Selective Weed Control in Non-Crop Areas

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Table of Contents

Section One

Introduction

This publication is intended to provide a thorough introduction to selectively managing vegetation in non-crop areas, specifically for those interested in becoming certified pesticide applicators in Category 10, Rights-of-Way, in Pennsylvania. The term 'non-crop area' in its strictest interpretation could refer to all areas where a crop, or any intentionally planted vegetation, is not grown.

Our discussion will include areas established to specific vegetation, as well as areas managed primarily to prevent certain vegetation from becoming established. Examples of planted non-crop areas include grass plantings on roadsides and airports, erosion control plantings such as crownvetch, and plantings to create wildlife habitat. Areas managed more to exclude certain types of vegetation would include electric ROWs, where tall-growing trees are incompatible with overhead wires; and natural areas managed to consist solely of native species.

We will limit our discussion to areas where some type of vegetation is desirable. Therefore we will not consider areas where total vegetation control is practiced, such as electric substations, railroad ballast, storage tank farms, refineries, under highway guiderails and fencelines, and around signposts. Management of areas such as these is described in the publication *Non-Selective Weed Control in Non-Crop Areas.*

A basic principle we can adopt for selectively managing vegetation in non-crop areas is

Based on the management objectives of your area, first determine what vegetation is NOT desirable, then try to create conditions favorable to desirable vegetation, but not the undesirable vegetation.

This is simply common sense. It is the basis of effective vegetation management, which when approached as a program, or system, is referred to as *Integrated Vegetation Management.*

Section Two

Introduction to Integrated Vegetation Management

Integrated Vegetation Management (IVM) is a subset of Integrated Pest Management (IPM). IPM is a means to take a structured approach to common sense pest control. IPM stresses using all methods that are practically available, in a coordinated, or integrated manner, to manage pests; in conjunction with the setting of pest thresholds, and careful monitoring of pest populations and effectiveness of treatments.

The stress is on the concept of management. Any ecosystem, whether it is a electric right-of-way, a corn field, a dairy barn, or a flower production greenhouse, has many natural forces interacting in a constantly changing manner. Nature does not stand still - it is a constant, inter-connected chain of action and reaction. IPM stresses encouraging the natural forces that work to our benefit, and acting to enhance these processes. IPM is not warfare - its goal is to be a series of gentle nudges to allow natural processes to assist us in producing a natural commodity, whether it's livestock, food or fiber, a hazard-free right-of-way, or a pleasing landscape.

Since we are dealing almost exclusively with management of vegetation in a ROW setting, we narrow our focus from IPM to IVM.

Pest Thresholds

The first step in implementing an IVM program is to define what the pests are. Part of this process is realizing that all areas of the ROW are not the same in terms of their vegetation management requirements. Therefore, a species may be considered a pest in one area of a ROW, but not in another. Figures 2.1 and 2.2 illustrate how utility and roadside ROWs can be divided into different management zones. Management zones provide a framework to define what a pest is.

In an electric transmission ROW, as portrayed in Figure 2.1, the area of most concern is that directly under the conducting lines. In a scheme termed Wire Zone/Border Zone Management by Bramble and Byrnes, the area under the conductors is maintained as a groundcover of herbaceous plants and low growing woody species such as lowbush blueberry (*Vaccinium angustifolia*) and sweetfern (*Comptonia peregrina*). This type of vegetation maximizes clearance under the wires, and access to the towers. The area extending from the outside of the Wire Zone to the edge of the ROW is the Border Zone. Here herbaceous vegetation, shrubs, and small trees are allowed to propagate. This type of vegetation maintains the necessary clearance from the conductors, provides a tall-tree-free area with relatively little maintenance input, and provides high-value wildlife habitat. Distribution ROWs are much narrower, and are usually managed as one zone.

A highway ROW can also be divided into several functional zones. A narrow secondary road typically has a ROW width of 33 feet, which usually leaves only about 8 feet on either side of the travel lanes to manage. In these tight quarters, there is only one functional zone. In wider, limited-access roadways, as shown in Figure 2.2, there are often several management zones. The Non-selective Zone is the shoulder area right next to the travel lanes. To facilitate surface drainage, this area is kept free of all vegetation. Beyond this shoulder area is the Safety Clear Zone, which provides space for vehicles to pull over safely, or to recover if they leave the road unexpectedly. This area must be kept free of woody vegetation that would be a hazardous obstacle. Beyond the Safety Clear Zone is the Selective Zone, where the concern is preventing the establishment of tall growing trees that could shade, or fall into the roadway.

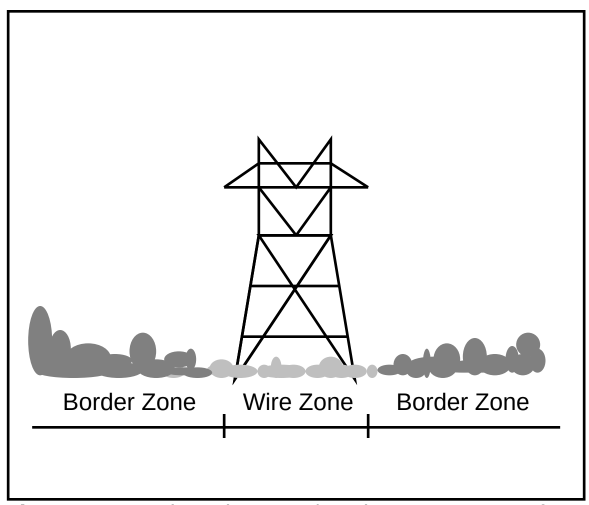

Figure 2.1: The Wire Zone/Border Zone system for managing transmission ROWs. The Wire Zone, the

area directly beneath the conductors, is maintained as herbaceous and very low growing shrubs. This maximizes line clearance and improves movement along the ROW and access to the towers. The Border Zone is composed of grasses and forbs, shrubs, and small trees.

Once pest species are designated, a threshold level must be determined. The threshold level is the level of pest infestation that requires a control action. In commodity production, thresholds are set based on economics. When a pest level becomes high enough that the cost of the reduced yield exceeds the cost of the control measure, the threshold has been reached. In ROWs, the criteria for setting action thresholds is often functional, rather than economic. For example, in an electric transmission ROW, the presence of even one tall tree under the conductors cannot be tolerated. In ROWs, then, we usually use thresholds in a location sense, rather than a population level. A given species can grow *here* in the ROW, but not *there*. The examples of management zones in Figures 2.1 and 2.2 provide a means to set thresholds.

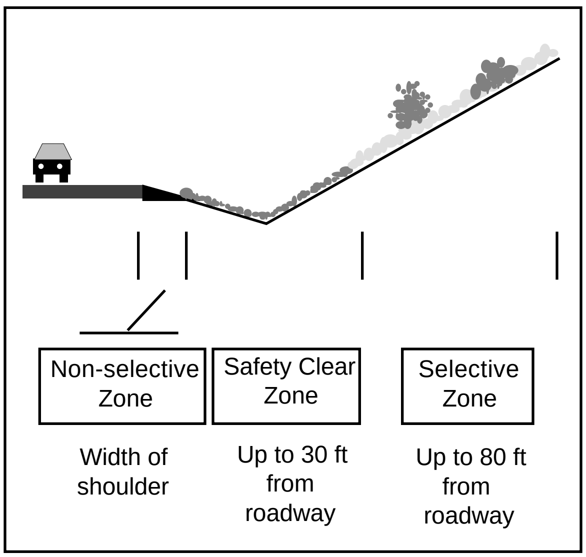

Figure 2.2: Application of the Management Zone concept to a highway ROW. The Non-selective Zone is kept free of vegetation to facilitate surface drainage from the travel lanes. The Safety Clear Zone is kept free of woody vegetation to allow recovery for vehicles that have left the roadway. The Selective Zone is kept free of tall growing trees that could eventually fall into the roadway.

Control Methods

Methods available to manage pests can be broadly grouped into four categories; Cultural, Mechanical, Biological, and Chemical. These categories are by no means sharply defined. There are instances where a practice could arguably be placed in more than one category.

Cultural Control

When we are managing a particular species, cultural methods are practices that enhance the growth and vigor of that species. When the desired species is more vigorous, it can withstand more pest pressure before there is a negative effect. If we are managing a roadside turf, an example of a cultural practice would be proper mowing - reducing the frequency and increasing the cutting height to minimize stress on the turf. Other cultural practices such as fertilization and liming are typically not an option for utility turfs, which makes proper mowing all the more essential.

Another example of a cultural practice in IVM is establishment of a permanent groundcover. When an area has been disturbed due to construction or maintenance activities, re-establishment of vegetation is usually necessary. Selection of the best adapted groundcover is an ideal opportunity to reduce long-term maintenance efforts. However, selecting the best species is just the beginning - to realize the benefit, care must be taken to properly establish the groundcover. This can often be a challenge when the vegetation establishment is part of a very large, costly construction contract. Vegetation establishment is often among the last activities on a job site, but construction projects do not always end at an ideal time for seeding. This cannot be an excuse for sub-optimal establishment practices. Temporary seedings or soil stabilization measures should be taken the time of year is not suitable for establishment of the optimal seed mix. When you consider that the vegetation is expected to essentially last forever, and that if properly established, the vegetation provide reduced long-term costs, it becomes clear that a temporary seeding is the prudent course.

Let's consider an example. The final grading of a construction project is completed in late June, and a perennial grass mix of creeping red fescue (Festuca rubra) and hard fescue (Festuca brevipila) is specified for establishment. Fescues are cool-season grasses, and are best seeded in late summer/early fall. The next-best alternative is early spring, followed by the dormant season. Summer seedings are never recommended.

