



Training Manual for Right-of-Way Vegetation Management

Contact: Lee H. Townsend, Department of Entomology

Preface

This publication was prepared by a committee of specialists in the University of Kentucky Cooperative Extension Service, personnel in the Vegetation Management Association of Kentucky, and members of the Division of Pesticides of the Kentucky Department of Agriculture. When used in conjunction with the Environmental Protection Agency (EPA) Core Manual, *Applying Pesticides Correctly*, this manual will provide information to meet minimum EPA standards for certification of commercial applicators in Category 6, Right-of-Way Pest Control. Additional helpful information for right-of-way applicators may be obtained from the Cooperative Extension Service, regulatory agencies, pesticide labeling, pesticide dealers and industry representatives, and utility rights-of-way company personnel involved in vegetation management.

The following persons contributed to this training manual:

J. D. Green, *Extension Weed Specialist*
J. R. Hartman, *Extension Plant Pathologist*
M. P. Johnson, *former Extension Entomologist*
J. E. Primus and D. L. Spatcher, *Du Pont Company*
J. Stringer, *Extension Forester*
W. C. Wheeler, Jr., *Louisville Gas and Electric Company*
L. H. Townsend, *Extension Entomologist, Editor*

Contents

Introduction	2
Goals	2
Planning Requirements	2
Characteristics of Rights-of-Way	3
Terrain and Vegetation	3
Levels of Vegetation Management	3
Biology and Ecology of Weeds	4
Classification	4
Life Cycle	4
Dissemination and Persistence	5
Stages of Vegetation Succession	6
Vegetation Management Control Methods	6
1. Biological Control	6
2. Mechanical Control	6
3. Chemical Control	6
Classification of Herbicides	6
Method of Application	6
Selectivity	7
Chemistry	7
Other Herbicides	8
Herbicide Application Methods and Equipment	8
Soil Factors That Influence Herbicides	9
Soil Texture	9
Organic Matter	9
Soil pH	9
Soil Moisture	9
Environmental Factors That Influence Herbicides	9
Soil-Applied Herbicides	9
Foliar-Applied Herbicides	10
Public Relations Concerns	10
Environmental Concerns	11
Groundwater Advisories	11
Endangered Species Act	11
Calculating Rates	11
Mixing	12
Glossary	12

Mention or display of a trademark, proprietary product, or firm in text or figures does not constitute an endorsement and does not imply approval to the exclusion of other suitable products or firms.

Introduction

Rights-of-way are the areas involved in common transport. They are essential for the proper functioning of a modern society and include:

- federal, state, county, and township highways and roads;
- public airports;
- railroads;
- electric utilities (including substations, switching stations, transmission lines, and distribution lines);
- pipelines (including pumping stations);
- public surface drainageways;
- public irrigation waterways;
- banks of public bargeways and areas around locks and dams; and
- bicycle, bridle, and other public paths or trails (outside established recreational areas).

Rights-of-way may be found everywhere and are placed in every type of terrain, soil, climate, vegetation complex, and land-use area. Vegetation management on rights-of-way is desirable and necessary for both aesthetic and practical reasons, including:

- safety due to improved visibility on transportation rights-of-way,
- reduced fire hazard by encouraging less fire-prone plants,
- soil erosion control,
- assured continuity of utility services,
- promotion of public health and comfort, and
- ornamental values enhanced by control of nuisance vegetation.

Rights-of-way must generally be kept free of large brush or trees. That is, they must be maintained at an early stage of plant community succession, and vegetation must be continually managed. In addition, maintaining land in this stage often favors the growth of persistent vines, such as kudzu, which can be as undesirable as large woody plants. The type of vegetation management necessary depends on the function of the right-of-way, as well as its topography, biology, and ecology.

The type of vegetation present is very important. Undesirable vegetation includes plants that:

- create a safety hazard or nuisance;
- disturb the normal operation or functional activities of the right-of-way;
- are considered “noxious”;
- overcrowd desirable vegetation;
- damage right-of-way structures, such as road surfaces, railroad ballast, utility wire poles or supports, and pipelines and pumping stations;
- provide cover for undesirable wildlife; and
- are a pest to crops and cropland if allowed to spread.

Vegetation management is necessary and in most cases desirable. But most rights-of-way are long and narrow, so they often touch the property of many landowners. Neighbor conflicts may become magnified, especially if vegetation management efforts go beyond rights-of-way boundaries.

Public relations problems between right-of-way users and their neighbors are minimized when the public is informed of the vegetation management needs and methods and when vegetation management personnel know and execute a program with definite goals and plans.

Goals

The principal goal of vegetation management is to ensure the protection, operation, stability, continuance, and safety of the common transport involved. Other goals of a well-planned vegetation management program may be to:

- naturalize the right-of-way using native plants where possible, to make it blend in with the surrounding landscape, and benefit the native ecosystem;
- reduce maintenance costs;
- reduce erosion or water quality problems; and
- provide food or shelter for wildlife.

Planning Requirements

Successful right-of-way vegetation management requires good planning that incorporates well-developed goals and objectives into a rational, comprehensive, and practical program. This planning must include recognition of the environmental requirements of both desirable and undesirable plants and the use of methods that will accomplish the goals and objectives in an economical and environmentally sound manner.

A properly planned and executed management program uses varied control techniques and strategies that are determined by economics, terrain, vegetation, and public relations. The program should have options for alternative management methods, such as cropping and grazing, as well as chemical weed and brush control.

Good planning and execution can result in:

- increased public acceptance of the right-of-way facility,
- fewer complaints about the right-of-way,
- reduced maintenance cost,
- decreased damage to facilities and structures,
- fewer operational interruptions,
- increased safety,
- improved public relations and less legal difficulty with public action groups and right-of-way neighbors,
- reduced erosion and water pollution,
- improved cost planning and control, and
- better utilization of equipment and reduced work load fluctuation.

Characteristics of Rights-of-Way

Rights-of-way are composed of a series of narrow strips of land that are used for different types of common transport. They range from highly manicured highway rights-of-way to low-maintenance rights-of-way for electric or gas lines in forested areas. Each has a different requirement for vegetation control. Electric utility rights-of-way vary in width from 30 feet to 200 feet and have been set aside for the erection of poles and guys, towers, and electrical conductors necessary to carry electricity from the generator to the customer. Electric companies usually acquire rights-of-way from property owners through an easement that grants the utility company the right to install and maintain the facilities necessary to transmit and distribute electricity. The utility company does not normally purchase the land for the rights-of-way; rather, it simply acquires permission or easement from the property owners to install the needed facilities. In many instances, one or more types of rights-of-way are combined. For example, a highway right-of-way is often built next to a utility right-of-way.

Terrain and Vegetation

The terrain over which these rights-of-way pass is just as varied as the material being transported. It will vary from cropland or pasture to rugged, mountainous terrain. Rights-of-way also pass over streams, rivers, lakes, ponds, and roads. A variety of vegetation grows along most rights-of-way. The level of vegetation management necessary depends on the type of right-of-way and the sections within it.

