdling and frilling. Irregularly spaced cuts will result in incomplete control, and injection during periods of rapid sap flow may be less effective than during other times of the year. Large trees are easier to treat than small ones, but their size, coupled with the dead leaves, makes the effects of treatment highly visible.

Figure 12. Tree injection can be done year-round and requires no special equipment. Photo: James Miller, USDA Forest Service, www.bugwood.org

Plant Growth Regulators

Roadside Turf

Plant growth regulators are used to alter the growth of roadside grasses. They control or suppress seedhead production and reduce plant height. This can reduce the number of mowing cycles needed for roadside maintenance. A secondary benefit is delayed plant maturity of some species. Plants stay green longer in the season, reducing the risk of fire. Timing of the application for seedhead suppression is critical and should be done early in the growing season. If the treatment is applied too early, it has no effect. If applied too late, the risk of a grass fire increases. Treat for foliage reduction and grass stunting after the first mowing. If the grass is thin, weeds can grow through the turf.

Growth regulators are effective for use in areas where mowing is hazardous and difficult such as around guide rails, signs, median islands, and bridge cones. It is not uncommon to combine broadleaf control with grass growth regulation in a single application.

Tree Growth Regulator

The tree growth regulator paclobutrazol (Profile 2SC) slows vegetative growth. It is applied as a basal drench or by soil injection and used to reduce resprouting of trees after they have been trimmed. By slowing the resprouting process, trimming cycles can be extended.

Summary

Some rights-of-way and industrial areas are managed for elimination of all weeds, while other areas are managed to promote specific types of plant cover. Each manager establishes objectives and programs to reflect the types of vegetation, climatic conditions, budget, available equipment, and local public perception of acceptable management. Vegetation control requires a variety of methods. Each control method has advantages and disadvantages, and no single method can address all weed control problems. The most cost-effective program with the least environmental disturbance can be achieved through integration of control methods.

Study Questions

1. Applying an herbicide solution to the lower 12-24 inches of the stem of a woody plant is what type of treatment?
   a. Foliage
   b. Cut stump
   c. Injection
   d. Basal

2. Selective weed control programs usually include:
   a. Release of grasses
   b. Control of all vegetation
   c. Control of broadleaf weeds
   d. Both A and C

3. Sites where nonselective weed control programs are important include:
   a. Storage yards
   b. Substations
   c. Wooden bridges
   d. All of the above

4. What is the best example of a selective type of control?
   a. Mowing
   b. Soil-active herbicides
   c. Selective postemergent herbicide
   d. Fire

5. Plant growth regulators are used to:
   a. Suppress seedhead production
   b. Reduce sprout growth
   c. Reduce the frequency of mowing
   d. All the above

6. Methods of controlling woody plants include:
   a. All the following
   b. Foliage spray
   c. Basal application
   d. Cut stump treatment

7. Steep slopes, frozen ground, or saturated soils should not be treated by what method?
   a. Broadcast foliar
   b. Soil-active treatment
   c. Cut stump
   d. Low volume basal

8. The specific treatment for nonselective weed control can be influenced by
   a. Weed species
   b. Herbicide cost
   c. Duration of control desired
   d. All the above

9. Nonselective weed control is important where:
   a. Inspection is necessary
   b. Fire prevention is critical
   c. Concern for litter and rodents is high
   d. All the above

10. Sites where selective weed control programs are important include:
    a. Roadside turf
    b. Railroad brush
    c. Railroad crossing
    d. All the above

Herbicide Application Equipment

Herbicides usually are applied in a liquid form. Dry formulations may be used in limited situations. All liquid spray equipment comes with certain advantages and disadvantages. Most sprayers operate at low pressures of less than 40 psi at the spray tip.

Broadcast Liquid Application

Sprayers often are equipped with a row of similar nozzles mounted on a boom. These boom sprayers are used for broadcast applications of herbicides. The nozzles break the spray solution into small droplets and distribute it in a specific pattern. The nozzle design or type, operating pressure, size of the opening, discharge angle, speed, and distance to the target are all factors in nozzle performance.

Nozzle parts include the body, cap, strainer (screen), and tip, or orifice. The nozzle body holds the strainer and tip in the correct position, and the cap secures the strainer and tip to the body. Some nozzle bodies come with built-in check valves to prevent dripping. Nozzle tips made by the same manufacturer can be used interchangably, enabling applications in a variety of spray patterns using a single nozzle body. The nozzle is chosen for a specific application based on the spray application rate, the type of product, and the required spray droplet spectrum.

Boom with Conventional Tips

Regular flat fan

The regular flat fan nozzle is common for boom liquid spray applications. The regular flat fan tip produces a narrow oval pattern with tapered edges and is used for broadcast applications at 15-60 psi. For even distribution, the spray pattern that emerges from the nozzles requires an overlap of 30-50%. For a uniform boom application, the nozzles should be evenly spaced with all fans at the same angle. The boom height should remain constant and parallel with the ground. Spacing of the nozzles on the boom, the spray angle, and boom height should be carefully controlled for proper overlap.

The angle between the edges of the spray pattern is known as the fan spray angle. Fan tips come with spray angles of 25, 50, 65, 73, 80, and 110 degrees. Nozzles usually are spaced 12-20 inches apart on the boom. The required boom height in relation to the ground varies with the fan angle. Nozzles can be spaced closer or wider apart by raising or lowering the boom to compensate for these changes.

Flooding flat fan nozzle

A flooding flat fan nozzle delivers a wide-angle flat spray pattern of 115-125 degrees. The wide spray angle allows for coverage of wide swaths using relatively few nozzles while operating within the recommended pressure range of 8-25 psi. This type of nozzle produces a large spray droplet. Droplet distribution is fairly uniform across the pattern but not as even as the spray pattern of a regular flat fan nozzle. Tips should be tilted 45 degrees for broadcast spraying with a recommended nozzle spacing of 40 inches. Nozzles should have 100% overlap so the width of the spray pattern on the ground is twice as wide as the nozzle spacing. Boom height may have to be adjusted until this overlap is achieved. Flooding flat fan nozzles are not recommended for contact postemergence herbicides due to poor coverage of target plants.

Whirl-chamber nozzle

The side-entry hollow cone, or whirl-chamber, nozzle produces a wide-angle, hollow-cone spray pattern at very low pressures. This type of nozzle has a large opening that resists clogging. Because of the wide spray angle, the boom can be operated close to the ground, thus reducing drift. Spacing for double coverage and angling 15 to 45 degrees to the rear is recommended for uniform application.

Rain Drop

The Rain Drop nozzle produces a hollow-cone pattern and large droplets for drift control. Although the pattern is similar to the whirl-chamber tip, this nozzle contains a secondary chamber where the swirling action of the spray solution further reduces the size of the small droplets. The spray angle varies from 80-100 degrees depending on disc-core combination in the nozzle. When used for broadcast application, the nozzle should be angled 30-45 degrees from horizontal to obtain uniform distribution.

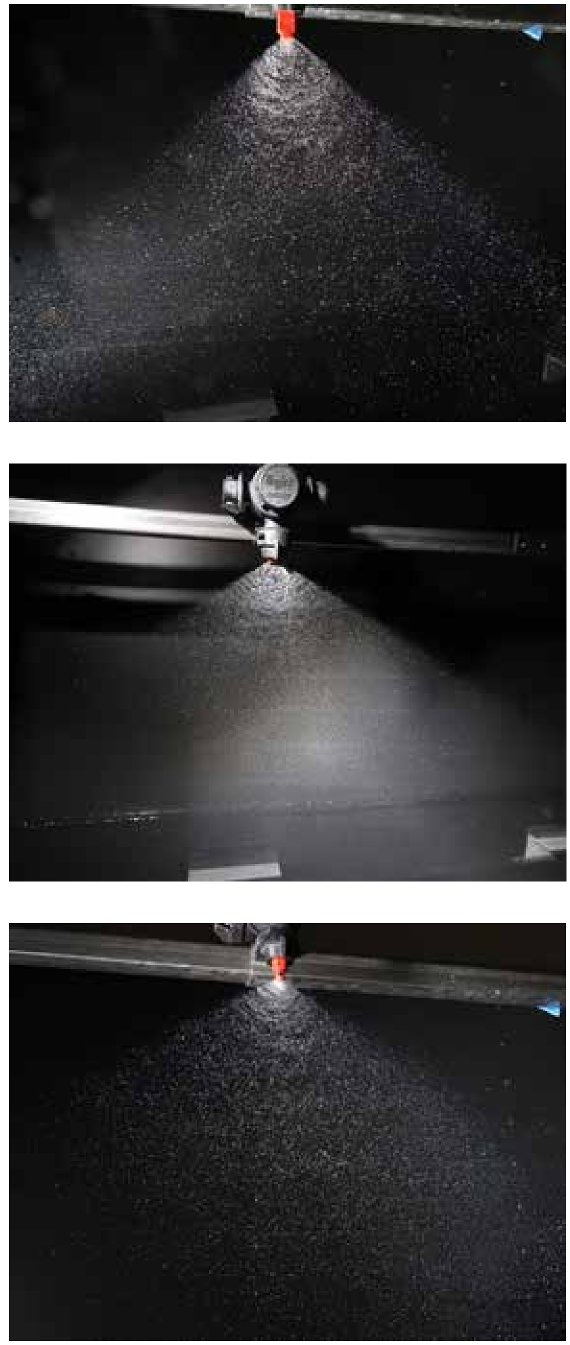
This nozzle generally is used at 20-40 psi. These nozzles should have 100% overlap, ajusting the boom height until this overlap is achieved. Larger droplets produced with this nozzle may not provide adequate coverage for some foliar pesticide applications.