Late June is a poor time to seed grass in the northeastern U.S. due to reduced rainfall and quick drying of the soil due to high temperatures. Fragile young seedlings with a very shallow root system are not likely to survive between infrequent rains. In this situation, the area should be mulched and seeded with a short-lived, fast-establishing species such as annual ryegrass (*Lolium multiflorum*). If it becomes well established, the annual ryegrass can be killed with an herbicide that leaves no soil residue, and the permanent seeding can be done in late August or early September. The long-term savings provided by a properly established, well adapted groundcover greatly outweigh the added short-term cost of the temporary seeding.

Mechanical Control

Mechanical controls physically remove or harm the pest species. Cutting, pulling, or digging weeds are examples of mechanical methods. Cutting is by far the most common mechanical method practiced on ROWs. When practiced alone, cutting usually provides only temporary control or suppression of undesirable species.

Mowing a weedy turf rarely controls the weeds - it simply shortens them. If the turf is mowed too short or too often, the turf suffers and weeds become worse. On the beneficial side, a well-timed turf mowing can prevent problem weeds from going to seed; and mowing off the weeds in a new seeding can open the canopy, and improve turf establishment.

Cutting of woody vegetation is done with hand-held chain saws or clearing saws, as well as tractor-mounted mowers. When brush has become tall and dense, sometimes a program including mechanical control is the only option.

Mechanical control can be an extremely effective means to reduce the size or density of problem brush, but failure to integrate this practice with an herbicide application to suppress resprouting will provide a result that is short-lived and costly.

Biological Control

Biological control is the use of other organisms to control pest species. The traditional practice of biological control is the introduction of an organism to prey on a specific pest plant. In an IVM setting, planting competitive groundcovers, or preserving existing groundcovers with selective herbicide applications could arguably be considered biological control.

Examples of traditional biological control include identification and introduction of predator and parasitic insects, as well as disease organisms against insect pests. Insects have been introduced to feed on specific plant pests. Soil bacteria have been used to inhibit plant fungal diseases. Companion planting in the garden often pairs a plant that repels certain insects with a plant that is susceptible. These are just a few of the many examples of biological control.

Chemical Control

Chemical control is the use of pesticides. Examples of pesticides include insecticides, fungicides, herbicides, rodenticides, and nematicides. Pesticides are an extremely useful, but potent tool. It is essential to understand how a pesticide works to use it effectively. Effective pesticide use must complement other control measures, not replace them. The use of chemicals to manage pests is the practice that really forces us to think about a coordinated approach to pest management, because poorly considered use of pesticides can have a detrimental effect on the efficiency of other methods, and can lead to the 'one step forward, two steps back' syndrome.

Improper use of pesticides can be extremely detrimental. Potential consequences include, in increasing order of severity - poor control of the target pest; damage to non-target organisms, including beneficial organisms; and environmental contamination, which can be short- or long-term, depending on the scale of the misuse and the nature of the pesticide.

Method Integration

The proper coordination of the different control practices is what makes IVM. It is not enough to be able to list several practices that you are using to manage undesirable vegetation. It is important to understand how these practices work together. For example, when managing insect pests, insecticides should be selected and applied in a manner that affects the pest, but preserves beneficial predaceous and parasitic insects. This can be a matter of material selection, application placement, application timing, or simply not applying. When managing vegetation with herbicides, it is important not to mow or mechanically disturb treated plants soon after treatment, so that the herbicide has an opportunity to move through the plant. Another example of method integration would be cut-surface herbicide treatments to control brush. When non-coniferous woody plants are cut, they usually resprout vigorously with multiple stems. Within a few seasons, the brush is much denser and more problematic than it was before cutting. By simply adding the step of treating the cut surface with an herbicide to suppress resprouting, the process of cutting the brush becomes extremely effective.

Scouting and Monitoring

A final facet of an IVM program is scouting and monitoring, which allow the vegetation manager to identify and prioritize pest infestations, and devote resources where they are needed most.

In a crop setting, scouting is done periodically, often in concert with environmental conditions that are favorable for certain economically important pests. Pest level information from the scouting is used to determine whether control measures are necessary. In an IVM setting, scouting determines the abundance of plants that are targets based on the clearance objectives of the different management zones, and determines the priority of treatment. Scouting may also be conducted during the control action. For example, if a selective herbicide application is being conducted, the applicator is essentially scouting by seeking, and treating only target plants.

Monitoring and effective record keeping provide the manager with an indication of the effectiveness of control measures, and therefore allow a constant fine tuning of the vegetation management program.

With this introduction to IVM, we can now begin a more detailed discussion of the implementation of a vegetation management program. This will involve considering the management objectives for the ROW, the characteristics of the management area, and the tools available. Section three will focus on site considerations.

Section Three

Site Characteristics

Effective vegetation management is a combination of efficient utilization of available resources, and knowledge of the site to be treated. This section will discuss characteristics of the site that affect vegetation management. For our purposes, site characteristics will be categorized as vegetation, soil, terrain, water, and proximity to non-targets.

Vegetation

The nature of the vegetation present at a site is one of the most important factors in determining the most appropriate management. For management purposes, vegetation can be categorized in many ways, based on the setting.

For example, in a non-selective, or bare ground situation, such as a substation, management is almost exclusively with herbicides. All vegetation is a target, and can be classified as 'seed', 'seedling', and 'established', since these categories help determine which types of herbicide are necessary. Selective vegetation management is a different situation since you would like to leave desirable vegetation while eliminating the target plants.

We should review a few points of basic plant biology that will play a role in our control practices. Plants are classified as annual, biennial, or perennial, based on their life cycles.

Plant Life Cycles

One point that should be made about classifying plants by their life cycles is that man-made classifications rarely fit perfectly. Many plants, particularly 'weedy' plants, are variable in their behavior. Yellow rocket, which is listed as winter annual below, can also occur as a summer annual, a biennial, or a perennial. The listings below describe how these plants typically grow.

Annuals live one growing season, and reproduce by seed only. Summer annuals germinate in the spring or early summer, and complete their life cycle before winter. Winter annuals germinate in the fall, overwinter, then complete their life cycle in the early spring. The most effective management programs prevent annuals from going to seed, so that the population of viable seed in the soil is not increased. Examples of annual weeds are listed below.

Summer Annual Weeds

horseweed, marestail	*Conyza canadensis*
common ragweed	*Ambrosia artimisiifolia*
common lambsquarters	*Chenopodium album*
pigweed(s)	*Amaranthus* spp.
prickly lettuce	*Lactuca serriola*
giant foxtail	*Setaria faberi*
smooth crabgrass	*Digitaria ischaemum*

Winter Annual Weeds

shepherdspurse	*Capsella bursa-pastoris*
yellow rocket	*Barbarea vulgaris*
common groundsel	*Senecio vulgaris*
Japanese brome	*Bromus japonicum*
downy brome	*Bromus tectorum*

Biennials are plants that live for two growing seasons and reproduce only by seed. Typically, biennials germinate in the spring, grow close to the ground without stem elongation (rosette) the first season, overwinter, then elongate or 'bolt', flower, set seed and die. The distinction between what is a winter annual and what is a biennial is sometimes a gray area. Management of biennials is much like annuals, with the emphasis on preventing seed production. Biennials tend to grow much larger than annuals, so it is much easier to control them during their first season while they are still somewhat small. Examples of biennials are listed below.

common burdock	*Arctium minus*
white, and	*Melilotus alba*
yellow sweetclover	*Melilotus officinalis*
bull thistle	*Cirsium vulgare*
musk thistle	*Carduus nutans*
teasel	*Dipsacus sylvestris*
wild carrot	*Daucus carota*
poison hemlock	*Conium maculatum*
wild parsnip	*Pastinaca sativa*
spotted knapweed	*Centaurea maculata*

Plants that live more than two years are considered perennial. Perennials can be woody, or herbaceous (non-woody). Some perennials reproduce only by seed, such as dandelion (*Taraxacum officinale*). Many species can also reproduce without flowering, or vegetatively. Examples of vegetative propagation and species are listed below.

Shoots from Spreading Roots

Canada thistle	*Cirsium arvense*
tree-of-heaven	*Ailanthus altissima*
black locust	*Robinia pseudoacacia*

Rhizome (creeping, underground stems)

quackgrass	*Elytrigia repens*
Johnsongrass	*Sorghum halepense*
Japanese knotweed	*Polygonum cuspidatum*
common reed	*Phragmites australis*

Stolon (creeping, above-ground stems)

white clover	*Trifolium repens*
creeping bentgrass	*Agrostis palustris*

Bulb (enlarged stem bases)

wild garlic	*Allium vineale*

Plant Categorization by Management Objectives

In terms of managing plants, we can categorize them as grasses, forbs (herbaceous broadleaved plants), shrubs, and trees. A ROW is a confined space surrounding some type of man-made system. Large growing trees take up space, and are most likely to interfere with the function of the hardware in the ROW. Grasses and forbs on the other hand are usually low-growing, are less likely to interfere with the function of the ROW, and take up space that might be occupied by trees. A simple way to view ROW management then is to manage trees in a way to preserve and encourage the growth of grasses and forbs.

The size and number of stems per acre (density) of the target trees in a ROW will determine how selectively you can treat them. Small, scattered trees can easily be selectively treated using backpack sprayers without impacting desirable forbs and grasses. Dense populations of small to moderate sized brush cannot feasibly be treated without impacting nearby non-target vegetation. If a high volume spray application is made, the spray solution will contact adjacent plants. If the herbicide is selective (a 'broadleaf' herbicide), the application will leave grasses but injure forbs. If the herbicide is non-selective, all contacted vegetation will be injured.

Soil

The characteristics of a soil in a ROW can have a profound impact on the effectiveness of different vegetation management methods. Being the growing medium for the plants in the ROW, the soil certainly has an unavoidable impact on the vegetation present, and therefore, how the ROW is managed. An example of this effect would be cut slopes on a roadside. Quite often the soil exposed by such operations is quite infertile; and droughty due to very shallow depth to bedrock. In such situations, it is nearly impossible to establish a groundcover that would hinder the establishment of undesirable woody species. It is not uncommon in Pennsylvania to see soils that will not support crownvetch; but that will still support growth of ailanthus, commonly known as tree-of-heaven (*Ailanthus altissima*). In such a setting, cultural control methods are much more challenging, as alternate plant material for the slope must be identified and established.