Levels of Vegetation Management

Highways and railroads need complete vegetation control in the roadbed. The shoulder of the road or rail line is usually kept free of vegetation to allow drainage. The rest of the right-of-way may consist of grass or low-growing shrubs (see Figures 1 and 2). The type of vegetation allowed to grow will be limited to plants that do not interfere with the movement of vehicles or the vision of their drivers.

Electrical transmission lines through forested areas may have the following sections of the right-of-way:

- a central path or road for inspection and/or maintenance crews,
- an area of low-growing shrubs or grasses under the wires (see Figure 3),
- an area kept cleared of large trees 25 to 75 feet on either side of the centerline (greater clearance required for extremely high voltage), and
- an edge of easement or an area off easement having dangerous trees removed as necessary (depending on easement description).

Electrical distribution lines are often virtually surrounded by vegetation, but continual efforts are made to clear vegetation to eliminate power outages. Sometimes mature trees that pose a dangerous threat to electrical facilities must be completely removed.



Figure 1. Railroad Right-of-Way.



Figure 2. Highway Right-of-Way (Photo by A. D. Luscher).



Figure 3. Utility Right-of-Way.

Gas pipelines are somewhat different in the area of rights-of-way because the soil is disturbed when the pipe is laid. Generally, the soil is laid bare until grass or other vegetation re-invades the right-of-way. Pipeline rights-of-way are usually kept mowed. Grasses and low-growing broadleaf plants are the predominant vegetation.

Biology and Ecology of Weeds

Weed is a term used to describe unwanted or out-of-place vegetation. Right-of-way managers must deal with weeds that range from low-growing grasses to large trees. The biology of a weed is concerned with its establishment, growth, and reproduction, as well as the influence of environment. The ecology of a weed is primarily concerned with the effects of climate, physiology, and biological factors on the plant.

Classification

There are many ways to classify weeds. For control purposes, they can be divided into two major groups: grasses and broadleaves. Broadleaf weeds can then be divided into herbaceous and woody plants.

1. **Grasses (Monocots)** have one (mono) cotyledon (cot) or seed leaf. The large veins in the leaf run parallel to one another. Flower parts are in groups of three (see Figure 4).
2. **Broadleaf Weeds (Dicots)** have two (di) cotyledons (cots) or seed leaves. The large veins of the leaf form a network rather than being parallel. The flower parts are typically in groups of four or five (see Figure 5).
 - **Woody plants** include trees, shrubs, and woody vines.
 - **Herbaceous plants** have no definite wood structure. They have no persistent aboveground stem, and they naturally die to the ground.

Life Cycle

The life cycle or growth habits of weeds in a right-of-way determine the vegetation management methods necessary for the most effective weed control.

Annuals—Annual weeds are plants that develop from seeds, mature, produce seeds, and die in one growing season. **Summer annual** plants germinate from seeds in the spring, grow through the summer, produce seeds, and die in the fall (see Figure 6). Examples are crabgrass, foxtail, fall panicum, pigweed, and lambsquarters. **Winter annual** plants germinate from seeds in the fall, overwinter, mature, produce seeds, and die in the spring or early summer (see Figure 7). Examples are chickweed, henbit, cheat, and shepherd's purse.

Annual weeds frequently can be controlled with residual herbicides applied to the soil before the plants emerge. Foliar herbicides, either contact or translocated, are also effective in controlling annual weeds. Usually the combination of a foliar herbicide plus a residual herbicide will provide the most dependable weed control.

Biennials—Biennial weeds complete their life cycle over a two-year period (two growing seasons). They frequently develop from seed and form a rosette (a low-growing cluster of leaves) during the first year. During the second growing season, the stems elongate, flowers and seeds develop, and the plant then dies (see Figure 8). Biennial weeds include poison hemlock, Queen Anne's lace (wild carrot), common mullein, and musk (or nodding) thistle. Biennial weeds can usually be controlled using the same methods effective on annual weeds, but they are easier to control during the first year of growth.

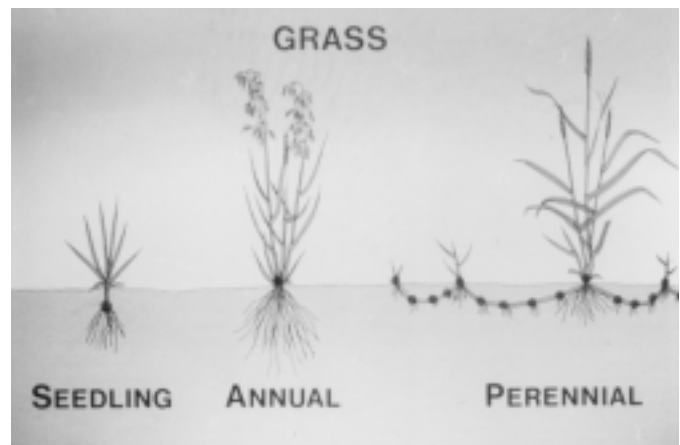


Figure 4. Grass Weeds (Monocots).

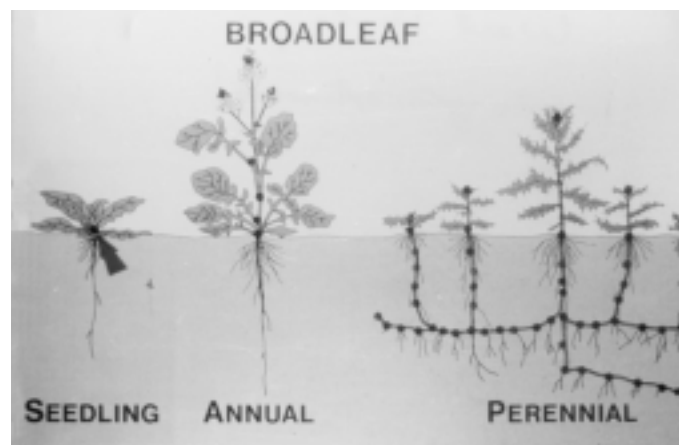


Figure 5. Broadleaf Weeds (Dicots).

Perennials—Perennial weeds live for three or more seasons and reproduce by seed and/or vegetative parts. They are often more persistent than annuals or biennials. Control may require repeated applications of foliar translocated herbicides. Soil-applied herbicides may have to be applied at high rates to control perennial weeds. Johnsongrass, quackgrass, Canada thistle, brush, shrubs, and trees are perennial weeds.

Simple perennial weeds ordinarily reproduce only by seed, but vegetative reproduction can occur if roots or crowns are cut by tillage implements. Cut pieces may send out feeding roots and stems to become new plants (see Figure 9). Dandelion, curly dock, and plantain are examples of simple perennials.

Bulbous perennial weeds, such as wild garlic, reproduce by bulbs and bulblets, as well as by seeds. Both aerial bulblets and seeds may be produced in the flower heads. Secondary bulbs may develop below the ground.