Turbulence chamber nozzle

The turbulence chamber nozzles include a turbulence chamber to absorb energy within the nozzle to increase the size of the spray droplets. Examples of this design include the Turbo Teejet and Turbo TwinJet. While these nozzles are more efficient than traditional nozzles in producing larger droplets at low pressure, both can produce larger droplets at higher pressures, which provides an advantage when using spray controllers that can vary the flow rate and pressure with equipment speed. Turbulence chamber nozzles may only be available in smaller tip sizes.

Air induction nozzle

To increase droplet size and reduce drift, some nozzles (TurboDrop, AI TeeJet, Raindrop Ultra) introduce air into the nozzle body by venturi action through an inlet port. The droplets containing air bubbles are larger than those produced by similar sized nozzles with turbulence chambers. The air-filled droplets collapse when they hit the target, wetting a greater leaf area. Air induction nozzles work well with normal adjuvants and surfactants but do not work as designed if drift control products are used. Compared to conventional nozzles, higher operating pressures of 40-60 psi are suggested when using spray controllers to maintain the desired pattern if the pressure drops. Most air induction nozzles are only available in smaller tip sizes. (Figures 1, 2, and 3).



Figures 1-3. These images show the difference in droplet size based on the type of nozzle selected. Nozzle: AIXR 11004 (air inclusion 110-degree flat fan coarse spray); XR11004 (flat fan medium/fine spray); and TTI04 (Turbo Teejet Extra coarse spray). Photo: Mark Ledebuhr, Application Insights, LLC 2020, www.bugwood.org

Boom with Special Accessories

Controlled droplet applicator or rotary-cup atomizer

The controlled droplet applicator (CDA) sprayer uses a grooved spinning cup that breaks the liquid into uniformly sized droplets by centrifugal force. The spray solution flows into the bottom of a spinning cup under low pressure and spreads evenly across the inner surface of the cup. Shallow channels or grooves on this surface deepen as they extend outward to the top. The spray solution is moved up the grooves by centrifugal force and is released as uniform droplets.

The speed of the atomizer disc and the flow rate of the spray solution determine droplet size. Small electric motors provide power to spin the nozzles. Sizes range from a small handheld type to large truck-mounted units. The advantages of this type of sprayer include uniform droplet size and the low water volume per acre (less than 10 gallons). On the other hand, the sprayers are relatively expensive and foliar penetration may be limited because no downward force is applied to the droplets. Use is not recommended under windy conditions.

WeedSeeker

The WeedSeeker sprayer has a built-in sensor that evaluates variation in spectral reflectance to detect plants from other backgrounds and automatically treat them with herbicide. The WeedSeeker unit consists of a light source, optical sensor, and computer-controlled nozzle assembly. When mounted at the optimum height, WeedSeeker views an area 12 inches wide on the ground. The sprayer has an internal light source that emits a modulated light. This reduces variability due to clouds and shadows and allows the WeedSeeker to operate at night. External solenoid spray valves can be activated with a valve-driver cartridge installed in the WeedSeeker unit. Use of this feature is recommended with herbicide formulations other than soluble liquids and allows the WeedSeeker to operate faster than 10 mph. A disadvantage of this system is that it cannot distinguish different types of vegetation and is only useful where bare surfaces are desired.

Boomless Spraying

Boomless spraying enables the application equipment to stay on the tracks or roadside and spray areas off the side of the equipment. This results in a more uniform speed and rate of application as well as faster speed. Obstructions can interrupt the spray pattern but do not interfere with boomless spray application as much as with a boom application. Even though this equipment is usually mounted on the side of the application equipment, it can also be attached to the end of a boom to spray a wider swath or reach a greater distance from the equipment.

Off-center nozzle

Off-center (OC) nozzles tips are commonly used for railroad and roadside boomless spray applications. They produce a flat-fan spray pattern with the nozzle at the side rather than over the center of the pattern. OC nozzles are used either without a boom or at the end of booms to extend the effective swath width. The ability to treat a wide swath, the variety of sizes available to alter swath width and the gallons applied per acre, the ease of mounting, and the low cost all contribute to the popularity of these nozzles.

Particle drift is a concern because of the wide range of droplet sizes produced by these nozzles. Spray droplets near the application equipment are small, while the droplets on the outer edge are large. Coverage can be variable because air turbulence distorts the spray pattern as it leaves the nozzles. Off-center nozzles usually are permanently mounted to the application equipment at a height that gives a specific swath width. Because of the shape of the pattern, a slight change in height makes a substantial change in swath width and application rate. Drift control additives can be used with these nozzles.

Boom-Buster nozzle

The Boom-Buster nozzle is a straight stream diffuse nozzle. The spray solution is split by a plastic vane and forms a fan pattern very similar to the OC nozzle. The Boom-Buster nozzle produces larger droplets than a regular off-center nozzle.

Straight stream nozzle

Straight stream nozzles produce a solid stream pattern like water flowing from a pipe. These nozzles are used to spray a distant or specific target. For right-of-way application, they typically are used as a cluster of nozzles. Each part of the cluster is set to treat a defined section of the right-of-way. Some vibrating or oscillating action is usually added to aid in breaking the solid stream into smaller spray droplets. Swath width is adjusted by turning specific nozzles or sets of nozzles in the cluster off or on. They may be attached to booms or in handguns to apply herbicides in a narrow band.

Radiarc

Radiarc is a group of straight-stream nozzle tips aligned on a single plane, like the fingers on a hand. It uses an oscillating motion to mechanically break up the streams of spray solution. Swath width is adjusted by plugging selected tips. A Radiarc can be mounted to spray either a horizontal or a vertical spray pattern and adjusted to treat a swath width from 4-25 feet wide. A uniform spray pattern can be obtained by altering the tip sizes.

Directa-Spra®

The Directa-Spra also uses straight stream nozzles. The units are fitted at the factory to spray an arc of 90, 180 or 360 degrees; 180 degrees is the most common. The nozzle clusters rotate around the center point. Swath widths from 10-25 feet and applications of 25-50 gallons per acre are obtainable.

Injection sprayers

Injection sprayers use an electronic controller to monitor the spraying operation and are most used for roadside applications. The controller monitors equipment speed and swath width, and the operator adjusts the amount of chemical injected into the spray stream to maintain a constant herbicide rate of application. Equipment speed is measured with radar, or wheel or drive shaft rpm; swath width is previously defined for each set or cluster of nozzles.

By knowing which nozzles are on, the controller determines how wide a swath is being treated. When the equipment speed is known, the area being treated per minute can be determined. Because the desired rate of chemical per acre has already been defined, the controller changes the amount of chemical injected into the spray system when necessary to ensure the chemical is applied at a constant rate.

The chemicals are pumped directly from supply reservoirs, so there is no tank mixing. The spray heads, clusters of straight stream nozzles, tilt and adapt to cut and fill slopes. The controller warns the operator if the desired application rates cannot be met by the system. Another advantage is that spray pressure remains constant, so the spray pattern is uniform. Rates of chemical application can be changed at the operator's discretion. The controller can separately control multiple boom sections.

When the herbicide injection is made at the suction side of the pump, there is a delay of several seconds before the injected chemical reaches the nozzle or clears the hoses after injection has stopped. This time lag can represent a few hundred feet on the ground so the operator must be aware of right-of-way conditions well ahead of the equipment. Excess pump flow (bypass) must not be returned to the water tank since it contains the herbicide injected before the pump, and some will be returned to the tank. The nozzles in the spray head are set to spray sections of the roadside, and the controller is programmed to these widths. If the spray head is tilted up or down during application, these spray swaths change, and misapplication can occur when the controller is unaware of the change.

Handgun applications are possible if the unit has been previously programmed. It will automatically adjust the amount of material injected into the spray stream to give a spray volume with the correct percent of herbicide. Some units can print an application record or incorporate a GPS receiver to automate some spraying functions.