A very wet soil can restrict the use of mowing as a management method. If a soil is wet on only a short-term basis, mowing such an area can be delayed. If a soil is wet for longer periods, it most likely will support wetland vegetation. In addition to the high water table causing mowing to be difficult, the wetland ecosystem should be regarded as fragile, and worthy of preservation. The rutting and resulting soil compaction caused by a mowing operation would be highly disruptive, and therefore unacceptable. Alternative methods in such an area include hand cutting undesirable woody vegetation and treating the stump with an herbicide labeled for wetland applications; using equipment that would inject herbicide directly into the target stem; or if vegetation size is appropriate, the use of a low volume foliar application .

Soil characteristics in a ROW will usually impact management with herbicides more than other methods. Characteristics influencing herbicide use include soil texture, permeability, hydrology, and depth to bedrock.

Soil Texture

Soil texture is determined by its relative composition of particle sizes. Particles less than two millimeters (mm) in diameter are considered to be soil particles. Soil particles are classified, from largest to smallest, as sand, silt, and clay. The size ranges for soil particles are listed below.

sand	2.0 to 0.05 mm
silt	0.05 to 0.002 mm
clay	<0.002 mm

Soils that are sandy are referred to as coarse textured, or 'light' soils. Soils high in clay are fine textured, or 'heavy'. Soil texture is also affected by the amount of organic matter, or humus. A soil that is fine textured, or high in organic matter content has much more surface area per unit volume. These soils have more chemical binding sites, and adsorb herbicides more readily. When herbicides are tightly bound to the soil, they are less available for uptake by plant roots. This is why many soil active herbicides call for higher application rates when soils are high in clay or organic matter.

Soil Permeability

Soil permeability describes the rate which water and air will move through the soil. Permeability can also be termed as internal drainage or infiltration rate. Soil permeability is determined by soil texture and soil structure. Soil structure is the arrangement of soil particles into aggregates. A soil that consists of mostly small particles may be quite permeable because the particles are grouped into distinct aggregates, separated by well defined pore spaces. These aggregates then behave like large particles, and the soil has permeability characteristics more like a coarse textured soil.

Highly permeable soils are cause for concern if you are considering the use of a highly soluble herbicide; or a highly persistent herbicide (Figure 3.1). Picloram and dicamba are examples of herbicides that are highly water soluble, and can move quickly through a permeable soil, and possibly reach groundwater. Bromacil and tebuthiuron are examples of herbicides that are not particularly soluble, but because of their long persistence in the soil, they too can move through a permeable soil and threaten groundwater.

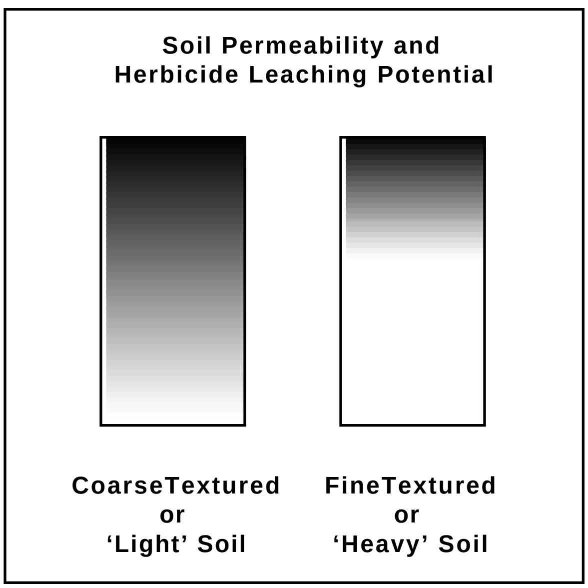

Figure 3.1: A demonstration of the role of soil texture on permeability, and resulting leaching of an herbicide. The herbicide, represented as black, has leached farther in the more permeable, coarse textured soil on the left.

Soil Hydrology

Although its meaning encompasses many aspects of the interaction of water and soil, we will use the term 'soil hydrology' to simply describe how wet a soil is, or how close the water table is to the surface of the soil.. This is a concern because if we apply an herbicide to a saturated soil, we are also applying the herbicide to the water in the soil. This water may or may not be groundwater, but we definitely have increased the chance of the herbicide moving with the water and causing undesirable off-site damage. For this reason, many herbicide labels prohibit the use of products on saturated soils, or in areas below the high water mark where tides affect soil water level (tidal wetlands).

Soil Depth

Another soil characteristic that influences herbicide movement through the soil is the depth to bedrock. A soil may be fine textured, and therefore effectively bind herbicides, but if this fine textured soil is very shallow, there is an increased likelihood that an herbicide can leach through this soil and reach groundwater. Bedrock is often criss-crossed by cracks and seams which make it much easier for water to move through it.

Terrain

Terrain influences soil development and movement of water on a site. These site factors each have a section devoted to them elsewhere in this chapter.

Another impact of terrain is on the selection of management methods. On relatively flat terrain, a ROW manager has many more options available, compared with steep terrain. For brush control on very steep terrain, the only options available may be helicopter-based applications; or crews on foot, equipped with chainsaws or backpack sprayers. These crews may have to work some distance from a support vehicle, and may have to be secured with ropes in extreme situations.

Water

Water can have a profound impact on a ROW and how it is managed. To protect this precious resource, a ROW manager must be aware of the surface and groundwaters present, as well as their source and destination. In addition to knowing where ponds, lakes, streams, and wetlands are located, it is important to understand where intermittent waters like rain runoff or snow melt flow. It is much easier to prevent sediment or herbicide contamination of water when you know when and where they will be present.

The integrity of groundwater is best maintained by establishing buffer zones around landscape features that provide access to groundwater, such as streams, ponds, springs, sinkholes, and bedrock outcroppings (Figure 3.2). Buffer zones virtually eliminate the direct application of pesticides to these sensitive areas; and reduce the potential for runoff carrying sediment or pesticide residues from reaching these areas. The use of buffer strips can also be extended to intermittent waterways within the ROW, much like a grass waterway in a row crop field.

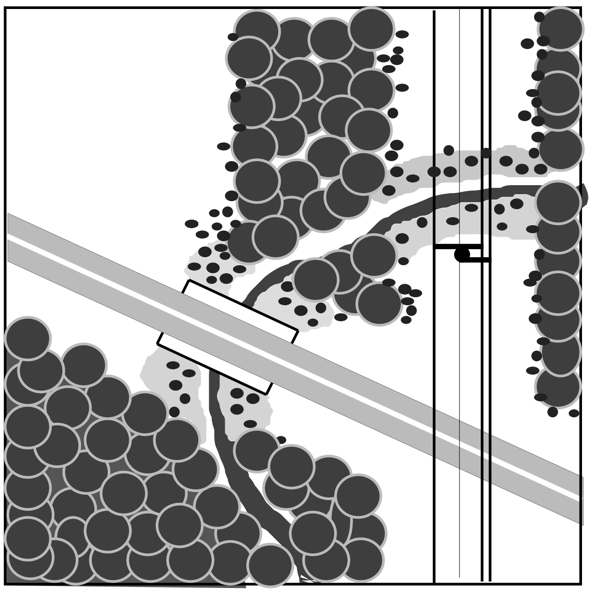

Figure 3.2: A bird's eye view of buffer zones, indicated by shading, next to a stream, crossing electric transmission and highway ROWs through a wooded area . The potential of contamination of the stream from herbicides or sediment is reduced by excluding broadcast spray or mowing operations. Undesirable vegetation within the buffers is treated individually, with techniques such as cut/stump treatment, or low volume backpack applications. Any backpack spraying would be done with the applicator's back to the water, spraying away from the stream.

To be effective, the buffer areas should be constantly vegetated, so management of undesirable species within the buffers should be highly selective. For example, if a ROW is being treated with a high volume herbicide treatment, simply switching to an herbicide mixture registered for use around water would not be sufficient if this mixture reduced the groundcover in the buffer, and reduced the ability of the buffer to slow surface runoff. A buffer area not only serves as a boundary to keep potentially harmful activities at some distance from a groundwater site, but also should be composed of dense, low growing vegetation to reduce runoff into the sensitive areas. Grasses provide the most runoff protection, but a plant community that is largely herbaceous would do well. Buffer strips may have to be managed using highly selective, individual stem treatments such as chainsaw/stump treatment, basal bark, or low volume foliar treatments.

The integrity of surface and groundwater is also protected through practices such as herbicide mix selection, and proper application. Herbicides with greater potential to enter groundwater through leaching or surface runoff should be avoided in ROWs featuring areas with a high potential for groundwater contamination. Additionally, applicators must be made aware of sensitive areas, and make their applications so that the applicator backs towards the sensitive area, spraying away from it.

Proximity to Non-targets

A final site characteristic we will discuss in this chapter is the proximity of non-target plants, and their influence on ROW management. A ROW is typically a relatively narrow, linear tract of land. On either side of the ROW is property that should not be impacted by ROW management treatments. The narrower the ROW, the more restrictive these boundaries can be.

Herbicide applications pose the greatest threat to non-target plants, although there are some other scenarios that present themselves. In an electric ROW, the primary consideration of plant targeting is height. Therefore, it is possible that species may preserved in the ROW that are relatively low-growing, but invasive. Examples include shrub species such as multiflora rose (Rosa multiflora), autumn and Russian olives (*Eleagnus umbellata*, and *E. angustifolia*); herbaceous species such as Japanese and giant knotweed (*Polygonum cuspidatum* and *P. sachalinense*), mile-a-minute (*Polygonum perfoliatum*), Canada thistle (*Cirsium arvense*), or purple loosestrife (*Lythrum salicaria*). In an electric ROW, these species would not hinder the transmission of electricity, and they would inhibit the establishment of tall growing woody species. However, these species would be troublesome if they spread off the ROW, and could negatively impact neighboring plant communities, whether they are agricultural, ornamental, or simply natural. Multiflora rose, mile-a-minute, Canada thistle, and purple loosestrife are classified as Noxious Weeds in Pennsylvania, and their spread is regulated by the PA Department of Agriculture. However, regardless of regulatory obligations, ROW managers should be aware of the impact that vegetation on the ROW can have on neighboring properties.