Creeping perennial weeds spread by lateral extension of the stems (stolons) along the soil surface, by stems (rhizomes) beneath the soil, by roots, or by seeds (see Figure 10). Mouse ear chickweed, knotgrass, and pennywort spread by creeping stems along the soil surface. Quackgrass, johnsongrass, and hedge bindweed spread by rhizomes. Sowthistle and red sorrel spread by creeping roots.

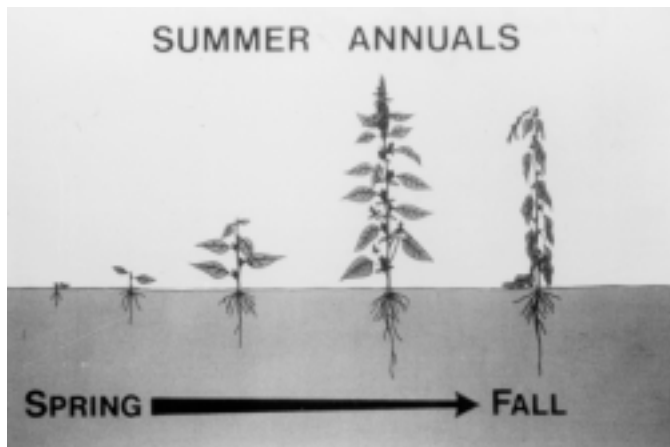


Figure 6. Life Cycle of Summer Annuals.

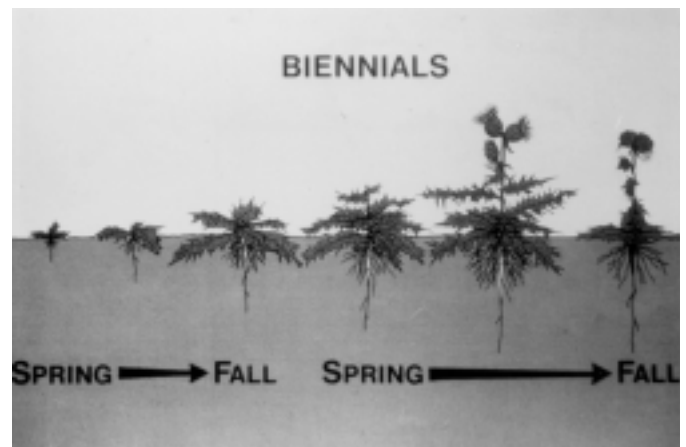


Figure 8. Life Cycle of Biennials.

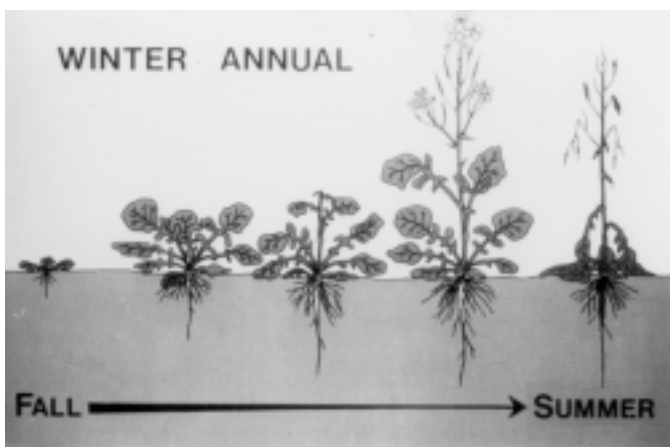


Figure 7. Life Cycle of Winter Annuals.

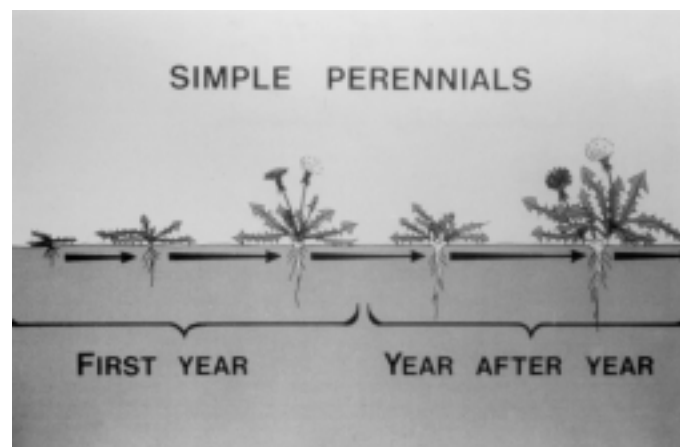


Figure 9. Life Cycle of Simple Perennials.

Dissemination and Persistence

Weeds spread through the dispersal of their sexual (seed) and asexual (rhizomes, stolons, tubers, roots, and bulbs) reproductive parts. Annuals and most biennials spread by seed, which can be carried by wind, water, animals, machinery, and crop seed. The persistence of annual and biennial weeds depends mainly on their ability to re-infest the soil with their seed. The introduction or infestation of perennials into an uninfested area depends on seed. Therefore, controlling seed production can prevent further spread of many species. Perennial weeds spread primarily by sexual means; however, many perennials also spread by asexual methods. Their spread is slow compared to most annuals, especially in noncultivated land that may occur in rights-of-way. Trees and shrubs have large root systems, and often the roots and stumps can sprout when the top is removed. Some species, such as black locust and beech, can readily produce root suckers or sprouts even when the top is not cut.

The length of time that weed seeds remain viable may depend on the species involved and the environmental conditions. In general, seeds that are viable but that do not germinate within a few days or months will remain in a dormant or resting stage. Dormancy may determine the time of year when weed seeds germinate, or it may delay germination for years, guaranteeing a source of viable seeds for years to come.

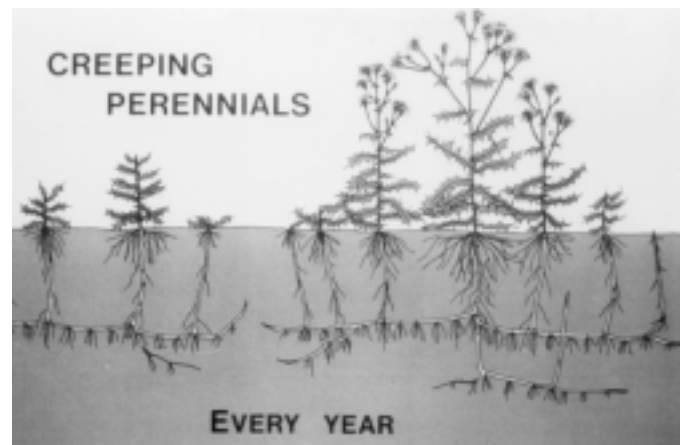


Figure 10. Life Cycle of Creeping Perennials.

Stages of Vegetation Succession

Vegetation succession refers to the orderly development of different types of plants on land where the original plants have been removed. Annual weeds, such as ragweed and pigweed, appear first on abandoned, cleared areas. Grasses, grass-like plants, and biennial or perennial herbaceous broadleaf weeds come next. Shrubs and trees are the final stage. Regardless of which stage of vegetation development initially found in a right-of-way, the trend is for it to develop into a forest.