Invert Emulsion Applicator

Emulsifiable concentrates (ECs) form an emulsion when added to water. This is seen as milky color because the oil droplets are surrounded by water. When water droplets are surrounded by oil, it produces a mixture known as an "invert emulsion," that is similar in texture to mayonnaise, which is a good example of an invert emulsion. This formulation was developed to reduce drift because large droplets are formed when sprayed. The herbicide and the water are kept in separate tanks and are inverted at the pump. The invert emulsion is sprayed though a manifold generally mounted on the sprayer and conventional application nozzles are not used. The droplet does not dry as fast because it is surrounded by oil, helping to improve plant absorption. The oil surface in contact with the leaf surface should also improve penetration, making this type of application particularly advantageous in dry climates. Most liquid herbicide formulations can be applied with this type of equipment. If the mixture contains too much active ingredient, it cannot not form an invert emulsion.

Thinvert®

The Thinvert application system consists of a patented series of spray nozzles and a patented thin invert emulsion spray fluid. The nozzles enable low volume applications in the range of 3-5 gallons per acre. The uniform droplets help to reduce spray drift. Although the thin invert emulsion is only slightly more viscous than typical oil carriers, the oil film on the outside of the drop greatly reduces droplet evaporation and improves penetration through the leaf cuticle and bark. Most herbicides can be applied using this system, even low-use-rate water dispersible granules. Optimum spraying pressure is about 60 psi. The system can be adapted for backpack sprayers, ATVs, tractors, trucks and other vehicles.

Directed Liquid Application

Handgun

The handgun is a common and versatile type of spray equipment. It is used to treat accessible and inaccessible sites with spot and broadcast treatments. The handgun is attached to a hose that in turn is attached, through the pump, to any size tank holding the herbicide mixture. The handgun is usually adjustable to change the spray pattern from a solid stream to a wide cone pattern. Pump capacity (gallons per minute), hose diameter, and hose length limit the distance the applicator can move from the sprayer.

Pump pressure in combination with the size of the orifice will determine the size of the droplet. The length and diameter of the hose used will determine the required pump pressure. The handgun is usually used for high-volume applications, generally more than 100 gallons of solution per acre, but any volume from 5-500 gallons per acre may be applied based on the target weeds and the need for uniformity of application. When equipped with off-center tips, it can be used as a boomless sprayer for low-volume application. All types of liquid formulations and drift control products can be applied. The handgun can be equipped with a soil probe for injecting tree growth regulators into the soil around the base of a tree.

Backpack Sprayer

A backpack sprayer is a self-contained unit (tank and pump) carried on the back of the applicator (Figure 4). The capacity of these sprayers is usually between 2 and 5 gallons. This type of sprayer may have a mechanical agitator plate attached to the pump plunger. The entire tank may be pressurized, or only a small chamber that draws from the main tank. This equipment is useful for selective applications and spot treatments. Backpack sprayers can be adapted for a wide range of nozzle configurations. For example, they can be used with short booms, Boom Busters, or OC nozzles for broadcast treatments, or adjustable cone nozzles, swivel tips, and rollover nozzles to treat individual stems as foliage or basal treatments.

Figure 4. Backpack sprayer. Photo: USDA Forest Service Region 8, www.bugwood.org

Dual Spray Gunjet

The dual spray Gunjet is particularly useful for treating individual foliage with a backpack sprayer but is adaptable to all types of sprayers. The traditional Gunjet is fitted with a special type of rollover valve that accommodates two spray tips that distribute different volumes and patterns. Only the front tip operates. The spray tip can be switched immediately by rotating the desired tip to the front position. Typically, one tip is a narrow fan of about 15 degrees and the other one is a wider even fan tip of about 40 degrees.

Spaced Cuts/Cut Stump

Spaced cuts, also called hack-n-squirt treatments, are made around the tree with a small amount of herbicide added to each cut. The cuts, approximately 1-2 inches wide, are spaced around the tree at about a 1-inch interval, edge to edge. A small amount of herbicide, 1-2 milliliters, is added to each cut. This technique works best with water-soluble herbicides. Erratically spaced cuts result in incomplete control. Injection in the early spring during periods of rapid sap flow may cause reduced effectiveness of this technique.

Hardwood trees that are mechanically cut will generally resprout from the stump. Treating the cut surface of the stump with an herbicide immediately after cutting greatly reduces the incidence of sprouting. The herbicide should be applied to the cambial area of the stump (outer edge of the wood) where the bark and wood meet. It is not necessary to treat the entire stump. The herbicides effective in spaced cuts are also effective when applied to fresh cut stumps.

Wiping Applicators

Wiping applicators, also called rope wicks, rub the concentrated herbicide solution on the plant's leaf and stem surfaces. The rubbing surface can be a sponge, canvas, or a specially constructed rope that has an interior of parallel fibers for wicking and an outer sheath of nylon braid for durability. Handheld wiping applicators usually are shaped like hockey sticks with the blade as the wiper and the shaft as the reservoir. Small units can be attached to backpack sprayers. Larger units typically have sections of exposed rope with the ends embedded in PVC pipe, which serves as the reservoir. They are relatively inexpensive and easily built. Because only the weeds tall enough to contact the rubbing surface are affected, nonselective herbicides can be used selectively to release low-growing vegetation or vegetation below the treatment height. Drift does not occur with wiping applicators. They are difficult to use for broadcast applications on slopes or uneven surfaces.

Kline Injector

The Kline Injector is used to inject tree growth regulator into the ground. The injector allows applicators to place material into the soil by simply squeezing a handle. An electronic flow meter indicates exactly how much solution is injected. The injector automatically agitates the solution at programmed intervals to ensure constant suspension. The basic unit of the Kline Injector adapts easily to a backpack, hand- or pull-cart or skid-mounted unit. The unit is powered by a 12-volt battery that can be recharged by plugging it into the charger supplied with the unit.

Mower Applicators

Burch Wet Blade

The Wet Blade is rotary cutter in which herbicides are metered precisely out of the hub of the blade. The blade is like a lawn mower blade but has an aerodynamic design that holds fluid along the cutting edge even while the blade is spinning. Coupled with the blade is a radar gun to monitor equipment speed, a peristaltic pump that moves fluid from patented Flo-thru cells, and a computer that regulates the fluid flow onto the blade. As the blade cuts through a plant, herbicide is deposited on the stem.

Brown Brush Monitor

The Brush Monitor separates the operations of mowing and applying herbicides into two specialized chambers. The cutting blades in the first chamber can handle stems up to 2-3 inches in diameter, blowing the cut debris to the side of the mower. The remaining cut stubble is treated with herbicide in the second chamber. In the enclosed herbicide chamber, the stubble encounters two treatment phases. First, a row of nozzles sprays herbicides directly onto the stubble. Then the system catches any unabsorbed herbicides in a series of scrapers, brushes, and chains that wipe the product onto the stubble in the second stage of the application.

Sprayer Maintenance and Cleaning

Proper maintenance and cleaning are necessary to keep foreign materials out of the sprayer, which can clog nozzles and damage the pump and other sprayer components. Avoiding contamination is equally important. To prevent injury to nontarget vegetation, clean spray equipment thoroughly after using a product. Always follow the instructions on the label, which usually require triple rinsing of the sprayer and the use of a cleaning product. The following practices are recommended to maintain and clean your spray equipment properly.

Use water clean enough to drink. Small particles often found in water from ditches, ponds, or lakes can clog nozzles and strainers. If you are in doubt, filter the water as you fill the tank.

Check and clean strainers daily. Partially plugged strainers create a pressure drop and reduce the nozzle flow rate. Cleaning also prevents contamination as strainers can collect pesticide residue that is not removed with regular cleaning procedures. A second set of strainers is recommended for thorough cleaning without slowing down operations. Most sprayers have up to three different strainers depending on the type of pump.

Check and clean the ends of boom sections to reduce the risk of contamination. The ends can accumulate pesticide deposits. New end caps may have to be added to keep air from being trapped at the ends of the boom and to reduce potential for residue buildup. End caps with a removable plug are available to facilitate cleanout. Eliminating trapped air shortens nozzle turn-off time.

Do not use metal objects to clean nozzles. This will destroy the orifice. When a nozzle becomes clogged, always remove it for cleaning.

Flush a new sprayer before using. A new sprayer invariably contains metal chips and dirt from manufacturing. Remove the nozzles and strainers, then flush the sprayer and boom with clean water. Thoroughly clean each nozzle before reinstalling.

Clean the sprayer according to the type of pesticide formulation. Always follow the label instructions. Residues from some formulations are more difficult to remove from the tank. To remove residues of oil-based herbicides, such as esters of 2,4-D and similar materials, fill the tank one-quarter to one-half full with a water-ammonia solution (1 quart of household ammonia to 25 gallons of water) or a water-trisodium phosphate (TSP) solution (1 cup TSP to 25 gallons of water). Circulate the solution through the system for a few minutes allowing a small amount to pass through the nozzles. Leave the remainder of the solution to stand for at least 6 hours before pumping it through the nozzles. Remove the nozzles and strainers, and flush the system twice with clean water.