Herbicide applications pose a threat to non-target vegetation by misapplication, spray drift, volatilization, and root uptake. Misapplication, drift, and volatilization can be reduced by following established procedures, and will be discussed in more detail in later in this text. Root uptake can be avoided by being aware of the vegetation at the edge of the ROW, and avoiding the use of soil active herbicides near the ROW edge. A useful rule of thumb to remember is that the root system of a woody plant extends 2 to 3 times the width of the canopy (Figure 3.3). There are many herbicides, and mixtures available with little or no soil activity, that would allow ROW managers to keep the ROW clear up to the boundary without injuring plants on neighboring property.

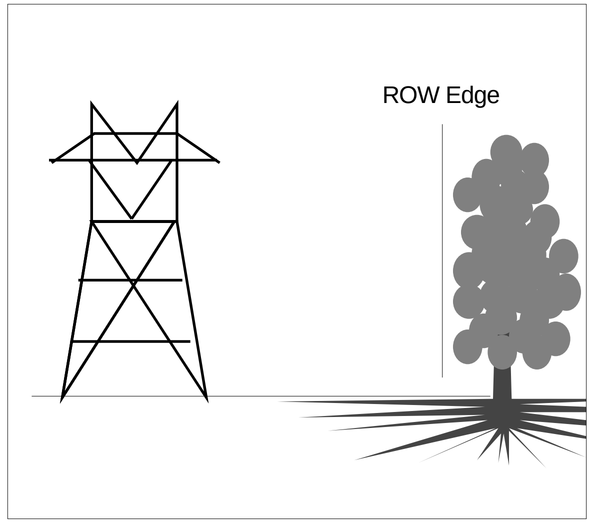

Figure 3.3: Although the branches of trees can be trimmed to the ROW boundary, the roots can extend a considerable distance - two to three times the width of the canopy. Herbicides that persist in the soil and can be picked by these roots can cause off target injury.

Section Four

Herbicide Characteristics

Herbicides can be classified in many ways. We can classify herbicides into chemical families based on their molecular structure and activity. Though such knowledge would be beneficial to the vegetation management practitioner, this detailed a knowledge of herbicides is not necessary to use them effectively. Initially, it may be more practical to classify herbicides into comparative categories such as soil applied vs. foliar applied, preemergence vs. postemergence, selective vs. non-selective, or contact vs. systemic. Table 4.1 provides a brief definition of each of these terms.

Table 4.1: A brief definition of terms used to distinguish herbicides. For any means of comparison, there is almost always an herbicide that is classified as 'both'.

Soil active - herbicides that are taken into the plant from the soil. Most are absorbed by the roots, some by emerging shoots.

Foliar - herbicides that are taken into the plant after application to the leaves and stems.

Preemergence - soil active herbicides that are applied prior to emergence, and act on weeds as they germinate.

Postemergence - herbicides that control weeds after they emerge. They can be foliar and/or soil active.

Selective - an herbicide that is active only on certain vegetation. It can be used to control one type of plant, while not harming another.

Non-selective - an herbicide that injures all vegetation.

Contact - an herbicide that injures only the portion of the plant it contacts.

Systemic - an herbicide that moves throughout the plant, able to cause injury away from where it contacted the plant.

A problem with imposing categories on herbicides is that they cannot be neatly split into two distinct groups, so there are always products that fall into both categories.. Table 4.2 demonstrates this with some commonly used non-crop herbicides.

For example,

Imazapyr (Arsenal) has both soil (root uptake) and foliar activity, and can be used pre- or postemergence.

Whether an herbicide is selective or not is often dependent on application rate.

The term 'Selective' becomes further complicated because we must distinguish between a selective herbicide, and a selective application - a non-selective herbicide can be selectively applied.

The distinction between contact and systemic activity is sometimes a matter of degree.

In addition to describing herbicides based on these categories, we will attempt to provide an understanding of how herbicides behave in the plant - their *mode of action* . A general understanding of how herbicides work in the plant will allow you to develop effective mixtures. The use of herbicide mixtures provides a broader spectrum of control, and allows you to reduce the amount of each ingredient used, compared to using a single product. However, a poorly chosen mixture could actually be less effective than using the individual products by themselves.

Table 4.2: An illustration of the difficulty of trying to characterize herbicides into simple categories

Product	Soil Active	Foliar	Pre-emergence	Post-emergence	Selective	Non-Selective	Contact	Systemic
Roundup Pro		●		●		●		●
Arsenal	●	●	●	●	●	●		●
Garlon		●		●	●			●
Tordon K	●	●	●	●	●			●
Escort	●	●	●	●	●			●
Finale		●		●		●	●	●
Reward		●		●		●	●	
Velpar	●	●	●	●	●	●		●

Herbicide Activity (and Selectivity)

The activity of an herbicide, or its ability to affect a plant, is dependent on many factors, such as the ability of the herbicide to enter the plant, movement within the plant to the target site, whether or not the target site of the herbicide is actually present, and the chemical fate of the herbicide after entering the plant. The variation in these factors from species to species is what causes differential activity, which is another way of saying selectivity. Selectivity is when you treat Species A and Species B with the same rate of an herbicide, and Species A is killed while Species B is relatively uninjured.

Herbicide Entry into the Plant

Herbicides have two routes of entry into a plant - through the leaves/stem or through the roots.

Entry Through Leaves/Stems

When an herbicide is deposited on the surface of a leaf or herbaceous stem, the first barrier inhibiting entry of the herbicide into the tissue may be a hairy surface. Dense hairs suspend droplets above the leaf surface, preventing the herbicide from actually reaching the leaf surface.

When the herbicide actually reaches the leaf surface, the next barrier to entry is the cuticle, a waxy layer covering the outer layer of cells of the leaf and green stems. The cuticle is a complex layer made up primarily of water repellent components such as waxes and oils. Herbicides diffuse through the cuticle, and reach the outer layer of leaf cells, the epidermis. Oil-soluble molecules such as esters of herbicides will diffuse through the cuticle with more ease than water soluble molecules such as amine salts.

Quite often, the thickness of the leaf cuticle or the orientation of the leaf surface has enough of an effect on herbicide absorption that a species may be protected from the effects of an herbicide. This is one of the factors that allows foresters to release southern pines from hardwood competition by overspraying plantations with glyphosate (Accord).

The Use of Surfactants

The chances of an herbicide getting past surface hairs and through the waxy leaf cuticle are improved with the use of surfactants. 'Surfactant' is a contraction of 'surface active agent'. Surfactants are typically a mixture of ingredients that aim to increase herbicide absorption through the following characteristics:

Reduce surface tension - reduces the tendency of a droplet to bead, so that the 'footprint' of the droplet covers a larger area of the leaf surface. Reduction of surface tension increases the tendency for a liquid to wet leaf hairs and flow down them, rather then perch above them

Humectant properties - reduces the evaporation of the droplet, providing more time for the herbicide molecule to diffuse into the cuticle. Herbicides are more likely to diffuse into the cuticle while in solution.

Leaf retention - the quality often referred to as 'sticking', or having the droplet of spray bounce off the leaf surface, or flow off the edge of the leaf.

Herbicide Entry through Roots

The plant root provides less of a barrier to herbicide entry than the plant's leaves or stems. By function, the root is a point of entry for water and dissolved minerals, while in contrast, the aboveground portions of the plant function to prevent the loss of water. The thick epidermis and the cuticle keep water in, and provide a considerable barrier to substances trying to enter the plant as well.

As long as an herbicide is capable of being suspended in the soil water solution, it can enter through the root hair. For this reason, only herbicides that are very tightly bound to soil particles, such as glyphosate (Roundup Pro) or diquat (Reward) are not available for root uptake. Even herbicides with solubilities less than one part per million, such as pendimethalin (Pendulum) or oryzalin (Surflan) can be taken up by roots.

Herbicide Movement in the Plant

Once an herbicide has entered the plant tissue, it must move within the plant to the site of activity. Over short distances, such as within the leaf where an herbicide is deposited, this can occur through diffusion, the movement of a material from a high concentration to a low concentration. Herbicides that are limited to this type of movement are *contact* herbicides because they only act on parts of the plant contacted by the herbicide application.

To move greater distances in the plant, such as from the leaves to the roots, an herbicide must enter the plant's transport tissue. Herbicides capable of moving in the plant's transport tissue are called *systemic*.

Plants have two types of tissue for transport - the xylem and the phloem. Xylem moves water and dissolved minerals from the roots to the leaves - the direction of flow is upwards Xylem tissue is not alive - once each individual tube-like cell is completely formed, the cell dies. Examples of herbicides that move primarily through the xylem include photosynthetic inhibitors such as hexazinone (Velpar), diuron (Karmex), bromacil (Hyvar), or tebuthiuron (Spike).

The phloem is living tissue that transports sugars and other organic molecules from where they are made or stored, to where they are needed for growth. Movement within the phloem is not up or down, it is towards the growing points. Examples of phloem-mobile herbicides include growth regulator herbicides such as dicamba (Vanquish); amino acid synthesis inhibitors such as glyphosate (Roundup Pro), imazapyr (Arsenal), or sulfometuron methyl (Oust); and lipid synthesis inhibitors such as quizalofop-P-ethyl (Assure II) or fluazifop-P-butyl (Fusilade II).