The type of vegetation that is desirable for a particular right-of-way will depend on its function, as well as safety, wildlife, and soil conservation considerations. In general, annual weeds and forests are considered to be undesirable right-of-way cover. A community of certain grasses, grass-like plants, perennial herbaceous broadleaf weeds, or shrubs is suitable for most rights-of-way.

Vegetation Management Control Methods

The three methods of control used in right-of-way vegetation management are biological, mechanical, and chemical.

1. Biological Control

Animals, birds, and competing plants are used in biological control of vegetation. This method can be inexpensive if a stable right-of-way plant community is established. However, it requires an intimate knowledge of the ecology of the area and the steps needed to keep a stable system. When rights-of-way cross pasture land, grazing usually eliminates the need for vegetation control. In some cases, desirable vegetation is deliberately introduced onto the utility right-of-way. Maintenance and cultivation of these plants ensure the control of unwanted vegetation. Also, planting trees or shrubs that do not grow to line height can be used to help reduce control costs. This is true with Christmas tree farms or tree nurseries. The desirable vegetation is harvested or removed before it becomes a problem to the utility company. Landowners may also use rights-of-way to improve wildlife habitat or biodiversity.

2. Mechanical Control

Mechanical control is the oldest way to manage vegetation. It includes hand-pulling, hoeing, blading, mowing, cutting, pruning, carefully controlled burning, flooding, bulldozing, and cropping. Mechanical control methods usually require a lot of labor and can be very expensive.

In some cases, however, mechanical controls can be the least expensive method of vegetation management for the right-of-way company. Areas that are being cropped or residential and industrial areas maintained by the landowners are often kept in superb condition at no cost to the right-of-way company. Unfortunately, many areas cannot be maintained by the landowner's normal cultural practices. Many of these areas cannot be managed with less expensive methods, so mechanical controls are necessary.

Mowing is a common way to maintain pipeline and highway rights-of-way. Hay production is used in some states but is

not practical in Kentucky. Mowing crews are used to maintain roadsides on almost all of our highways and secondary roads.

Cutting or pruning by utility arborists is often the only acceptable management method for trees and brush that invade utility rights-of-way. Trees that grow around electrical and telephone wires are often considered to have ornamental value and must be selectively pruned. Special care must be taken to use Natural Target Pruning techniques to avoid extensive damage to trees. In Kentucky, utility arborists, who are also Certified Arborists, can be relied on to use appropriate pruning methods. Tree topping along utility rights-of-way is not appropriate. Proper timing can improve the effectiveness of cutting or pruning. Research has shown that when trees or shrubs are cut directly after full leaf out, they do not sprout as vigorously as they do when cut during late summer or winter.

Cutting or pruning is often used to control brush and trees on railroad and highway rights-of-way. Large mechanical brush cutters are used to eliminate brush and small trees. Chainsaws, brush hooks, hand saws, and axes are needed when working in areas where large mechanized brush cutters cannot be used.

Burning is used in some states to control right-of-way vegetation. This method is usually cheap and effective, but it is not practical in Kentucky because of legal and environmental complications.

Flooding is an effective way to control vegetation along the edges of canals and navigable rivers or lakes. The Corps of Engineers effectively uses this method to maintain vegetation and reduce mosquito breeding along the shorelines of the waterways it administers.

Mechanical control methods are very expensive, so most rights-of-way operators would rather use less costly methods of vegetation control if possible. For instance, hand clearing of utility rights-of-way can cost four times more per acre than chemical control of the same vegetation. Also, hand cutting of some hillsides may be more dangerous to workers.

3. Chemical Control

Terrain often makes regular maintenance using mechanical methods impractical. Chemical control is often the only practical way to control vegetation where rights-of-way cross rugged, mountainous terrain.

Tree growth regulators (TGRs), such as paclobutrazol (Profil), can be used to slow the growth of trees. This allows more effective management of pruning cycles. TGRs can reduce the amount of branches removed from trees. This reduces the amount of time needed to prune and clip treated trees.

Classification of Herbicides

Herbicides can be grouped according to common characteristics, such as methods of application, selectivity, or chemistry.

Method of Application

Herbicides may be applied to soil or to plant foliage. Soil-applied herbicides must be taken up by seeds or underground vegetative plant parts. For optimal results, they must remain in the soil in an active or available form for a certain period of time. This time is referred to as soil persistence or soil residual

life. These terms are generally used in reference to soil-applied herbicides, but they may apply to certain herbicides that are primarily applied postemergence but also leave some “active” residue in the soil. The estimated soil persistence of some right-of-way herbicides are listed in Table 1.

Products applied to the foliage are commonly referred to as postemergence herbicides. They control weeds either by direct contact with the plant tissue or by translocation to other plant parts. Weeds sprayed with contact herbicides usually die within a few hours or days. There is very little, if any, residual control. Contact herbicides are used primarily to control annual weeds. Examples are paraquat (Paraquat) and MSMA (Ansar). Weeds treated with translocated herbicides generally require several days to die. These herbicides are often capable of controlling annuals, biennials, and perennials. Glyphosate (Accord, Roundup), 2,4-D (several trade names), and dicamba (Banvel, Vanquish) are just a few of the translocated herbicides. Some herbicides, such as fosamine (Krenite), are only partially translocated and can be used to chemically prune large trees.

Selectivity

Herbicides may be classified as selective or nonselective; however, herbicide selectivity is rate dependent. At low rates, some herbicides are selective, whereas, at high rates, they become nonselective.

Selective herbicides kill some kinds of plants but have little or no effect on others. The use of selective herbicides allows the removal of unwanted weeds from desirable crops. 2,4-D is a selective herbicide that removes broadleaf weeds but will not injure grasses.

Nonselective herbicides kill all vegetation. Examples are paraquat (Paraquat), bromacil (Hyvar), and glyphosate (Roundup, Accord).

Chemistry

Herbicides with similar chemical characteristics are grouped into **families**. Here are some of the common herbicide families used in rights-of-way:

Phenoxy herbicides are usually applied to foliage to control annual and perennial broadleaf weeds. They can also be taken into the plant through its roots. **Spray or vapor drift may injure nearby desirable broadleaf plants.** 2,4-D and MCPA are phenoxy herbicides.

Picolinic acid herbicides control many annual and perennial broadleaf weeds. They are readily absorbed by roots and foliage and move within the plant to the growing points of stems and leaves. This causes a variety of growth regulator type effects. These herbicides have a moderate to high leaching potential since they are weakly bound to soil. Examples of picolinic acid herbicides include clopyralid (Transline) and picloram (Tordon, Pathway).

Sulfonylurea herbicides control many annual and perennial broadleaf and grassy type weeds. They can be applied to leaves or to soil. A surfactant is used with foliar applications to enhance absorption into the leaves. Injury symptoms are typically slow and may not show up for two to three weeks after

Table 1. The estimated persistence of some of right-of-way herbicides.