If using wettable powders, amine forms, or water-soluble liquids, rinse equipment thoroughly with a water-detergent solution (2 pounds of detergent to 30 to 40 gallons of water). Treat water-soluble materials the same as water-soluble liquids, allowing the water-detergent solution to circulate throughout the system for several minutes. Then remove the nozzles and strainers and flush the system twice with clean water.

Before storing your sprayer, add 1 to 5 gallons of lightweight oil, depending on the size of the tank, before the final flushing. As water is pumped from the sprayer, the oil leaves a protective coating inside the tank, pump, and plumbing. To prevent corrosion, remove the nozzle tips and strainers and dry them. Store parts that are prone to corrosion in a can of light oil such as diesel fuel or kerosene.

Dry Applications

Pellets

Pelletized formulations vary in size depending on the product. Smaller pellets can be applied with the equipment used to apply granular formulations. The advantage of pellets is that they can be spread by hand if the applicator wears appropriate protection. Backpack blowers have been adapted for use in spreading pelleted products. Pellets are a convenient method for treating inaccessible areas or small weed infestations. Several herbicide suppliers have developed hand applicators for use with their products.

Granules

Granular spreaders can be motorized or operated manually to apply granular and pelletized formulations. Spreaders can be especially useful for reaching areas not readily accessible to spray equipment. Granular applicators for treating rights-of-way sites distribute granular herbicides by way of spinning or whirling discs. This is usually a broadcast treatment that distributes granules evenly over the entire area. Granular spreaders typically are simple and inexpensive. Use presents minimal drift hazard, and there is less risk of exposure risk to the applicator. Granule formulations tend to be more expensive per acre than liquid formulations and are not suitable for foliar applications because granules will not adhere to most foliage.

Granule spreaders should be calibrated for a particular product formulation as particles differ in size and bulk density, and further adjustments may be necessary to accommodate the operator. When using a ground-driven applicator, the operator should maintain uniform speed to ensure that the application rate and swath width do not change. Traveling too fast for ground conditions can cause the equipment to bounce resulting in an uneven application. The spinning disc type spreaders may give poor lateral distribution, especially on side slopes. A granular applicator should be easy to clean and fill. It should have some type of agitation mechanism over the outlet holes to prevent clogging and keep the flow rate constant.

Summary

An array of equipment is available for applying herbicides. Each is designed for specific application situations. It is up to the applicator to use the equipment correctly. The applicator controls the quality of the results.

Study Questions

1. Spray nozzle performance depends on:
   a. All of the following
   b. Nozzle type
   c. Distance of nozzle from the target
   d. Operating pressure

2. Nozzle tips that are used evenly spaced on booms include:
   a. Regular flat fan
   b. Radiarc
   c. Whirl chamber
   d. Both A and C

3. Nozzles that produce a hollow cone spray pattern include:
   a. Off-center
   b. Raindrop
   c. Straight stream
   d. None of the above

4. Nozzles that should be angled 15-45 degrees from horizontal include:
   a. Raindrop
   b. Straight stream
   c. Whirl chamber
   d. Both A and C

5. An application device that rubs the herbicide on the leaf surface is:
   a. Trigger pump
   b. Spot gun
   c. Wiping applicator
   d. Handgun

6. A commonly used nozzle for boomless spraying which produces a flat fan pattern is:
   a. Regular flat fan
   b. Off-center
   c. Straight stream
   d. None of the above

7. Mechanical spray devices for boomless spraying include:
   a. Radiarc
   b. Directa-Spra
   c. Vibrating clusters of straight stream tips
   d. All of the above

8. A boomless spray device that contains a group of straight stream tips, like the fingers on your hand, and that oscillates is the:
   a. Directa-Spra
   b. Radiarc
   c. Spot gun
   d. CDA

9. A spraying device that uses a grooved spinning cup to break the spray stream into uniform droplets and applies low gallons per acre is:
   a. Handgun
   b. Boom-buster
   c. CDA
   d. Wiping applicator

10. Equipment typically used for spot treatment include:
    a. All of the following
    b. Backpack sprayer
    c. Trigger pump
    d. Spot gun

Equipment Calibration

Calibration is the process of measuring and adjusting the amount of chemical the equipment delivers to a target area. Measurement involves collecting or predicting the amount of spray solution the machinery will spray in a period of time. Application speed, nozzles, pressure or herbicide concentration should be adjusted to make sure the correct amount of herbicide is applied.

Measurement Phase

Equipment can be calibrated in several ways. For instance, the volume/area method can be used to determine how many gallons of solution will need to be applied per acre. For this method, start with a full tank of water and travel over a prescribed distance to create a treatment area of known size. Measure how many gallons it takes to refill the tank, and use this number to calculate gallons per acre. Or use the time/volume calibration method by holding a container under the nozzle to collect the output for a given amount of time. From this, it is possible to determine the number of gallons applied per minute. Gallons per acre can be estimated by knowing the width of the spray swath and the speed of application. Both of these methods can be used to determine the desired application rate and adjust equipment to achieve the desired rate.

Speed

Speed and solution output are inversely related. An increase in speed decreases output. Conversely, output increases by slowing down.

Nozzles

Changing nozzles has a direct effect on the application rate. The larger the orifice, the more material that will be applied. A smaller orifice will apply less material.

Pressure

Output also depends on pressure. Changing pressure influences application rate, but only by a small margin. It is the least effective way to change application rate. Raise the pressure to apply more material and reduce the pressure to spray less. Increasing the pressure can increase drift potential.

Concentration

The concentration of the herbicide in the tank can be adjusted. Increasing or decreasing the amount of carrier in the tank is an effective way of achieving desired application rates.

Arithmetic Phase

Measurements and adjustments are critical to proper calibration and application of herbicides. Adjustments can be made in several ways that are separate from the arithmetic supporting calibration. One of these involves working with the equipment and the second one involves working with a calculator, pencil, and paper. Improper calibration can occur due to arithmetic errors carried over from the measurement phase. The calculations usually involve three main findings: 1) the area to be treated; 2) how much a full tank can cover; and 3) how much product to put in the tank. The arithmetic can be done in a variety of ways. Below are a few simple methods used to properly calibrate herbicide applications.

Area

Problem 1: How many acres are there in an area 1,135 feet long by 460 feet wide? (1 acre = 43,560 ft^2)

Area = length multiplied by the width. Multiplying 1,135 feet by 460 feet, the area covered is 522,100 square feet (ft^2). Converting this to acres, one acre is equal to 43,560 ft^2. Dividing 522,100 ft^2 by 43,560 ft^2 per acre, the total area is 11.98 acres.

Problem 2: How many acres are treated on a right-of-way 32 miles long by 16 feet wide? (1 mile = 5,280 ft)

Solution: Convert 32 miles to feet (32 × 5,280 = 168,960 ft) and multiply this number by 16 feet wide, divide the total (2,703,360 ft^2) by the acre conversion number (43,560 ft^2) to get acres (62.1 acres).

Solution: As a rule of thumb, an 8-foot swath one-mile long equals one acre (16 ft by one mile = 2 acres, and so on). So, 32 miles times two 8-foot swaths is 2 times 32, which equals 64 acres (approximately).

Application Rate Gallons per Acre (GPA)

Problem 3: If you applied 1,600 gallons of spray to 64 acres, what is the application rate in gallons per acre (gpa)?

Solution: To find the answer, divide 1,600 gallons of spray by 64 acres, which equals 25 gallons per acre (gpa).

Application Rate in Pounds of Product per Acre

Problem 4: The product label calls for the application of 2 lbs of product per acre. How much product would be required to treat 64 acres?

Solution: 64 acres × 2 lbs per acre = 128 lbs of product.

Problem 5: If you treat 0.8 acre with 180 lbs of a granular herbicide, how many pounds of product was applied to one acre?

Solution: If 180 lbs of herbicide was applied per 0.8 acre, then 180 lbs divided by 8 will give the amount applied per 1/10 of an acre, or 22.5 lbs. Multiply 22.5 lbs by 10 to determine the amount needed for a full acre, which is 225 lbs of herbicide.

Product per tank

Problem 6: The sprayer tank holds 2,400 gallons and is calibrated to apply 40 gallons of solution per acre. The program calls for the product Oust at a rate of 3 oz per acre and Roundup at 2 qt per acre.

Part A: How many acres can be treated with a full tank?

Solution: The spray tank holds 2,400 gallons, and each acre requires 40 gallons of solution. Every 40 gallons equals one acre. Dividing the tank capacity (2,400 gallons) by the gallons applied per acre (40), you would apply a full tank to 60 acres.