The activity of herbicides mobile in the phloem is highly influenced by the type of growth a plant is going through at the time of application. Phloem-mobile herbicides move with the carbohydrates in a plant. Early in the season, herbaceous perennial plants produce new foliage from carbohydrate reserves in the roots. In this situation, carbohydrate movement is from roots to leaves. Herbicides applied to the foliage at this stage will not get to the roots - the top of the plant will be 'burned off', but it will regrow.

Sometimes herbicide activity is affected by how readily an herbicide will translocate. One of the reasons growth regulator herbicides such as 2,4-D are relatively inactive on grasses is thought to because they are not effectively transported, compared to broadleaf species.

Herbicide Target Sites within the Plant

The site where an herbicide actually acts on a plant varies with herbicide. The growth regulator, or 'broadleaf' herbicides, such as 2,4-D, dicamba, or triclopyr (Garlon) are thought to mimic the activity of the plant hormone auxin, and may have several sites of activity.

At the other extreme are herbicides such as the 'ALS inhibitors' - herbicides such as sulfometuron methyl or imazapyr that inhibit the synthesis of amino acids by binding to the enzyme acetolactase synthase. There is one specific site on this huge enzyme that these herbicides bind to. It turns out, however that this enzyme occurs in at least two slightly different forms, even within the same plant species. One form of this enzyme is not affected by these herbicides, and individual plants containing this form of the enzyme are resistant to these herbicides - they are completely ineffective.

Herbicide Metabolism within the Plant

Foreign molecules typically do not move about in plants unscathed. Because herbicide molecules often are made of commonly occurring chemical groups, they are subject to the vast array of chemical processes occurring in plants. Herbicide molecules are inactivated in many ways - they are cleaved, or broken apart so that there parts may be used elsewhere; they are conjugated, or joined to other molecules; or they may bind to sites where they are not active.

Quite often what determines whether an herbicide is active on a plant species is how quickly the herbicide molecule is broken down. A common example of this process is the herbicide atrazine and corn. Corn metabolizes atrazine very quickly - so although atrazine enters corn in an effective concentration, and corn contains the site of activity, the atrazine molecule is broken down before it ever reaches the site of activity.

So clearly, the path an herbicide takes from the end of the spray nozzle to the site of activity is a tortuous one. With so many variables affecting the fate of an herbicide, it becomes apparent why herbicides can be so variable in their activity between plant species.

Herbicide Use and Mode of Action

For non-crop weed control applications, we can categorize herbicides by usage as broad spectrum residual, preemergence, and postemergence. The definition of some of the terms is narrower in this scheme. For example, herbicides classed as ‘Broad Spectrum Residual’, and ‘Preemergence’ are both effective as preemergence herbicides. For our purposes, however, we use the term ‘Preemergence’ to describe a group of herbicides that control weeds from seed, but have little or no activity on established weeds - to be effective, these herbicides must be applied prior to (or very soon after) emergence.

Broad Spectrum Residual - non-selective; remain active in the soil after application; active against established vegetation.

Preemergence - remain very close to soil surface; for control of seedlings; not effective on established vegetation.

Postemergence - taken up through foliage or stems, effective against established vegetation.

For our discussion of herbicides, the common names, or active ingredient, will be used. Reference to rates will be in active ingredient, unless specified otherwise.

Broad Spectrum Residual (BSR) Herbicides

BSR herbicides are typically non-selective at labeled use rates, and remain active in the soil after application. Their utility for selective vegetation management is limited to situations such as controlling scattered brush with spot applications to the soil.

BSR's are the herbicides that are sometimes referred to as 'soil sterilants'. This is a poor description of these herbicides for two reasons. First, BSR's do not sterilize the soil. They act on growing plants. They do not kill ungerminated or dormant seeds. They do not kill the other organisms in the soil, such as fungi, bacteria, nematodes, earthworms, and insects. It is soil *fumigants* such as methyl bromide, metam sodium, and dazomet that are used to sterilize soil. Second, the use of herbicides is a source of concern for many people, and inaccurately characterizing herbicides as being more toxic than they are is poor public relations.

BSR's are useful to control established vegetation and prevent germination of additional weeds. Like most technologies that are very potent, BSR herbicides can cause serious problems if they are misused. Due to their potency and long life in the soil, they can cause considerable damage if they move off-site after treatment. These herbicides should only be used in the amounts needed. When sites are fairly free of established vegetation, BSR use should be reduced or eliminated in favor of a combination of preemergence and low-residual postemergence herbicides.

Examples of commonly used BSR herbicides include sulfometuron methyl, imazapyr, bromacil, tebuthiuron, and prometon. The common name, product example, and mode of action of BSR herbicides is summarized in Table 4.1.

Table 4.3: Examples of broad spectrum residual (BSR) herbicides for non-crop weed control applications, listed by mode of action (italicized type).

Herbicide	Product Example
Amino Acid Synthesis Inhibitors	
sulfometuron methyl	Oust
imazapyr	Arsenal
Photosynthetic Inhibitors	
bromacil	Hyvar X
hexazinone	Velpar L
prometon	Pramitol
tebuthiuron	Spike

Amino Acid Synthesis Inhibitors

Sulfometuron methyl and imazapyr are examples of amino acid synthesis inhibitor herbicides. They act on plants by inactivating an enzyme that is required for the synthesis of three amino acids. There are 20 amino acids that serve as the building blocks of all proteins. Proteins are composed of hundreds, sometimes thousands of amino acids. All 20 amino acids are essential to the production of all proteins. When the plant loses the ability to produce any of these amino acids, protein synthesis stops. When protein synthesis stops, growth stops, and the plant slowly dies.

The amino acid synthesis inhibitor BSR's can be taken up through foliage or roots, providing pre- and postemergence activity. Sulfometuron methyl and imazapyr are relatively new compounds, and are used at rates much lower than the older photosynthetic inhibitor herbicides. Sulfometuron methyl is commonly used at rates of 0.09 to 0.19 lbs per acre, or 2 to 4 ounces of product per acre. Imazapyr is commonly used at rates of 0.5 to 1.0 lbs per acre, or 1 to 2 quarts of product per acre, to provide bare ground. Contrast these rates with those for bromacil and tebuthiuron, which will be used at rates from 3 to 6 lbs per acre. Prometon is used at rates starting at 10 lbs per acre.

Photosynthetic Inhibitors

Bromacil, hexazinone, prometon, and tebuthiuron are photosynthetic inhibitors. Hexazinone can be readily absorbed through foliage, while the other three are taken up primarily through the roots. Once in photosynthetic tissue, they block key steps in the photosynthetic process. Rather than being captured and converted to high energy 'fuel' molecules, light energy is converted into highly reactive molecules called free radicals. These free radicals damage cell membranes, causing death of the cell.

Photosynthetic inhibitors work relatively slowly, as they must move through the soil into the root zone before they can enter the plant. The length of time required to observe control of treated plants varies with size. Seedlings may be killed within a week. Affected trees go through a yellowing, then loss of leaves. They may put out a new flush of leaves several times before they finally use up all their energy reserves and die.

Preemergence Herbicides

Preemergence herbicides are used to prevent establishment of weeds from seed. Some preemergence herbicides will also provide control of seedlings. Preemergence herbicides stay very close to the soil surface. This is due to the low solubility of these herbicides, or their ability to bind strongly to soil particles, or both. Preemergence herbicides do not control established vegetation, which is why many can be used to prevent weeds from seed in landscape beds or turf.

Preemergence herbicides have limited uses for selective vegetation management in non-crop areas. They are widely used in ornamental turf and landscape plantings to prevents weeds coming from seed, but there is little need for this application in a non-crop area. There primary use in non-crop areas is in bareground situations.

Table 4.4: Examples of preemergence herbicides for non-crop weed control applications, listed by mode of action (italicized type).

Herbicide	Product Example
Photosynthetic Inhibitors	
diuron	Karmex
norflurazon	Predict
Root Inhibitors	
oryzalin	Surflan
pendimethalin	Pendulum
prodiamine	Endurance
trifluralin	Snapshot 2.5 TG
Cell Wall Inhibitors	
dichlobenil	Casoron
isoxaben	Gallery

Photosynthetic Inhibitors

Diuron and norflurazon inhibit photosynthesis, very much like the BSR's bromacil and tebuthiuron - they are taken up the roots, and move with the water stream up to the leaves. However, they are much less potent, and at label rates do not pose near as much hazard as the BSR's if they move off-site. Diuron will control existing seedlings at the time of application.

Root Inhibitors

The root inhibitor herbicides will not control seedlings that are present at the time of application. To be effective, root inhibitor herbicides must be in place in the soil prior to seed germination. They are taken up by the newly emerging root, and act on the plant by preventing cell division in the growing root tip. Therefore, the root system never develops, and the young plant dies. The root inhibitor herbicides are more effective on grasses than broadleaf weeds.

Cell Wall Inhibitors

Isoxaben interferes with the formation of the cell walls in the germinating plant, causing grossly abnormal growth, and death prior to emergence. Isoxaben is used primarily for preemergence broadleaf weed control in ornamental beds and turf, but can be useful in industrial situations where bare ground must be maintained near desirable plants.

Postemergence Herbicides

Postemergence herbicides are the workhorse materials in a selective vegetation management program. Compared to BSR herbicides, postemergence herbicides provide relatively quick control of existing vegetation, particularly if it is well established. Postemergence herbicides provide quicker activity because they enter primarily through the foliage. They enter the plant within minutes or hours after application, compared to the much longer time required for a soil active herbicide to move through the soil and be taken up by the roots. Many postemergence herbicides have very little, if any, soil activity. This allows you to control well established vegetation, and avoid the risks associated with herbicides that remain active in the soil for long periods.

There is a wide array of postemergence chemistry available for non-crop usage. A summary of postemergence herbicides is listed in Table 4.3.

Table 4.5: Examples of postemergence herbicides for non-crop weed control applications, listed by mode of action (italicized type).