Common Name	Brand Name	Average Persistence* (months)
bromacil	Hyvar-X	12-36
chlorsulfuron	Telar	6-36
clopyralid	Transline	6-12
dicamba	Banvel, Vanquish	1-3
2,4-D	(various names)	1
fluazifop-P-butyl fenoxaprop-P-ethyl	Fusion	-----
fosamine ammonium	Krenite	less than 1
glyphosate	Roundup Pro, Accord	-----
hexazinone	Velpar	12-24
imazapyr	Arsenal, Chopper, Habitat, Stronghold	6-24
metharionate	MSMA	-----
metsulfuron	Escort	6-24
pendimethalin	Pendulum	-----
picloram	Tordon, Pathway	6-36
prodiamine	Endurance	-----
prometon	Pramitol	12-24
sulfometuron	Oust	6-24
tebuthiuron	Spike	12-36
triclopyr	Garlon, Crossbow	1-2

* The length of time may vary depending on the rate of herbicide applied and environmental conditions.

application. Examples include chlorsulfuron (Telar), metsulfuron (Escort), and sulfometuron (Oust).

Triazine herbicides are generally taken into the plant through the roots; however, some members of this family can also be absorbed through the foliage. When used as a foliar treatment, a surfactant or an oil is generally included to enhance absorption. Triazines provide nonselective control of various grasses and broadleaf weeds when used at rates recommended for non-cropland. Regardless of whether or not they are applied preemergence or postemergence, the triazine herbicides generally accumulate in the leaves where they inhibit photosynthesis. Prometon (Pramitol) is a triazine herbicide.

Uracil herbicides are more easily absorbed by the roots than by the shoots of plants. The addition of a surfactant does, however, increase their foliar activity. After being absorbed by the roots, uracil herbicides move to the leaves of plants where they inhibit photosynthesis. The effects of uracil herbicides on perennial weeds are generally slow and may take several months. Bromacil (Hyvar X) is an uracil herbicide.

Urea herbicides are most effective when applied as a preemergence treatment. However, their postemergence activity can be increased when they are applied with a surfactant. Like the triazine herbicides, the ureas do not prevent germination of weed seed. Instead, they accumulate in the leaves of emerged plants where they inhibit photosynthesis. Although the urea herbicides provide control of both grasses and broadleaf weeds, they are considered to be more effective on broadleaf weeds. Diuron (Karmex) and tebuthiuron (Spike) are urea herbicides.

Other Herbicides

The following are **other herbicides** not included in the above families:

Dicamba (Banvel, Vanquish) is used to control woody plants as well as many broadleaf herbaceous plants. At label rates it has very little, if any, effect on grasses. Dicamba is absorbed by the leaves, stems, and roots and translocates throughout the plant. It is relatively mobile in the soil.

Fosamine ammonium (Krenite) is used in controlling woody plants. It should be applied during a two-month period prior to fall coloration. When applied to deciduous plants at this time of the year, there is little or no effect until the following spring when bud development is prevented or limited. Pines, however, show a response shortly after application.

Glyphosate (Accord, Roundup) is used to control many annual and perennial weeds including grasses, broadleaves, brush, and certain trees. It can be applied to the foliage of actively growing plants where it is absorbed by the leaves or as a tree injection or cut stump treatment. Glyphosate is rapidly and tightly adsorbed by soil.

Imazapyr (Arsenal, Chopper, Habitat) controls many annual and perennial weeds, including certain grasses, broadleaves, vines, brush, and trees. Plant growth is inhibited within a few hours after application, but injury symptoms may not appear for two to three weeks after application. Arsenal can be applied to the soil or to the foliage of plants.

Triclopyr (Garlon, Crossbow) is a growth regulator type selective herbicide for control of many woody plants and broadleaf weeds. Most grasses are tolerant to Garlon. It can be applied as a ground or aerial foliage spray or as a basal or tree injection application. Garlon is absorbed by both foliage and roots and translocates throughout the plant. Some leaching may occur in light soils under high rainfall conditions.

Herbicide Application Methods and Equipment

Right-of-way sprays can be applied by ground or air, depending on the situation. Ground applications may include foliar spray treatment, basal bark treatment, stump treatment, tree injection, and soil treatment with pellets. Airborne equipment is carried by helicopter.

Foliar application includes both high and low volume techniques.

High volume spraying is normally done with truck-mounted equipment that delivers 60 to 400 gallons of solution per acre at high pressure through a hand-directed nozzle. This type of foliar spraying is fast and, in some instances, can deliver herbicide through dense brush. However, the risk of drift and unwanted effects on nontarget plants is relatively high. This technique requires more planning and precautions than other ground application techniques.

Low volume spraying is normally done with hand-held equipment, such as backpack sprayers or low pressure ATVs or tractor-mounted sprayers that deliver 10 to 60 gallons per acre at relatively low pressure through a hand-held wand. Low volume spraying also includes using boom sprayers and fixed height

nozzles to apply herbicides to low-growing grasses and weeds with a great deal of control over the amount and distribution of herbicide. This type of low volume technique is often used for band or strip spraying. All types of low volume spraying are likely to cause fewer environmental problems compared to high volume techniques.

Both high volume and low volume hand-held wand techniques generally require that mixes contain a specific percentage of herbicide in the final water-based solution. Labels also indicate that a specific amount of solution be applied per acre, ensuring that all foliage be sprayed to a point of runoff.

Individual Stem Applications are used to apply herbicides directly onto or inside the stems of individual woody plants (trees or shrubs). Basal bark treatments are used to apply specific formulations of herbicides to the outer bark of the small woody plants. The herbicide is absorbed through the bark and eventually contacts the transport tissues and growing portions of the stem. A number of different methods including the use of tree injectors, frill and squirt techniques, Hypo-Hatchets™ or similar devices, and cut stump treatments are used to deliver herbicides directly to the transport and growing tissues beneath the bark of woody plants. These treatments should not be applied to trees or shrubs where nontarget plants of the same species or genera are nearby (generally within 10 to 20 feet). Trees and shrubs of the same species or genera may form root grafts or sprouts from the same rootstock. In these cases, the herbicide can be translocated from one tree to another, killing or injuring the nontarget tree.

Basal bark treatments consist of several techniques of applying herbicides to the lower stem of small (less than 6 inches in diameter) trees and shrubs. Unlike the majority of ground application herbicides, which are mixed with water, those labeled for basal bark treatments are mixed with oil. The *full basal technique* requires that the herbicide be thoroughly applied around the circumference of the lower 18 inches of the tree. This is normally done using a backpack sprayer with a cone or flat fan tip. The *streamline technique* is used on trees or shrubs less than 3 inches in diameter and requires that a 6-inch-wide band of herbicide be applied to one side of the stem. Enough of the solution should be applied to allow its spread around the entire circumference of the stem. The *thinline technique* is similar to streamlining, with the exception that undiluted herbicide is used and only a thin band is sprayed completely around the stem. The streamline and thinline techniques are often applied with a hand jet, which shoots a stream of solution, rather than a hand wand and nozzle used for the full basal technique.