Part B: How much Oust should be added to mix a full tank of spray solutions?

Solution: Because you can apply a full tank to 60 acres and are using 3 oz of herbicide per acre, you will need 3 oz per acre times 60 acres, for a total of 180 oz of Oust. Because Oust is a dry product, you need to convert ounces to pounds. To do this divide 180 oz by 16 oz per pound. You will need to add 11.25 lbs of Oust to the full tank of 2,400 gallons.

Part C: How much Roundup do you need to add to mix a full tank of spray solution?

Solution: You are adding 2 quarts per acre for 60 acres for a total of 120 quarts of Roundup. To convert quarts to gallons, divide the 120 quarts of Roundup by 4, as there are 4 quarts in a gallon, which is 30 gallons of Roundup.

Percent Solution

Problem 7: How many gallons of surfactant would you add to a 1,500-gallon tank at the use rate of ¼ %?

Adjuvants are usually mixed or expressed as "percent solution." One percent is equal to a part per hundred and is usually expressed as a decimal equivalent.

50 % = (50 divided by 100) = 0.50
25 % = (25 divided by 100) = 0.25
10 % = (10 divided by 100) = 0.10
5 % = (5 divided by 100) = 0.05
1 % = (1 divided by 100) = 0.01
½ % = (1/2 or 0.50 divided by 100) = 0.005
¼ % = (1/4 or 0.25 divided by 100) = 0.0025

Solution: In this problem take the ¼ % (0.25) and divide it by 100 to get the decimal equivalent (0.0025). Multiply 0.0025 times the number of gallons in the tank, 1,500 gallons, and you will need 3.75 gallons of surfactant to add to the tank.

Problem 8: You are preparing for a high-volume application of a 1 % spray solution with a 400-gallon tank mix. The instructions are to "spray to wet." How much product should you add to the tank?

Solution: One percent of 400 gallons is 4 gallons (400 × 0.01 = 4). So, you would need to add 4 gallons of product to the tank as it is filling.

Problem 9: A low volume application is to be made with a 5-gallon backpack sprayer applying a 12 % spray solution. How much product would be added to the tank?

Solution: Five gallons multiplied by 12 % (0.12) equal 0.6 gallons (5 x 0.12 = 0.6).

Rate per 100 gallons

Problem 10: The label instructs you to use 5 oz of surfactant per 100 gallons of mixed solution. How many quarts of surfactant will be required for a 1,500-gallon tank?

(16 fluid oz = 1 pint; 32 fluid oz = 1 quart; 128 fluid oz = 1 gallon)

Solution: If you have a 1,500-gallon tank you need to divide this number by 100. Then multiply the answer by 5 oz. Thus, 15 multiplied by 5 oz equals 75 oz of surfactant in a 1,500-gallon tank. To convert this into quarts, divide 75 oz by 32 oz per quart. The amount of surfactant you need to add to the 1,500 gallons is 2.3 quarts.

Altering Speed and Output

Problem 11: If a sprayer applies 30 gallons per acre (gpa), and is traveling at 10 miles per hour, how many gallons would be applied at 15 miles per hour?

Solution: Speed and output are inversely related, so increasing one decreases the other. Use this formula to calculate the answer: old rate × old speed = new rate × new speed.

Using the known variables, such as speed and output (rate), and divide by the new variable to find the missing variable. In this case, you would multiply the original speed (10 mph) and original output (30 gpa), then divide by the new speed (15 mph) to arrive at the new application rate of 20 gallons per acre. The equation looks like this:

(10 mph) × (30 gpa) divided by (15 mph) = (20 gpa) the new rate.

If speed increases, the number of gallons applied per acre must decrease.

Problem 12: A sprayer is applying 40 gallons per acre at 12 mph, how many gallons per acre would be applied at a new speed of 10 mph?

Solution: When speed decreases, output must increase. Using the formula in the previous problem, the original values of 40 gpa at 12 mph would be equal to the new values of 10 mph at 48 gpa. The new application rate will increase because the equipment is moving slower. Here is the equation:

(12 mph) × (40 gpa) divided by (10 mph) = (48 gpa) the new rate.

Problem 13: A sprayer applies 20 gallons per acre at 12 mph. How fast would it have to travel to apply 30 gallons per acre?

As with the previous problem, if the number of gallons per acre increases, the mph must decrease. Multiply the original speed and output (20 gpa × 12 mph = 240), and then divide by the new output (30 gpa) to arrive at the new speed, which is 8 mph. Here is the equation:

(12 mph) × (20 gpa) = (8 mph) × (30 gpa)

Partial Tank

Problem 14: The sprayer is applying 40 gallons of spray solution per acre and the tank size is 2,200 gallons. The mix is Karmex at 6 lbs per acre. When there are 300 gallons of solution left in the sprayer tank, how much Karmex do you need to add to refill the tank completely?

Solution: A full tank is 2,200 gallons, but there are 300 gallons left. As a result, you would only need to add 1,900 gallons to fill the tank (2,200 – 300 = 1,900). The 1,900 gallons of fresh water divided by 40 gallons per acre solution rate equals 47.5, which is the number of acres that each require 6 lbs of Karmex. Multiplying 47.5 acres times 6 lbs of Karmex for each square acre, equals 285 lbs of Karmex that will need to be added before adding the 1,900 gallons of fresh water needed to fill the tank completely.

Pump Capacity

Problem 15: How many gallons per minute must a pump supply to apply 30 gallons per acre when treating a 16-ft swath at 12 miles per hour?

Solution: To calculate gallons per minute, you must first determine how many minutes it takes traveling at 12 miles per hour, to go one mile. This can be determined by dividing 60 minutes per hour by 12 miles per hour, which is equal to 5 minutes per mile. Next, determine how many acres were covered in one mile of right-of-way treating a 16-ft swath. One mile of right-of-way with an 8-ft swath is equal to one acre. Consequently, one mile with a 16-ft swath is 2 acres. The only other calculation required is to determine how many gallons to apply over the two acres. Because you already know that 30 gallons will be applied on one acre, then you would need to apply 60 gallons on 2 acres. Because 2 acres are covered per mile and it takes 5 minutes to cover one mile, then 60 gallons will be applied every 5 minutes. Dividing 60 gallons by 5 minutes, the gallons applied per minute will be 12, which is the minimum pump capacity required to make a proper application.

Summary

To properly calibrate the amount of material to apply to a given area, it is important to know a couple of formulas. For example, a 1-mile strip of an 8-foot swath is equal to 1 acre. In another example, the original output times the speed is equal to the new output times the new speed. Knowing the basics such as how to properly calibrate equipment and calculate the correct amount of herbicide that needs to be added to a tank, avoids misapplications and and helps to achieve effective weed control.

Knowing how to calibrate equipment, adjust for accurate calibration, and how to figure the number of acres and chemical requirements are the most important concepts. Minor application errors may seem unimportant when considering the output of a single nozzle, but when multiplied by many nozzles on a boom across many miles of treatment, it can have a tremendous impact at the end of a day, week, or job if not corrected.

Study Questions

1. How many acres are in an area 24 feet wide and 12 miles long?
   a. 12
   b. 24
   c. 36
   d. 48

2. If you applied 1,200 gallons of spray solution to 50 acres, what was the application rate in gallons per acre?
   a. 12
   b. 24
   c. 36
   d. 48

3. If the product is to be applied at 3 oz per acre and you are to treat 75 acres, how many pounds of herbicide will you apply?
   a. 8
   b. 10
   c. 12
   d. 14

4. The sprayer has a tank of 1,200 gallons and is calibrated to apply 30 gallons per acre. How many acres can be treated with a full tank?
   a. 40
   b. 60
   c. 80
   d. 100

5. How many gallons of surfactant would you add to an 800-gallon tank at the use rate of ¼ %?
   a. 0.25
   b. 1.67
   c. 2.00
   d. 3.25

6. How much product would need to be added to a 3.4-gallon tank to have a 15 % spray solution?
   a. 0.1
   b. 0.5
   c. 1.1
   d. 2.0

7. If a sprayer applies 40 gpa while traveling 8 mph, how many gpa would be applied at 12 mph?
   a. 12.8
   b. 16.4
   c. 22.3
   d. 26.7

8. A sprayer is applying 12 gallons per acre at 15 miles per hour. At what speed would it apply 30 gallons per acre?
   a. 2
   b. 4
   c. 6
   d. 8

9. How many gallons per minute must a pump deliver to supply 24 gallons per acre when treating a 8-ft swath at 10 miles per acre?
   a. 4
   b. 6
   c. 8
   d. 12

10. With the sprayer stationary, you collect 1 pint (16 oz) of solution in 15 seconds from one nozzle. There are four nozzles with a combined swath width of 8 feet. How many gallons per acre will you be applying when traveling at 10 miles per hour?
    a. 12
    b. 16
    c. 20
    d. 24

General Problems in Herbicide Application

Herbicides are used to keep utility and pipelines work areas, and storage sites clear of weeds in order to maintain safe and reliable service. They also play an important role in keeping railroad tracks and roadsides weed-free to allow safe, unobstructed traffic flow. By choosing the right herbicides and applying them correctly, herbicides can achieve the intended goals without harming the environment.