Herbicide	Product Example
Contact Herbicides	
pelargonic acid	Scythe
diquat	Reward
glufosinate	Finale
Amino Acid Synthesis Inhibitors	
chlorsulfuron	Telar
glyphosate	Roundup Pro
imazapic	Plateau
imazapyr	Arsenal
metsulfuron methyl	Escort
Growth Regulator (Broadleaf) Herbicides	
2,4-D	many
clopyralid	Transline
dicamba	Vanquish
fluroxypyr	Vista
picloram	Tordon K
triclopyr	Garlon 3A
Lipid Biosynthesis Inhibitors (Grass Herbicides)	
clethodim	Envoy
fluazifop-p-butyl	Fusilade II
quizalofop-methyl	Assure II
sethoxydim	Vantage
Photosynthetic Inhibitors	
hexazinone	Velpar

The activity of contact herbicides is limited to where they are applied - they do not move through the plant. Contact herbicides are useful for controlling seedlings, and may control some annuals throughout the season. Contact herbicides will not control biennials and perennials, and even well established annuals will often regrow. Because they do not move in the plant, adequate coverage is essential for control.

Systemic herbicides move through the plant, or translocate. Herbicides that are truly systemic are transported through the plant's conducting tissue.

To be effective, whether contact or systemic, postemergence herbicides should be applied to actively growing plants. Plants growing slowly due to temperature stress, or suffering drought stress are less likely to be controlled.

Contact Herbicides

Diquat, glufosinate, and pelargonic acid are examples of contact herbicides. They act very quickly. On a warm day, when plants are actively growing, the effects of pelargonic acid can be seen within minutes. Diquat often provides complete activity within 2 days, while glufosinate will provide complete activity in 4 to 7 days during active growth. These materials work by damaging plant cell membranes. The fluid within the cell leaks out, and the tissue quickly dies. This activity is limited to where the herbicide actually contacts the plant. These materials are effective when plants are small enough to be adequately covered by spray solution. Where dense canopies occur, these materials will burn off the top layer only.

Systemic postemergence herbicides can be grouped as amino acid synthesis inhibitors; growth regulator, or hormone herbicides; fatty acid synthesis inhibitors; photosynthetic inhibitors; and 'unknown' - the mode of action of some herbicides has not yet been determined.

Amino Acid Synthesis Inhibitors

Examples of postemergence amino acid synthesis inhibitor herbicides include glyphosate, imazapyr, chlorsulfuron, and metsulfuron methyl. Just as described for the amino acid synthesis inhibitor BSR herbicides, these herbicides prevent the synthesis of specific amino acids, resulting in the death of the plant.

Glyphosate, imazapyr, chlorsulfuron, and metsulfuron methyl are mobile in the plant's vascular system, and move throughout the plant. Glyphosate is non-selective, imazapyr is broad spectrum, while chlorsulfuron and metsulfuron methyl are more active on broadleaf species.

Glyphosate has no soil activity, as it is tightly bound to soil particles and unavailable for root pick up. Imazapyr has considerable soil activity, and was previously discussed as a BSR herbicide. At much lower rates, imazapyr can be used to increase the control spectrum of herbicides such as glyphosate, without providing long-term soil activity. Chlorsulfuron and metsulfuron methyl have soil activity, but not enough to be used alone to maintain bare ground. They are chemically similar to sulfometuron methyl, and are also used at very low rates.

Growth Regulator Herbicides

Growth regulator herbicides, also know as 'hormone' or 'broadleaf' herbicides are widely used for broadleaf weed control in turf, and brush control applications. These herbicides mimic the activity of the plant hormone auxin, and profoundly interfere with the plants ability to regulate growth. Typical symptoms include leaf and stem curling and twisting, fusion of stems, and gall-like formations on woody plants. These vary in their soil activity, from very little for triclopyr or 2,4-D; to considerable soil activity for dicamba and picloram.

Lipid Biosynthesis Inhibitors

Several of the selective grass herbicides have labeling for non-crop uses. In non-crop settings, their most frequent use would probably be control of annual grasses in wildflower plantings. They are also useful for removing other grass species from fine fescues, which are highly tolerant of this type of herbicide chemistry.

Photosynthetic Inhibitors

Hexazinone (Velpar) is a photosynthetic inhibitor, and was previously discussed in the BSR section. Hexazinone is another example of a material that can be used as a BSR at high rates, and as a selective material at lower rates. It is particularly useful for suppression of thistles in crownvetch. Hexazinone can also be used as a spot concentrate application to control woody vegetation. Hexazinone moves in the xylem, so it will translocate upwards after root uptake, however, it does not move into the root system after a foliar application.

Unknown Mode of Action

Fosamine ammonium (Krenite S) is widely used as a brush control herbicide, but its mode of action is unknown. Applied late in the season, fosamine produces minimal symptoms, but in the spring the treated brush does not leaf out. Another feature of fosamine that makes it popular is that it provides 'side trimming' - it only affects the side of the tree that is treated.

Section Five

Selective Herbicide Application Techniques

There is a dizzying array of techniques available to apply herbicides to manage vegetation in non-crop areas. We will categorize these techniques by their target, method, carrier type, carrier volume, and selectivity. These characteristics are described in more detail below.

Target - Herbicides can be applied to plant foliage, plant bark (or stems), or to the soil.

Method - We use this term to describe whether the herbicide is being *broadcast* over the entirety of a target area, or whether targets are being *spot-treated* within an area.

Carrier Type - Herbicides can be applied as a liquid, whether water- or oil-based; or as a dry material.

Carrier Volume - This concept is most readily applied to liquid applications. High volume applications feature a low concentration of herbicide and call for complete coverage of the target, spayed to the point of run-off. Low volume applications rely on higher concentrations of herbicide and stress using as little solution as practical to treat the target.

Selectivity - Selective applications do not affect certain vegetation that is present on a site. Non-selective applications will injure all the vegetation that is treated.

Applications to Plant Foliage

Foliar applications are probably the most widely used. Applying to foliage provides the greatest amount of surface area to intercept the pesticide solution. Once plants have fully 'leafed out', foliage applications also provide the best route for phloem-mobile herbicides to translocate to the root system to provide complete control.

The term 'leafed out' describes when enough growth of a perennial plant has occurred so that the above-ground portion of the plant is producing enough sugars from photosynthesis that it can support itself. Early season growth of perennial plants is supported by energy reserves. Individual leaves do not support themselves until they have completely expanded. So, 'leafed out' describes the condition where there are enough fully expanded leaves to support their own functioning as well as provide the energy for the younger, expanding leaves, and even begin exporting carbohydrates to replenish the root system.

Foliar applications made too early in the season tend to just kill the top growth that is present, leaving the root system intact to regenerate new shoot growth. This points out one of the drawback of foliar applications - a short work season. In Pennsylvania, foliar applications, particularly for brush control, should not be initiated until late May to early June. Some common target species, such as tree-of-heaven (ailanthus), are among the latest woody plants to leaf out. Foliar applications to brush can only extend to fall coloration, further shortening the application season. Some species, such as boxelder maple (*Acer negundo*) drop their leaves quite early, often in September; while species such as black locust (*Robinia pseudoacacia*) may retain green foliage into November.

High Volume Foliar Applications

High volume foliar applications on non-cropland are characterized by a low concentration of herbicide - usually 1 to 2 percent on a volume basis, moderate to high pressure, and are often made with a handgun mounted on a hose reel. The handgun is commonly equipped with an adjustable spray nozzle that varies from a wide, hollow cone to a straight stream. The pattern is regulated by a trigger valve, or by a twist-actuated valve. The trigger valve allows for more rapid adjustment of the spray pattern, but requires more hand/forearm muscular effort than the twist-valve. The drawback of the twist-valve is that pattern adjustment or spray shut-off is not as quick as it is with the trigger valve.

A functional high-volume set-up calls for a fairly large spray tank, and a vehicle substantial enough to carry a full tank plus hardware. A 300 gallon tank is going to hold 2,400 lbs of water. A high output piston or diaphragm pump is required to generate adequate pressure to overcome the pressure drop that will occur when you have several hundred feet of hose.

Advantages

One of the primary advantages of high volume applications is that it is relatively easy method to train inexperienced applicators to use. Proper coverage entails completely wetting the entire target to the point of runoff. This is an easy condition to visualize. The results of a high volume application are fairly predictable - the chances are very good that it will be effective. Therefore, an inexperienced applicator can still achieve the desired results. With experience, applicators become able to use less solution as they become skilled in treating to the point of runoff, rather than well past the point of runoff. In other words, wet is wet - with experience you use less solution to make the target wet.

Another advantage of the high volume method is flexibility. With a hose-mounted handgun with an adjustable pattern - ranging from a wide, hollow cone to a straight stream, the applicator can adequately cover a wide range of target sizes and densities. Targets ranging from scattered small brush to patches of 15 to 20 ft tall resprouts or dense thickets Japanese knotweed ('bamboo') can be effectively treated.

Disadvantages

A disadvantage of the high volume approach is the inability to precisely target the application. If small targets are growing amongst non-target vegetation, it is difficult to treat the targets without treating the non-targets as well.

Another potential drawback of high volume applications is that the operation can become cumbersome if the targets are small and scattered - the applicator spends more time dragging and rewinding hose than applying. If this type of situation only occurs infrequently during an application that is targeting mostly large or dense vegetation, then this is but an annoyance. If most of the targets are small or scattered, a backpack-based treatment would be more feasible.

Broadcast vs. Spot Applications

In most situations where a high volume application is being made, it would technically be a spot application - only targets are being treated. It may turn out the targets are so dense that nearly the entire area is treated.

If a broadcast application is truly desired, it is often more effective to accomplish this using a fixed pattern device such as a high capacity off-center nozzles or a multi-nozzle oscillating spray head mounted on a truck, tractor, or skidder. This approach provides the desired uniform coverage, but allows the use of a much lower spray volume.

A situation where a high volume broadcast application is often made is on industrial sites. In such settings, there may be too many obstacles to utilize a vehicle-mounted fixed pattern. In this situation, a hose mounted spray gun is often equipped with an off-center flat fan nozzle that allows the applicator to walk back and forth treating a uniform swath at consistent pace, while conforming to the irregular shape of the facility.