Cut stump treatments are applied on freshly cut stumps to prevent sprouting (coppicing) of hardwood trees and shrubs (see Figure 11). Best results are obtained when stumps are treated with undiluted herbicide within one to two hours after cutting. Once the cut surface dries, this treatment quickly loses its effectiveness. For small stumps, less than 10 inches in diameter, the entire surface should be covered. For larger stumps, only the outer 3 to 4 inches should be treated. Backpack sprayers with hand wands or handheld spray bottles can be used to apply the herbicide.



Figure 11. Cut stump treatment (photo by A.D. Luscher).

Tree Injections can be used to apply herbicide to the living tissues inside the bark of standing trees or shrubs. Tree injectors, specially designed 4- to 5-foot-long tubes with an injection pump and 1½- to 3-inch blade or injector on one end and are used to apply either liquid or pellet herbicides to trees of any size. Liquid tree injectors have blades that produce a slit through the bark, and the pump delivers a calibrated amount of solution into the slit. Pellet injectors have a head on the tube that drives the pellet into the bark. The *frill and squirt technique* is also used to apply herbicides inside the stems of woody plants. This is done by using a hatchet to slit the bark and then applying a calibrated amount of herbicide into the slit using a hand sprayer.

Several companies make devices that combine the squirt mechanism with a specially designed hatchet. Brand names such as Hypo-Hatchet™ and Silvaxe™ are examples. The liquid herbicide is placed in a container on a belt or backpack and is attached to the hatchet with a hose. The hatchet has a pump mechanism and injection ports built into the head. Striking the stem creates a slit and injects a calibrated amount of solution into the slit. Herbicides labeled for tree injection will indicate the amount of herbicide needed per inch of stem diameter and the spacing of injections around the stem.

Soil applied pellets can be used in very small amounts by hand broadcasting or specific placement around the stems of trees and shrubs (e.g., multiflora rose) or brush. After a rain, the solution is moved into the roots of woody plants that have their root systems within the dispersal area of the herbicide.

Soil Factors That Influence Herbicides

Soil texture, organic matter, pH, and moisture content are some of the major soil properties that influence the efficacy of a soil-applied herbicide.

Soil Texture

The relative amounts of clay, silt, and sand in soil can determine the availability of certain herbicides. Usually, as the clay content of the soil increases, the amount of herbicide available for uptake in the plant decreases. Clay particles are primarily negatively (-) charged, so they tend to attract or adsorb

positively (+) charged particles. Herbicides that tend to be positively charged in the soil (e.g., prometon) are bound to a greater extent by clay particles than herbicides that are negatively charged (e.g., picloram). This is why the rates of certain herbicides vary with soil texture.

Organic Matter

The organic matter or humus content of the soil is primarily negatively (-) charged, so herbicides can bind to it. In general, herbicides are more strongly adsorbed to humus than to clay particles. A small increase in the organic matter content of the soil can greatly reduce the effectiveness of some herbicides.

Soil pH

The pH of the soil can influence the effectiveness and persistence of certain herbicides. For example, metsulfuron (Escort) degrades rapidly when soil pH is less than 6.0. When soil pH is above 6.0, degradation rates are slower and depend more on soil microbes.

Soil Moisture

In order for a soil-applied herbicide to be taken up in the plant, there must be a certain amount of moisture present in the soil. Generally, soil-applied herbicides do not work as well under very dry conditions as they do when the soil moisture is adequate. Soil moisture may also indirectly affect the persistence of various herbicides by influencing their breakdown by microbes or certain chemical reactions. Because of this, soil-applied herbicides usually last longer when the soil is dry rather than when it is moist or wet.

Environmental Factors That Influence Herbicides

Results achieved from herbicide applications may vary greatly. This variability (often a lack of control) may be due to improper application (e.g., improper choice of herbicide, poor equipment, incorrect calibration, lack of agitation, or ineffective product). Many of these problems can be prevented or corrected by the operator. However, much of the variability is due to factors that the applicator cannot control, such as environmental conditions, variation of soils, and differences in susceptibility of various plant species.

Before considering the effect of environmental factors, it is essential to consider how the herbicide is applied. Herbicides may be applied as soil, foliage, stump, or basal bark treatments. The influence of a given environmental factor may be quite different, depending on the type of application. Environmental conditions have very little effect on stump or basal bark treatments; however, they may have a great effect on soil and foliage applications.

Soil-Applied Herbicides

Rainfall (soil moisture) and temperature are two environmental factors that have the most influence on the performance of soil-applied herbicides.

Rainfall is as important for chemical weed control as it is for plant growth. Herbicides applied to the soil surface must be moved into the root zone of the plants to be controlled soon after the application is made. Herbicides generally do not perform as well during periods of drought as they do when moisture is adequate.

The amount of rainfall needed to move a herbicide depends on its water solubility. For example, picloram (Tordon) is very soluble in water, so it has a higher potential to move in soil with water compared to many other herbicides. Leaching of water-soluble herbicides is greatest under heavy rain that falls in a short period of time. Excessive movement of herbicide in the soil may cause injury to desirable plants close to the rights-of-way that have been treated.

The influence of rainfall on the efficacy of herbicides is interrelated with additional environmental factors, as well as soil texture and soil structure. Temperature influences the performance of soil-applied herbicides by affecting chemical reactions in the soil, microbial activity, and plant growth processes. Decomposition of herbicides by chemical reaction and microbial activity in the soil occurs more rapidly at high temperatures; therefore, herbicides are less persistent under these conditions.

Temperature has a profound effect on the absorption, translocation, and metabolism of soil-applied herbicides by plants. Other factors being constant, the effects of these processes increase with increasing temperatures. Herbicides usually perform best under temperatures at which plants grow rapidly. Under conditions of extremely high or low temperatures, the toxicity and selectivity may be dramatically altered due to the influence of temperature on these physiological processes.

Foliar-Applied Herbicides

Environmental factors probably have a greater effect on the performance of foliar-applied herbicides than on soil-applied herbicides.

Factors affecting plant growth in general, such as soil moisture and temperature (discussed above), have the same effect on foliar-applied herbicides. Rapidly growing succulent plants are generally more susceptible to postemergence herbicide treatments than are plants in any other condition.

In order for a herbicide applied to the foliage to be effective, it must be absorbed into the plant through the cuticle of the leaf. Plants grown under drought stress develop a thicker cuticle than those grown under more favorable conditions. This thicker cuticle limits absorption of the herbicide. The translocation of systemic herbicides may also be limited in plants grown under drought-stressed conditions.