Environmental Fate

Environmental fate refers to what happens to the herbicide after it is applied to industrial areas. When an herbicide leaves the application equipment, it is subject to some well-defined environmental processes. These processes are influenced by the chemical and physical properties of the herbicide and the spray solution. They move herbicides around in the environment or restrict their movement and regulate the breakdown of the herbicides.

Transfer Processes

Herbicides in the Air

Once an herbicide is released into the air, currents can move the herbicide off target. Movement in the air can be reduced, but it cannot be eliminated completely. Movement of herbicides off target is an important concern to applicators. Uncontrolled movement in air can be from particle drift or volatilization. Both have the potential to cause damage to areas outside the treated site and to non-target organisms.

Drift: Particle drift occurs when wind physically moves the herbicide and carrier from the target site during the spraying operation. Spray drift can damage susceptible plants adjacent to the area or unintentionally expose animals or people to a chemical. An application should cease if the spray cannot be kept on the target area.

Drift potential increases under the following conditions:

- as the distance from the spray nozzle to the ground increases,
- as droplet or particle size decreases, and
- as wind speed increases.

Use the following practices to minimize drift:

- Spray at lower pressure.
- Use spray tips with narrow discharge angles.
- Use the largest practical nozzle openings to obtain large droplets.
- Reduce the distance between the nozzle and the weed.
- Reduce application speed.
- Use drift control additives that increase solution viscosity.
- Spray during low wind speeds. Be mindful of inversions and do not spray when there is no wind.
- Use attachments or modifications to spray equipment, such as shielded booms and drift-reducing nozzles.

Evaluate the wind speed and direction before spraying to determine potential for damage to occur. To avoid harm to sensitive areas downwind, such as homes, water, and crops, spray when wind speeds are low and the wind is not blowing toward sensitive sites. Do not make spray applications when winds are calm or when conditions favor inversions. If in doubt, do not spray.

Volatilization: This can occur during or after a spray application when the herbicide changes into gas or vapor that is readily moved by wind. Herbicide evaporates as droplets fall from the sprayer or residue settles on leaves, soil, asphalt, gravel, and other surfaces.

Potential for volatility increases under the following conditions:

- as air temperature increases,
- as surface temperatures increase, and
- as relative humidity decreases.

Volatility can occur hours after an area is treated, especially during a hot summer afternoon. Vapor losses are reduced or stopped when the herbicide becomes bound or adsorbed to the plant and soil surfaces or penetrates the foliage or soil. Volatilization is not as common as particle drift, but it has the potential for moving the herbicide a greater distance from the target.

Herbicide products vary greatly in volatility. Some pesticide active ingredients can be formulated as both oil-soluble esters and water-soluble amines. The esters are always more volatile than the amines. Because of their oil-solubility, esters provide better penetration of the plant cuticle than the amines; but are a greater drift hazard due to their volatility. Esters typically are used during the cool weather because of superior efficacy, but when the weather warms up the amines are less of a drift hazard and typically provide just as good control. Esters are all formulated as emulsifiable concentrates making them more prone to volatilization. Their oil-soluble active ingredients are packaged with an emulsifier that allows them to be mixed with water. Choosing nonvolatile herbicide formulations and avoiding application during periods of excessively high temperatures can reduce volatility. Some labels note temperature limits.

Herbicides in Water

Flowing water (creeks, streams, ditches) is a means for herbicides to move in the environment. Herbicides can reach water as a result of direct application, drift, spills, incorrect filling, cleanup, disposal methods, erosion, runoff, and leaching. Water from treated ditches flowing into fields can damage crops and contaminate water for drinking, fishing, recreation, and irrigation. To prevent herbicides from entering and contaminating the water, turn off the sprayer when crossing and leave buffer strips along the water's edge.

Herbicides in Soil

Some or all of most herbicide applications reach the soil eventually. Herbicides can be washed from plant leaves and enter the soil when it rains, or they can be transferred to the soil on dead plant parts. High-volume liquid applications of herbicides can drip onto the soil, and some herbicides are applied to the soil directly. The environmental impact depends greatly on an herbicide's fate in the soil.

Herbicide moves in the soil by leaching, or downward movement through the soil, or by moving laterally across the soil surface or within the soil profile, usually in conjunction with flowing water. The amount of herbicide lost through leaching depends on several factors:

- adsorption (the attraction between soil particles and herbicide molecules)
- soil texture (amount of sand, silt and clay particles)
- herbicide solubility
- amount and intensity of rainfall, and
- degree of soil compaction.

Usually, the greatest amount of herbicide leaching occurs in sandy soils and the least in compacted soil or in soils that contain clays or organic matter. Desirable trees can be injured if roots absorb the herbicide. This can be a problem when soil-active herbicides are used around roadside plantings or when they are used where the right-of-way passes through forests, along the edges of woodlots, near shade trees, or orchards.

Lateral movement becomes a concern following an intense rainfall event after an application, or when soil-active herbicides have been applied to saturated soils that cannot soak up the rain. Light showers are more likely to move the herbicide into the soil and reduce lateral movement. Use caution when applying herbicides on moderate to steep slopes, saturated or frozen soils, or on areas susceptible to water erosion as all soil-active herbicides can move laterally. Movement downslope can be a problem after guide rail applications as guide rails are often placed on fill slopes. The presence of dead vegetation or scalloped edges will be visible throughout the growing season and possibly into the next year.

Compaction caused by construction or drying and hardening of soil during drought periods encourages surface water flow. As water flows over the treated site, it picks up some of the herbicide and moves it laterally along the surface as runoff, which can be deposited where it is not wanted. Treated soil can injure plants if carried off the application site by water erosion. In sloping areas, use bare ground treatments with caution. Downward leaching can move herbicides from inches to a couple of feet, whereas runoff or lateral movement can move herbicides much greater distances.

Removal Processes

Persistence in soils is an essential feature of herbicides used for residual weed control. Many of the uses of soil-active herbicides require residual activity for several months. Herbicide residues must persist for several weeks for pre-emergence treatments to be effective because seed germination can occur throughout the growing season. Soil and herbicide characteristics as well as environmental factors influence herbicide degradation and breakdown.

Adsorption

After application, herbicides may become adsorbed (attached to soil particles) to clay and organic matter particles much like iron is attracted to a magnet. The extent of this attachment increases as the percentage of organic matter and/or clay increases. This reduces the amount of chemical available to plants and slows both leaching and microbial breakdown. Increased soil moisture reduces herbicide adsorption.

Plant Uptake

Herbicides absorbed by plant roots can be either accumulated or be deactivated in the plant. Generally, only a relatively small amount of herbicide is lost in plant residue, but once herbicides are taken up within the plant, plants can degrade sizable amounts of the herbicides.

Degradation Processes

The environmental processes responsible for breaking down herbicides include microbial breakdown, chemical breakdown, and photodecomposition.

Microbial Breakdown

Microorganisms (microscopic living organisms in the soil such as fungi and bacteria) feed on all types of organic materials as well as herbicides. Specific microorganisms readily attack some herbicides because of their chemical structure. Temperature and moisture affect microbial growth. Warm moist soils are ideal for microbial activity and promote rapid breakdown of herbicides. Microbial breakdown is the main way herbicides are degraded in the environment. Persistent herbicides usually are not broken down easily by microorganisms and are only slightly soluble in water.

Chemical Breakdown

Reaction with water (hydrolysis), salts, acids, and other substances in the soil can deactivate herbicides. These reactions increase in warm, moist soils, which are the same environmental factors that accelerate microbial breakdown.

Photodecomposition

Most herbicides undergo some level of photodecomposition (breakdown by sunlight). Rainfall typically moves herbicides away from the soil surface and direct sunlight on rights-of-way.

Environmental Issues

Non-Applicator Exposure

Be aware of crews, people, or equipment near the treatment area.

- Avoid spraying when spray drift can contact bystanders or work crews.
- Avoid spraying equipment or tools used by others.
- When making a roadside application in traffic, space the trailing vehicle farther back from the sprayer to reduce the potential for the spray to be blown onto following motorists.
- Keep herbicides in properly labeled containers and do not make them easily accessible to children.
- Treat mailboxes at their base rather than spraying over the top.