Selective vs. Non-selective Applications

By nature, high volume applications are not particularly selective by placement - particularly if the applicator is relying more on the throw capabilities of the sprayer rather than his or her feet to get the herbicide on the target. Selectivity is more an issue of herbicide chemistry.

Applications can be made to brush or broadleaf weeds that do not injure grasses. Therefore, if a lot of grass is present, applications of growth regulator herbicides such as Garlon (triclopyr), Tordon K (picloram), or Vanquish (dicamba) would leave much of the understory intact.

High volume applications of glyphosate (Accord,) are often made to utility ROWs. Although glyphosate is non-selective, this application is non-selective in the short term only. Glyphosate has no soil activity, so the area is quickly recolonized by the seed bank.

Low Volume Foliar Applications

Low volume foliar applications are characterized by herbicide concentrations that are in the range of 5 to 10 percent on a volume basis, and are usually applied at a coverage equivalent to between 5 and 20 gallons/acre. Low volume applications are often made with backpack sprayers equipped with adjustable cone nozzles, such as a Spraying Systems #5500 ConeJet with an X-6 tip; or swivel-body valves providing the applicator a choice of spray tips. Typically, one tip would be a 15 degree flat fan, such as a Spraying Systems 1506, which provides reach for taller plants; and a wider pattern tip such a Spraying Systems 4004 flat fan for closer targets.

An recent innovation has been the introduction of the Thinvert® system, which features a thin invert emulsion carrier and spray tips specially designed for this carrier. The Thinvert system provides uniform droplet size, giving the applicator more control over spray deposition, plus the milky-white carrier is easy to see on the target. Thinvert application volumes are intended to be between 3 and 5 gallons/acre.

Low volume applications can also be made from vehicles with fixed-pattern devices such as a Radiarc® or fixed-boom sprayers, which can be configured to deliver carrier volumes between 10 and 20 gallons/acre.

Desired coverage for low volume applications is characterized as placing discrete droplets on the leaves of the target, rather than completely wetting them.

Advantages

The primary advantages of backpack-based low volume applications are mobility and selectivity. This type of application is ideal for small to medium size targets in low to moderate densities. Practical target size ranges from seedling to about 15 ft. The application can be made wherever a person can walk.

The applicator must get much closer to the target, and has a sprayer with a much lower flow rate, compared to a high volume application, so very small targets can be selectively treated even when surrounded by desirable vegetation that should not be treated.

Tractor, skidder, or ATV-based low volume applications provide a very efficient means to cover many acres between refilling the spray tanks. Such applications are utilized on utility ROWs after a mowing operation, before resprouts get too tall.

Disadvantages

Drawbacks to the low volume method include encountering patches of dense, large target vegetation; and increased training requirements.

Compared to high volume equipment, a low volume sprayer has a very low flow rate and limited reach while providing adequate coverage. Encountering dense patches of large vegetation, such as brush resprouts from suckering species such as sumac, ailanthus, or black locust is troublesome to the applicator. It takes much more walking to get herbicide on the area than it would if the applicator was performing a high volume application. It also requires walking through dense patches of vegetation that could often be treated from the perimeter with the greater reach of a high volume application.

Training applicators to apply low volume, particularly if they are accustomed to high volume applications, is critical. It is very useful to closely supervise initial efforts to achieve very light coverage, as well as thoroughness, particularly on larger targets. It is also very useful to give applicators an opportunity to come back to the site to view the results of their efforts so that they may make any necessary adjustments to decrease volume or increase coverage. There is definite art to achieving the necessary coverage while minimizing the solution used.

Consistent understory damage is an indication of over application, or sloppy targeting. Live branches on otherwise dead plants suggests that coverage needs to be a little more thorough.

Broadcast vs. Spot Applications

Due to the low flow rate (small nozzles) of a low volume foliar application, it is very well suited to spot applications for either herbaceous or woody targets.

Low volume applications are not as well suited for broadcast coverage if you are using a conventional backpack. Such a system does not have the reach to cover a lot of area efficiently, and the applicator ends up walking most of the area.

If you are using vehicles, or a motorized backpack, there are many hardware configurations available that provide 10 to 20 foot wide spray patterns. To use a fixed pattern, however, the target vegetation must be relatively short, so that the spray device can be mounted above the canopy.

Selective vs. Non-selective Applications

Low volume backpack applications can be highly selective, even if the herbicides used are not selective. The low flow rate and limited reach of a backpack application make it possible to be very specific in your targeting, and nearly eliminate non-target injury.

Non-selective application to large areas using a low volume approach are best done with a fixed pattern setup, using a motorized backpack or vehicle. For small areas, or band applications such as treating a fenceline, a backpack application would work well.

Applications to Plant Stems

Herbicide applications to plant stems can be used to control brush. These applications provide a high degree of selectivity when they are applied one stem at a time. Stem applications also provide operational flexibility because they can be made any time of year. There are environmental conditions that will limit the use of these treatments, and there are species issues that affect application timing.

When the species of concern are root suckering species, such as ailanthus, black locust, sumac, or sassafras, the target of the control operation is the root system. The herbicides used for stem treatments are systemic, and move with carbohydrates in the plant's phloem tissue. Therefore, to control the roots, herbicide treatments should be applied when there is net movement of carbohydrates into the roots. This is the foliar application window, from 'full leaf-out' to fall color. Stem applications made outside this window will result in top kill of the plant, but there will be substantial suckering. Mis-timed stem applications can actually make the situation worse, as there will be several resprouts for each treated stem, and the sprouts will grow very quickly as the plant will invest a lot stored root energy to replace the canopy lost to the original treatment.

Application methods described in this section are basal bark, cut surface, and dormant stem. Basal bark and cut surface treatments are applied to individual stems, while dormant stem treatments are applied much like a foliar treatment - without foliage.

Basal Bark Applications

Basal bark treatment describes the application of an herbicide/oil mixture to the *complete circumference* of the lower portion of a tree stem. Early implementations of this technique used 2,4-D and 2,4,5-T at concentrations of 1 to 2 percent in diesel or kerosene, applied at high volumes so that the solution puddled at the base of the tree. This is referred to as 'conventional' basal bark. A more recent implementation has been to use much higher concentrations, 20 to 30 percent, of an herbicide such as Garlon 4, in specially formulated basal oils, applied at a very low volumes. The lower 12 to 18 inches of the bark is treated down to the soil line with just enough solution to become wet, with no runoff. This is referred to as 'low-volume' basal bark.

Since the introduction of low volume basal bark applications, this method has become the standard basal bark practice, and therefore is the convention; and 'conventional' basal bark is rarely used. Therefore, we will not further discuss 'conventional' basal bark, and will simply use the term basal bark, which will mean low volume basal bark. Many herbicides still have labeling for conventional basal bark, but we will not consider these uses here.

Standard equipment for a basal bark application is a backpack sprayer equipped with a single nozzle spray wand. Ideally, the spray wand should be configured so that the valve is at the tip, to enhance quick shut-off, and prevent dripping of the concentrated herbicide solution between targets. This can be accomplished by using a 'basal wand' which has a cable-actuated shut-off at the tip, or by installing a pressure-limiting check valve at the tip of a conventional wand. The most commonly used nozzle configuration is a Spraying Systems #5500 ConeJet with a Y-2 tip, which is the smallest orifice available. The adjustable cone tip that comes standard with many backpack and pump-up hand held sprayers is too big, and will result in over-application and material waste if used.

Basal applications girdle the treated stem by killing the cambium. It is essential to completely encircle the stem with the treatment, as even very thin 'bridges' of living cambium will support most of the existing canopy of a tree. Treatments during the dormant season tend to affect the treated area only, though herbicide present in the xylem tissue will be carried to the canopy in the spring, and may cause injury symptoms to appear in the expanding leaves. Applications made during active growth will cause dramatic foliar symptoms as the herbicides used for basal bark treatment are all readily carried in the upward flow of water in the plant's xylem tissue. Treatments made after full leaf-out but before leaf drop will be translocated to the root system.

Because basal bark treatments are applied to individual stems, there need not be any discussion of the issue of broadcast vs. spot application, or selective vs. non-selective application. Further discussion will be limited to advantages and disadvantages of basal bark treatments.

Advantages

Basal bark applications are highly selective, and provide operational flexibility. The application is made using low volume equipment, with the applicator standing immediately adjacent to the target, so that off-target application is limited to a small 'halo' a few inches in diameter surrounding the stem. During the winter months when surrounding herbaceous vegetation is dormant and matted down, there is no non-target vegetation present to injure.

When the herbicide triclopyr (Garlon 4 or Pathfinder II) is used, basal bark treatments can be used to control undesirable trees growing right next desirable trees. Triclopyr has essentially no soil activity, so as long as it is not applied to non-target plants, they will not be injured.

Timing flexibility is another advantage of basal bark treatments. The only situations when basal bark treatments cannot be made is when there is standing water, or deep snow at the base of the target stem, or when the bark is saturated with water. Woody species that do not root sucker can be treated any time. Root suckering species should be treated during the foliar season to effect control of the root system.

Basal treatments can be useful when trees are too tall for effective foliar treatment. Basal bark treatments are recommended on stems up to six inches in diameter, although larger stems of many species can be controlled as well. Quite often, stems of this size are too tall to be practically treated with a foliar application.

Disadvantages

Basal bark treatments are labor-intensive because each and every stem has to be treated. Where stem densities are high, such as patches of sumac, the application becomes excruciating. Basal bark is best suited to low to moderate stem densities.

Cut Surface Applications

The term 'cut surface' describes the treatment of exposed cambial tissue, via techniques such as stump treatment, hack and squirt, or injection. Very small volumes of solution are used, so the herbicide concentration of the mixture is quite high, from 25 to 100 percent, depending on the product.