Foliar-applied herbicides usually perform best when applied during a period of high relative humidity. This greatly increases foliage absorption by delaying drying of spray droplets and hydrating the cuticle, making it more permeable. High relative humidity also may enhance translocation of systemic herbicides. Very light rainfall, such as a drizzle, dew, or fog, increases absorption and effectiveness by remoistening the dry herbicide on the leaf surface. However, heavy rainfall shortly after application may wash the herbicide off the plant. The amount

of the herbicide washed from the plant depends on the quantity of precipitation, the rate of herbicide application, the chemical characteristics of the herbicide, and the use of an additive. Water-soluble herbicides, such as salt formulations of 2,4-D are washed off more easily than oil-soluble herbicides, such as ester formulations of 2,4-D.

In addition to the effect of temperature on the plant's physiological processes, temperature also influences absorption of herbicides into leaves. Plants grown under high temperature frequently develop a thicker cuticle that restricts herbicide absorption. Due to the interaction of these physiological processes, the effect of the temperature at the time of application on herbicide performance depends on the herbicide being applied. In general, best results can be expected from foliar herbicides applied during warm weather to actively growing plants and followed by a period of several hours with no rainfall (see Figure 12).

Sunlight is an additional environmental factor that influences the performance of many soil- and foliar-applied herbicides. It is essential for the activity of certain herbicides, but it is seldom a limiting factor in their performance. However, the herbicide paraquat kills plants more rapidly on clear, sunny days and more slowly on cloudy days.

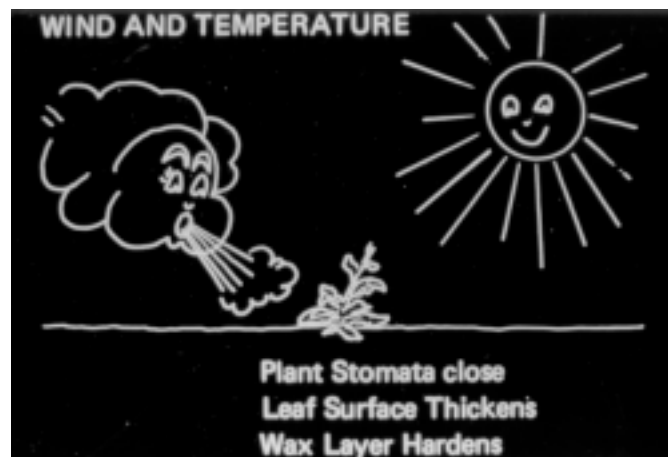


Figure 12. Wind and Temperature Effects (Photo courtesy of Dow Chemical Company).

Public Relations Concerns

Following label directions and proper application practices are absolute requirements to obtaining satisfactory results from any herbicide treatment. All treatments must be applied uniformly at the recommended rate over the area to be treated. Foliar treatments must be applied in a sufficient volume of carrier (usually water) to ensure adequate coverage.

When treating rights-of-way, it is very important to keep the spray mixture within the treated area during and after the actual spray application. There are two characteristics of herbicides that account for the majority of instances in which herbicides sprayed on rights-of-way reach nontarget locations and result in damage complaints. These characteristics are drift and volatilization of the herbicide.

Drift refers to the movement of spray particles or droplets through the air to areas not intended for treatment. The amount of drift that can occur depends on the particle or droplet size and the amount of air movement at the time of spraying. Herbicide spraying should not be done if the wind speed is greater than 5 miles per hour. The following table shows when particles of fog or mist size present the greatest possibility for drift to occur. These size particles are generated readily by high pressure spraying equipment.

Spray Droplet Size and Its Effect on Spray Drift.

Droplet diameter (microns)	Type of droplet	Time required to fall 10 ft in still air	Distance droplet will travel in falling 10 ft (3 mi/h breeze)
5	Fog	66 minutes	3 miles
100	Mist	10 seconds	409 feet
500	Light Rain	1½ seconds	7 feet
1000	Moderate Rain	1.0 seconds	4.7 feet

From *Weed Science: Principles and Practices*, G. C. Klingman.

Volatilization of herbicides is a chemical process whereby the herbicides change from a liquid to a gas. The herbicide, in the form of a gas or vapor, can move with the air currents for a mile or more to injure sensitive crops.

Drift and volatilization are problems of major concern in right-of-way maintenance. They represent potential hazards to sensitive crops, gardens, and ornamentals and may have harmful effects on wildlife, people, livestock, and aquatic areas near rights-of-way.

In many cases, movement of herbicides off right-of-way areas results in complaints from the public or property owners. Any complaints arising from herbicide application should be answered expeditiously and settled rapidly in a fair and amicable manner.

The general public is often not knowledgeable about the reason for and the nature of herbicide applications to rights-of-way. Applicators and operators can do much to alleviate public fear through a rational approach to effective communication. They should be aboveboard and totally honest in their communications in order to bring about the needed education of the public concerning herbicide use.

Environmental Concerns

Groundwater Advisories

The potential for contamination of groundwater is an important factor to consider when choosing herbicides. Several products have groundwater advisory statements on their label. Such statements advise not to apply these products where the water table (groundwater) is close to the surface and where the soils are very permeable (well-drained soils such as loamy sands). Refer to these statements and observe all precautions on the label when using these products.

Endangered Species Act

The Endangered Species Act (ESA) is intended to protect and promote recovery of animals and plants that are in danger of becoming extinct due to the activities of people. Under the act, the EPA must ensure that the use of pesticides it registers will not harm the species listed by the U.S. Fish and Wildlife Service as endangered or threatened, or to habitat critical to the survival of those species. To accomplish this, the EPA has implemented “Interim Measures,” including county bulletins showing the area(s) within the county where pesticide use should be limited to protect listed species. Pesticide active ingredients for which there are limitations are listed in table form in the bulletins. The limitations on pesticide use are not law at this time but are being provided for use in voluntarily protecting endangered and threatened species from harm due to pesticide use.

Calculating Rates

The economic value of a herbicide depends on the relative amounts of active toxic chemicals that are contained per pound or gallon. This is expressed in percent of active ingredient, acid equivalent, or pounds per gallon for liquids.

One pound of an 80 percent wettable powder (WP) formulation of a herbicide contains more active ingredients than 1 pound of a 20 percent granular product (pound for pound). An amine salt formulation of 2,4-D containing 4 pounds per gallon, acid equivalent, is of more value than the same formulation containing 2 pounds per gallon. Since mixing charges and cost of containers, freight, and handling have to be paid on twice as much material for a 2-pound-per-gallon formulation as a 4-pound formulation, the cost per pound of active material is less in the 4-pound formulation than in the 2-pound formulation, although the cost per gallon of product is more.

The pounds of active ingredient (AI) or acid equivalent (AE) per gallon are given on the label of liquid herbicides. The percent is given on labels of powders, granules, and other dry materials. To calculate the amount of liquid herbicide required when the rate is expressed in pounds per acre, use the following formula:

$$(AE) \frac{(\text{rate in pounds per acre})}{(\text{pounds of herbicide per gallon})} = \text{gallons per acre.}$$

Example: If the rate is 1.5 pounds per acre, and the herbicide contains 4 pounds (AE) per gallon, then

$$\frac{1.5}{4.0} = 0.37 \text{ gallon, or } 8 \text{ pints} \times 0.37 = 3 \text{ pints.}$$

Use the same formula to calculate gallons of herbicide per 100 gallons of spray.