Pollinators

Bees and other beneficial pollinators (insects that carry pollen from one flower to another) should be considered when making herbicide applications. Flower pollination by honeybees is necessary for many agricultural crops. In general, herbicides are not hazardous to pollinators. Near apiaries, it is best to apply herbicides in the early morning or in the evening when bees are not active, but realize that the label language of some products may not allow application at this time. Whenever possible, warn the beekeeper so precautions can be taken to protect the hives.

Wildlife

Herbicides properly applied are not hazardous to wildlife since actual exposure is very limited. But wildlife can be influenced by the plant response to the herbicide treatment. When diverse plant cover develops, such as on utility right-of-way, habitat for certain species, including deer, rodents, songbirds, and butterflies, is enhanced with the improved protective cover.

A few herbicides have the potential to be toxic to fish. Concentrations used for aquatic weed control are carefully regulated to prevent injury to these and other aquatic organisms from the herbicide application. The greatest hazard to aquatic organisms occurs with the emulsifiable concentrate formulations because the organic solvents in the formulation are often toxic.

Endangered Species

Right-of-way and industrial areas may be ideal locations for threatened and endangered plant and animal species. In areas of intense agriculture or urbanization, rights-of-way and industrial areas may be the last remnant of undisturbed land. Wetlands containing endangered species may be adjacent to a right-of-way. Federal and state regulations may dictate management practices that prevent damage to endangered species.

Livestock

If the right-of-way crosses pastures or areas where livestock are confined, applicators should be aware of potential hazards. These are often addressed on the product label. For example, some plants, such as wild cherry or Johnson-grass, may become more attractive to livestock after spraying. As these treated plants respond to the herbicide, they produce prussic acid or cyanide that can kill animals. Also, if animals graze on a recently treated areas, they can also ingest herbicide residue from treated plants. The herbicide could be illegal residue in the meat or milk, thus restricting the sale of these products. Be sure to observe any grazing or hay cutting restrictions, as outlined on the herbicide label.

Biological Accumulation

Accumulation of some pesticides in the food chain raised public concern in the early 1960s. At each higher level in the food chain, non-degraded pesticides accumulated in the predator as the predator consumed its prey. This phenomenon (biological accumulation) had a detrimental effect on wildlife, especially predatory birds. Biological accumulation was associated with the organochlorine insecticides. These oil-soluble materials were not easily degraded in the environment and accumulated in the fat of animals. All pesticides are tested today for their ability to accumulate in living organisms. None of the herbicides used for vegetation control accumulate in the food chain.

Brownout

Brownout is the discoloration of plant foliage after an herbicide application. In highly visible areas, brownout can become a serious public relations issue because its occurrence is an unsightly contrast to the surrounding green vegetation. Brownout can occur as dead foliage resulting from brush and broadleaf weed control, or yellow (chlorotic) grass treated with a growth regulator. Several herbicide treatment methods can reduce the potential of brownout, including late-season foliage treatments, dormant basal treatments, cutting tall stems and treating the stumps, or using products that do not cause rapid foliage discoloration. Treating weeds when they are small reduces the visual effect and eliminates the need for cutting. Applying herbicides to brush late in the growing season reduces the visual impact because the leaves blend with the developing fall colors.

Backflash

Backflash is the uptake of herbicide by untreated trees adjacent to treated trees. This uptake occurs through root grafts, which can be a problem with trees that originate from root sprouts, such as aspen, oaks, or sassafras. It can occasionally occur between unrelated species. This is not a common occurrence, but if it happens, it would usually be noticed along the edge of a right-of-way or industrial areawhere affected trees are located out of the treated area but show effects similar to the treated trees. With some herbicides, treated trees or shrubs can release herbicide into the soil following their death. Occasionally a neighboring susceptible non-target plant can subsequently take up the released herbicide and show signs of injury.

Spills

An applicator is legally responsible for cleaning up and decontaminating any pesticide spill that occurs when mixing, applying or storing pesticides. Inform the supervisor immediately if a spill occurs so they can contact the state agency responsible for spills. Follow these procedures in the event of a serious spill.

- Confine it to the site and keep it out of water. Keep a shovel and stiff broom or other clean up materials on the truck.
- Work carefully and do not hurry.
- Do not let unauthorized people enter the area until the spill is completely cleaned up.
- If the product was spilled on a person, wash it off immediately.
- Do not leave a spill until it is cleaned up or responsible help arrives.
- Keep label and SDS sheets available to assist emergency personnel.
- Control, contain, call, and clean up.

Pesticide Fires

Although the majority of pesticide active ingredients are not flammable and do not present a fire hazard by themselves, many of the solvents used in liquid formulations are highly flammable. For this reason, consider all liquid pesticides a potential fire hazard. It is important to have a fire plan for each storage facility which outlines the appropriate measures to take if a fire occurs. Be sure the plan contains emergency telephone numbers for the pesticide manufacturers and local emergency-response personnel.

Adjacent Water, Wells, and Groundwater

The occurrence of herbicides in water and wells adjacent to rights-of-way or industrial sites is more likely to occur in limestone areas, sandy soils, and areas having high water tables. As the limestone dissolves, sinkholes develop. Herbicides can be washed directly into the underground water system by way of sinkholes.

Sandy soils are conducive to herbicide movement into underground water supplies since herbicides that have the potential to leach move readily through these soils. High water tables pose a problem because herbicides do not have to leach far to reach groundwater systems. In these instances, the herbicides move so quickly through the soil there is limited opportunity for soil adsorption and microbial degradation.

The following factors enhance the potential for groundwater contamination:

- herbicides with long soil persistence
- herbicides with high soil mobility
- application to soils with little adsorptive capacity, and
- soil with water table close to the surface.

The herbicide label may restrict the use of a product in certain geographic areas of the country. Always refer to the product label for geographic restrictions. When treating areas adjacent to aquatic sites such as ponds, use herbicides that are labeled for that purpose. Pesticides applied into standing water must have an aquatic label.

Application Issues

Obstructions and Physical Barriers

Fixed obstructions, such as switch stands, whistle boards, delineator posts, light posts, telephone poles, and guide rails can interrupt the spray pattern. Narrow county roads have obstructions such as fences, trees, ornamental plants, and mailboxes. Skips occur where the sprayer is turned off and on to avoid these obstacles.

Spraying around obstructions is accomplished by adapting the sprayer to miss or clear the most common ones, or by using booms with drop nozzles, or nozzles that do not require a boom such as Boom Busters or off-center nozzles. Obstructions such as workers or parked vehicles sometimes mean small areas are left untreated, and spot applications may be needed.These interruptions represent a small percentage of the total spray operation. Keep in mind that certain herbicides are corrosive and can have negative effects on automobiles, buildings, and other metal surfaces.

Ditches, Culverts, and Bridges

Ditches are important for removing surface water but can be a problem when adjacent to the right-of-way or industrial sites. Because moisture conditions differ, the size and species of weeds in the ditch may be different than those on the adjacent to industrial sites and may not be controlled with the same herbicide.

Be aware that water in a ditch can transport the herbicide off the industrial site moving the herbicide into a field, irrigation ditch, or a source of drinking water.

Check the herbicide label for guidance when treating in or around ditches. Turn the sprayer off when crossing a pool or body of water, regardless of its size. Treat the area around culverts and drainage inlets carefully. Leave a buffer zone around the water's edge. Strips of green vegetation serve as natural filters, catch eroded soil, and reduce the possibility of the herbicide entering the water source.

Highway Traffic

Highway traffic interferes with chemical application. The density of the traffic may require the use of slow-speed hazard signing and trailing or escort vehicles. These are important to your safety as well as to the motorists. Passing and oncoming traffic, especially trucks, creates air currents around the application equipment. These currents distort the spray pattern and can blow the spray droplets off the industrial site, thus increasing off-site drift. Drift is more of a problem on small, narrow sites or medians than on larger areas such as interchanges.

Traffic or pedestrians at intersections or highway rail crossings may not realize that you are spraying as you approach. Motorists or pedestrians may not be able to move to avoid the sprayer. Be prepared to turn the sprayer off. If possible, schedule the application to avoid peak traffic periods.

Accessibility and Terrain

Accessibility can restrict equipment or the method of application. Sites may be fenced off, located behind guide rails, hedgerows, and sound barrier walls. Wet ditches can cut off access to a section of the right-of-way. Steep slopes limit the type of equipment normally used to treat the site. Inaccessible areas should be spot treated by handguns or backpack sprayers. Cut slopes may need to be treated more often than fill slopes because weeds are more visible.

Over-application

Over-application of herbicide can result in injury to both desirable and undesirable plants, loss of selectivity, bare ground, and soil erosion. It is often the result of incorrect calibration or overlapping spray swaths. Both are avoidable by paying attention to application details. Be aware of these potential problems, particularly when treating irregularly shaped areas with broadcast application methods. Over-application often occurs when following the edges of a treated area to narrow points or by leaving the sprayer on while making turns in the treated area. Colorants can be added to the spray solution to make the treated areas more visible.