Stump treatment is the application of herbicide to the surface of a stump after the tree has been cut down. The target of the treatment is the tissue at the outer edge of the stump - the cambium. Killing this tissue prevents regeneration of new stem sprouts. On small diameter stumps it is easier to treat the entire surface. On larger stumps, it is more practical to limit treatment to the perimeter, saving material.

Hack and squirt treatment consists of making spaced cuts around the perimeter of the tree stem with a hatchet, and applying herbicide to the cut. The Hypo-Hatchet® is a device that accomplishes the treatment in one step. The head of the specially designed hatchet is fed by a tube from a herbicide reservoir, and a preset dose of the solution is metered into the cut as it is made.

Injection treatment is essentially the same as hack and squirt, but is accomplished by puncturing the bark, rather than hacking it open. Two devices that accomplish this are the E-Z-Ject® lance and the Eco Plug® system. The lance is spring loaded, and when compressed pushes a small cartridge containing herbicide through the bark. The plugs are installed with a hammer that has a cutting tool that removes a cylindrical plug from the stem. The flat side of the hammer is then used to tap in the plug, a tapered plastic capsule. As the tapered end seals the hole, the leading end of the capsule splits open, releasing herbicide. For either device, the treatments are spaced at 4 inch intervals around the stem.

Advantages

Much like basal bark applications, cut surface treatments can be highly selective, and provide operational flexibility because they can be done throughout the year. Additionally, injection treatments such as the E-Z-Ject or Eco Plugs are closed systems - there is no exposure of the applicator or the environment to the herbicides. For this reason, these techniques can be used in aquatic, and other sensitive settings.

Disadvantages

Like basal bark treatments, cut surface applications are labor intensive, and are best suited to low to moderate stem densities.

Application Timing Issues

There are two aspects of treatment timing to be considered with cut surface applications. One issue is the time that elapses between the cut and the application of the herbicide to the cut. The other is the time of year the treatment is done.

When using water-based (aqueous) herbicides, the cut surface should be treated right away. The water soluble ingredient will get into the stump more readily if the surface of the stump does not dry. During the growing season, the tree quickly begins forming a barrier at the cut surface, which will further impede the movement of the herbicide into the still living tissue. This becomes an issue with stump treatments because using a chainsaw is two-handed work. It can be cumbersome for the saw operator to have to treat the surface after cutting it. This can be addressed many ways. One is to have the squirt bottle containing the spray solution attached to the operator by means of a holster, or elastic strap. This way the operator never has to actually put the saw down. Another option is to have a designated applicator who treats stumps after operators have cut the tree.

The use of oil soluble herbicides provides some flexibility in timing of application after the cut. The penetrating ability of the oil carrier makes it less imperative to treat right away. Applicators can return the site after cutting and make what are essentially basal bark applications to the stumps, treating the bark to soil line as well as the surface. This will effectively prevent any stem sprouts from arising from the stump.

There are however, two potential drawbacks to delaying treatment after cutting. One is locating the stumps amid the slash and debris and existing vegetation. The other is potential loss of control of root suckering species, which is also closely related to the issue of time of year of cut surface treatments. When stumps are treated during the foliar season - when the canopy is sending sugars to the root system - stump treatments are effective at reducing sprouting in root suckering species. However, phloem movement is governed by the 'source-sink' process - sugars are moved from where they are made or stored (the source) to areas in the plant where they are currently needed the most (the sink). An actively growing tree canopy is the source, and once the canopy is making enough sugars to support itself, the roots become a sink. Cutting off the canopy with a chainsaw eliminates the source, and there will be a fairly quick change in the sugar allocation in the root system, as the carbohydrates present in the roots will be directed to producing new shoots. Delaying application to the stump of a root suckering species will probably reduce control of the root system. Even though an oil soluble treatment will penetrate and deliver herbicide to the phloem in the stump, if the treatment is delayed the phloem is no longer transporting sugars to the root system.

A guiding principle when managing root suckering species such as ailanthus, black locust, sumac, or sassafras, with cut surface treatments is to do the work during the foliar season, and get the material in the plant immediately, regardless of whether it's water or oil soluble.

If you are limited to cutting brush in the dormant season, treat suckering species during the prior summer or fall with a basal bark application, then cut the now-dead stems in the winter. Waiting to treat root suckering species in the dormant season after cutting will result in prolific suckering off the roots, even though the treatment may prevent stump sprouts.

Selectivity of Cut Surface Treatments

The placement of cut surface treatments is very selective because it is an individual stem treatment, done one stem at time. The only practical scenario for non-target injury is when soil active herbicides such as Arsenal (imazapyr), Tordon (picloram), or Vanquish (dicamba) are being used. The most likely means to affect non-target plants is to have stump treatments get washed off after application and be picked up in the soil. The chances of this occurring would increase in areas of high stem density, as more material gets applied per unit area. As mentioned before, injection treatments are a closed system, so the chance of non-target injury with this method is almost nil. Hack and squirt treatments have a minimal chance of affecting non-target plants, as it is unlikely that the small amount of material applied to the cuts could be washed out, run down the stem, and get into the soil to be picked up by adjacent plants.

Dormant Stem Applications

Dormant stem treatments differ from basal bark treatments in that the canopy of the woody plant is targeted, rather than the base; and the herbicide is mixed in water with a relatively high concentration of surfactants, rather than being mixed in oil. It is like a foliar treatment without foliage. This treatment is better suited to 'brushy' sites, where the plants are relatively short with lots of branches. Shrub species or tree resprouts are suitable targets. Research trials, as well as operational experience suggests that treatments should not begin until late winter - probably late February to early March, depending upon where you are in the state.

Coverage is critical because herbicide movement via translocation is going to be minimal after the treatment. When woody plants resume growth in the spring, the energy comes from locally stored carbohydrates. The bud draws energy from its mother twig - there is no long range phloem transport occurring at bud break. Dormant stem treatments are lower in herbicide concentration, and applied less heavily than a basal bark treatment, so depth of penetration by the herbicide into the woody plant is less compared to basal bark treatments. There is less herbicide accumulated in the xylem, which is interior to the phloem and cambium, therefore xylem transport of herbicide with the water stream headed for the expanding leaves will be minimal.

Advantages

Dormant stems treatments provide another means to lengthen the application season. Dormant stem treatments can begin one to two months before bareground work begins, which is the traditional start of the vegetation management season.

Disadvantages

Due to lack of foliage, there is very little target to hit. Most spray directed at the target goes right by it. Therefore, non-target herbaceous vegetation tends to be eliminated. Blow-by can be lessened by reducing spray volume and directing the spray more precisely, much like a low volume foliar treatment. This is very tedious, however, and best suited to low stem densities.

Another disadvantage is that the target is dormant. Therefore, control of the root system in suckering species can only be achieved with soil active herbicides, which greatly increases the chance of damaging non-target understory.

Applications to Soil

Herbicide applications can be made to the soil to prevent vegetation from seed, as well as control existing vegetation. Examples include total vegetation control, soil spot treatments, and cut stubble treatments.

Total vegetation control is practiced where bare ground is desired. Settings include industrial sites, petroleum tank farms, electric sub-stations, fence lines, unpaved parking lots, and highway guiderails and signposts. These areas are maintained in a bare condition so the annual herbicide treatments are primarily preemergent in their activity - they are intended to prevent establishment of vegetation. This type of application constitutes a separate certification category in Pennsylvania, Category 14 - 'Industrial Weeds'. This area of weed management is covered in the publication 'Non-Selective Weed Control in Non-Crop Areas.

Soil spot treatments describe the treatment of localized infestations of established, undesirable species, whether it be scattered brush or problem species that grows in clumps or colonies. A persistent herbicide is applied to the soil and is taken up by the roots of the plants in the treated area. If the herbicide is persistent enough, the plant is eventually killed. Spot soil treatments can be applied using liquid concentrates, or as pellets or granules.

Cut stubble treatment is typically used only in utility ROWs after a mowing has knocked down existing brush. A soil active herbicide such as picloram (Tordon K, Tordon 101M), imazapyr (Stalker), or the combination is broadcast over the stubble before regrowth occurs, and is taken up by the roots of the woody plants, preventing re-establishment. The area is then revegetated initially by species tolerant to the herbicide, and eventually by a broader spectrum of the seed bank as the herbicide degrades.

Advantages

Soil treatments tend to be quick and simple to apply. Spot treatments are literally applied to spots, requiring only a squeeze or two from a spotgun, or a handful of pellets or granules. Cut stubble treatments are applied to recently mowed areas using a fixed pattern spray device on a vehicle. In terms of effort, an application does not get much easier.

Disadvantages

The primary disadvantage of soil treatments is lack of selectivity, which is addressed in the next section. Even though soil spot treatments are much like individual stem treatments, they do not become as laborious. For example, if you are treating a colony of ailanthus, a thicket of stems from a common root system, you can apply the herbicide in a grid-like pattern. You do not need to apply a dose for each stem - they are close enough together that many stems will take up herbicide from one spot.

Selectivity

As mentioned above, the primary limitation of using soil treatment is selectivity. Spot treatments relying on tebuthiuron (Spike), hexazinone (Velpar, Pronone), or bromacil (Hyvar) are not selective. Any plant with roots in the treated spot can be injured or killed. The roots of woody plants can extend to two to three times the spread of the canopy. Soil treatments cannot practically be used anywhere near desirable woody plants.

Cut stubble treatments using picloram are similarly limited. Although picloram will not affect grasses that are present, trees adjacent to the ROW may have roots extending into the treatment area, and may be severely injured.

Summary

Clearly, there are many options available to manage most any vegetation problem in non-crop settings. Choosing the best approach boils down to knowing what the target vegetation is and how it grows; understanding the environmental characteristics of the site that affect the target vegetation; understanding the environmental characteristics that could be impacted by your actions; and considering the behavior of the herbicides you choose in the plant, and in the environment around the plant; and of course the resources you have available.