Example: If the rate is 2.5 pounds (AI) per 100 gallons, and the herbicide contains 2 pounds (AE) per gallon, then

$$\frac{2.5}{2.0} = 1.25 \text{ or } 1\frac{1}{4} \text{ gallons.}$$

To calculate the amount of dry product required when the rate per acre is given, use the following:

$$\frac{100}{\text{percent active ingredient}} \times \text{rate per acre} = \text{pounds product.}$$

Example: If the rate is 15 pounds active ingredient per acre, and the percent of active ingredient is 75, then

$$\frac{100}{75} \times 15 = 20.$$

Mixing

Never pour the concentrate directly into an empty spray tank. Either fill the tank half full, add the chemical, agitate, and complete the filling; or, start filling and add the chemical as the filling is continued. Operate the sprayer with the nozzles shut off, bypassing the spray through the tank for several minutes to ensure thorough mixing. Often, your exposure to concentrated chemicals is highest when mixing, and many right-of-way herbicides carry signal words indicating that eye protection is critical.

Glossary

Absorption—Uptake (in this context, of a pesticide) by plants, animals (including humans), microorganisms, or soil.

Acid Equivalent—The amount of an active ingredient in a pesticide formulation (e.g., an ester) expressed in terms of the acid from which it is derived; this figure is used in determining application rate.

Active Ingredient—The chemical in a pesticide product that is responsible for the pesticidal effects.

Adjuvant—A material added to a pesticide formulation to increase its effectiveness or aid in the application process.

Adsorption—The binding of a pesticide to surfaces (e.g., soil particles) by physical or chemical action.

Amine Salt—A pesticide formulation in which an acid is neutralized by an amine (a basic compound).

Annuals—Plants that live only one growing season, reproduce by seed, and die.

Application Rate—The amount of pesticide applied to a site; usually expressed as a liquid or dry measure per unit area; for example, pounds or pints per acre.

Basal Bark Treatment—An application to the woody stems of plants at and just above the ground line, including the root crown.

Biennials—Plants that live for two growing seasons; in the first season, they form a low vegetative “rosette”; in the second season, they flower, produce seed, and die.

Biological Control—Suppression of a pest population by its own natural enemies, such as predators or parasites.

Certification—Recognition by the regulatory agency that a person has demonstrated at least a minimum acceptable level of competence and is authorized to use or supervise the use of restricted-use pesticides in this area of certification.

Chemical Control—Suppression of a pest population by use of a pesticide.

Commercial Applicator—A certified applicator, whether or not a private applicator with respect to some uses, who uses or supervises the use of restricted-use pesticides on any property other than as a private applicator.

Contact Herbicide—A herbicide that kills plants primarily by contact with plant tissues rather than as a result of translocation; only the part actually touched by the herbicide is affected.

Dicot (Dicotyledon)—A plant with two cotyledons or seed leaves; a broadleaf plant with net-like venation.

Emulsifying Agent—A material that helps suspend one liquid in another with which it would not mix otherwise.

Emulsion—A dispersion of fine particles of oil in water.

Ester—An organic salt; an acid neutralized with an alcohol.

Extender—A material added to a herbicide formulation to extend its activity and effectiveness.

Foliar—Relating to the leaf or foliage of plants; e.g., a foliar spray is applied to the foliage.

Frill and Squirt—An individual tree application method in which a hatchet or chainsaw is used to make a cut through the bark where the chemical is applied.

General Use Pesticide—A pesticide that can be purchased and used by any responsible person.

Herbaceous Plants—Plants that do not form a woody stem.

Herbicide—A phytotoxic chemical used for killing or inhibiting the growth of plants.

Hypo-Hatchet™—An instrument used to inject a pre-measured amount of herbicide directly into the growing woody stem. Same as Silvaxe™.

Invert Emulsion—A dispersion of water in oil having a mayonnaise-like consistency.

Leaching—The movement of pesticides downward through soil with water.

Mechanical Control—Control of vegetation by hand-pulling, hoeing, blading, mowing, cutting, pruning, burning, bulldozing, cropping, or other nonchemical and nonbiological methods.

Monocot (Monocotyledon)—A plant having a single cotyledon or seed leaf and narrow leaves with parallel veins.

Perennials—Plants that live for three or more seasons and reproduce by seed and/or vegetative parts, such as bulbs, tubers, rhizomes, stolons, or roots.

Persistence—In this context, a measure of how long a pesticide remains in an active form at the site of application or in the environment.

Pesticide—Any substance or mixture of substances intended to prevent, destroy, control, repel, attract, or mitigate any pest.

pH—A value expressing the acidity or alkalinity of a solution on a scale of 1 to 14; the neutral point is 7.0; below 7 is acid and above 7 is alkaline.

Phenoxy—A chemical class of herbicides, including 2,4-D.

Phytotoxicity—Injury to plants due to exposure to a chemical.

Restricted-Use Pesticide—A pesticide that can legally be purchased and used only by or under the supervision of a certified applicator.

Rhizomes—Lateral extensions of plant stems beneath the soil.

Right-of-Way—An area involved in common transport.

Safener—A substance that prevents objectionable changes when two or more substances that otherwise would not be compatible must be mixed.

Selectivity—The characteristic of herbicides whereby certain plant species are killed while others are injured little if at all.

SilvaxeTM—Same as Hypo-HatchetTM.

Soil Sterilant—A chemical that prevents the growth of any organism in the soil—plants, animals, or microorganisms; the effect may be temporary or long-lasting, depending on the chemical.

Spray Disc—In aerial application; a revolving disc mounted under the spraying ship whereby the herbicide mixture is spread across the right-of-way by centrifugal force of the revolving disc.

Spray Drift—The physical movement of spray particles off the target area at the time of application.

Stolons—Lateral extensions of plant stems along the surface of the soil.

Stump Treatment—Herbicide applied to cut stumps or stems to prevent suckering or re-sprouting.

Sulfonylurea—A chemical class of herbicides, which includes chlorsulfuron, metsulfuron, and sulfometuron.

Surfactant—An adjuvant that improves the emulsifying, dispersing, spreading and/or wetting properties of a pesticide.

Translocated Herbicide—Herbicide that when applied to one part of a plant (leaves or roots), can be taken up by the plant and moved internally to another part of the plant.

Tree Growth Regulator (TGR)—A chemical that in small amounts alters the growth habits of trees.

Tree Injection—An application tool for injecting a herbicide directly through the bark of woody plants.

Triazine—A chemical class of herbicides, which includes atrazine and prometon.

Uracil—A chemical class of herbicides, which includes bromacil.

Urea—A chemical class of herbicides, which includes diuron.

Volatilization—The movement of particles of a liquid pesticide after it has been converted into a vapor; usually occurring at some time after application.

Woody Plants—Plants that live longer than two years and have a thick, tough stem or trunk covered with cork.