Invasion by Other Weeds and Herbicide Resistance

Weeds not controlled by the herbicide mixture will be released, and new species can invade the treated site. This can occur with perennial plants recovering from vegetative reproductive tissues or with annuals germinating from new seeds. Biotypes of some weeds such as kochia, annual ryegrass, and Russian thistle can develop resistance to herbicides previously used on the site. Applicators should be aware of resistant weeds and integrate different control methods or herbicides with different modes of action to prevent resistant weeds from becoming established.

Loading and Mixing

Loading and mixing along the industrial site can inadvertently contaminate water sources when water is taken from creeks, ditches, and fire hydrants. Most states require equipment to have devices to avoid back siphoning or the flow of water from the spray equipment back into the water source. Using an air gap in the filling line is the simplest way to prevent back siphoning (Figure 1). The water line is never inserted into the spray tank. Use a nurse tank that only carries water to avoid herbicide contamination of streams, lakes, or ponds when filling the spray tank with water. Make sure the correct valves are opened and closed on sprayers that have separate tanks for concentrates and water.

Some states have regulations regarding using open water sources for mixing herbicide tanks, and strict distance requirements when mixing chemicals near open water sources. Avoid mixing chemicals next to an open water source. After loading water, move the vehicle away from the creek or ditch before mixing to reduce the potential for a spill into the water.

Load the chemical concentrates carefully. Mixing at an untreated area on the right-of-way helps to reduce applicator exposure. Some states require spill containment equipment when mixing herbicide tanks. Diquat and glyphosate may be rendered completely ineffective by soil particles suspended in the water.

Empty containers should not be discarded on the right-of-way or at industrial sites. Secure them so they will not blow off the equipment and return them to the operations base for proper disposal. Close chemical containers after each use to prevent spills. Do not use empty herbicide containers for any other purpose.

Figure 1. An air gap prevents herbicide solution from contaminating water sources. Photo: Jan Hygnstrom

Public Relations

Right-of-way operations are highly visible to the public, leaving weed control managers open to criticism. Many of these negative encounters can be avoided by being considerate of public concerns and by being knowledgeable and informed. Use extra care in applying pesticides along rights-of-way, and adjust the timing of applications to reduce brownout.

Differences in Perception

Applicators and those who complain about their work sometimes hold different points of view. The applicator may see brownout of certain species as proof the job has been done properly. On the other hand, property owners may see the situation as a violation of the green space, which they consider an extension of their own property. Property owners may know right-of-way maintenance occurs but may not understand why it is necessary or how it is done. They are concerned about personal safety and how the work may affect the landscape's appearance. For example, property owners often worry whether the herbicides will contaminate their well or their garden vegetables.

Do not patronize or dismiss the concerns of property owners. Property owners may not appreciate an applicator telling them they know what they are doing or that no law requires them to tell the owner what they are doing. The best way to deal with the concerns of property owners before or during treatment is to answer their questions and respond to concerns clearly and directly. Be professional and view questions as an opportunity to educate and improve communication with the public.

Carelessness

Often, problems of pesticide application are best resolved by improving operational practices. Most problems are within the applicator's control and are not "unavoidable accidents." Commonly occurring violations or misuses result in significant and visual off-target impacts. Misuses include careless mixing or pesticide transfers that result in spills; roadside disposal of leftover spray mixture at the end of the day; contamination of surface water through drift, spills or improper disposal; and injury to off-target vegetation due to drift, volatility or lateral movement of pesticides.

Misuses relating to actual application usually are due to carelessness. It is possible to follow label instructions and still be careless. Avoid unnecessary risks by following these precautions:

- Familiarize yourself with the area to be treated before making an application.
- Take all possible steps to avoid drift.
- Use proper pesticides and equipment for the job.
- Check application equipment regularly to make sure that it works.
- Wear proper protective equipment.

Other concerns

Nearly all parts of a right-of-way or industrial areas are in some form of drainage system. It is easy to recognize drainage ditches, but greenways, contours and overflow areas can be less obvious. Pesticide treatments should have minimal or no effect on these areas. Follow label directions and precautions where right-of-way and industrial runoff water flows into sensitive areas or where the water is used for irrigation or for livestock. Sometimes pesticide applicators can cause problems for a landowner without realizing it. Do not cross tiled fields with heavy equipment when the ground is soft. Avoid crossing one hog lot or chicken yard into another without first cleaning the mud off equipment tires. Communicable diseases such as hog cholera can be spread from one area to another by unwittingly tracking contaminated soil. If the death or injury of an animal is blamed on a pesticide application, a veterinarian should examine the animal. If investigation shows that compensation is justified, make sure to respond fairly and promptly.

Often, a landowner's questions about pesticide applications go unanswered or are not answered to the owner's satisfaction. These situations generally result in a formal complaint and polarized viewpoints. Landowners think the applicator is hiding something, and the crew supervisor may view the questions as a nuisance. A simple solution to this problem is to know the answer to the landowner's question before it is asked, and to answer it respectfully. A quick, direct response to the public's concerns facilitates communication and results in a more enjoyable working environment.

Be prepared to respond to these and other commonly asked questions:

- What are herbicides, and why are they used?
- Do the herbicides affect birds?
- If my garden becomes contaminated, is it safe to eat the vegetables?
- Is it safe to eat wild berries from areas that have been sprayed?
- What kind of precautions are taken to make sure that pesticides do not get into groundwater supplies?
- Do herbicides and other pesticides pose any risk to me and my family?
- What happens if herbicides wash from the treated area into my pond; how does it affect the fish?
- If my cattle graze on treated rights-of-way, is the milk and meat safe to consume?

Summary

Herbicides help to maintain safe, reliable rights-of-way and industrial areas. With proper selection and correct application of chemicals, herbicides can be used to improve worker and public safety with no harm to the environment. There are a variety of potential problems and hazards associated with the changing conditions on a right-of-way that the applicator must consider during application. Following the label will prevent most environmental problems.

Study Questions

1. Physical problems encountered when spraying on roadsides include:
   a. All of the following
   b. Highway traffic
   c. Guide rails
   d. Steep slopes

2. The discoloration of plant foliage after herbicide treatment is:
   a. Volatilization
   b. Brownout
   c. Drift
   d. Backflash

3. The movement of herbicide down through the soil is called:
   a. Brownout
   b. Drift
   c. Photodecomposition
   d. Leaching

4. Leaching:
   a. All of the following
   b. Is necessary to move the herbicide into the root zone
   c. Can be a problem when off-site trees pick up the herbicide through their roots
   d. Is accentuated in sandy soil

5. Lateral movement:
   a. All of the following
   b. Can be encouraged by soil compaction
   c. Can occur on steep slopes
   d. Can occur when soil-active herbicides are applied on saturated soil

6. Potential well contamination is of particular concern in:
   a. All of the following
   b. Soils overlying limestone
   c. Sandy areas
   d. Areas with high water tables

7. Water flowing from the spray equipment to the water source is called:
   a. Drift
   b. Lateral movement
   c. Back siphoning
   d. Backflash

8. When wind carried the chemical and its carrier off the target area, this is called:
   a. Lateral movement
   b. Leaching
   c. Drift
   d. None of the above

9. Drift can be reduced by:
   a. All of the following
   b. Using low pressure
   c. Using the smallest nozzle possible
   d. Using nozzles with large fan angles

10. Winds are usually calmest during:
   a. Early morning
   b. Mid-day
   c. Early evening
   d. Both A and C

Answers to Study Questions

Why (Pages 5–12)

1. a	2. b	3. d	4. d	5. d
6. c	7. b	8. a	9. d	10. d

Plant Biology (Pages 13–22)

1. c	2. c	3. d	4. c	5. d
6. c	7. b	8. b	9. d	10. d

Vegetation Control (Pages 23–26)

1. c	2. c	3. b	4. a	5. c
6. d	7. d	8. a	9. c	10. c

Characteristics of Herbicides (Pages 27–36)

1. d	2. c	3. b	4. c	5. a
6. d	7. c	8. b	9. d	10. b

Weed Control (Pages 37–46)

1. d	2. d	3. d	4. c	5. d
6. a	7. b	8. d	9. d	10. d

Herbicide Application Equipment (Pages 47–56)

1. a	2. d	3. b	4. d	5. c
6. b	7. d	8. b	9. c	10. a

Equipment Calibration (Pages 57–62)

1. c	2. b	3. c	4. a	5. c
6. b	7. d	8. c	9. a	10. a

General Problems (Pages 63–71)

1. a	2. b	3. d	4. a	5. a
6. a	7. c	8. c	9. a	10. d

Frannie L. Miller
Pesticide Coordinator

Authors
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