Use and Characteristics of Herbicides for Non-crop Weed Control

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To the User of this Publication

This document provides information about herbicides and their uses, primarily for use as a study guide for applicators seeking certification in Pennsylvania Categories 10 - Rights-of-Way, or 14 - Industrial Weed Control. This document does not provide specific instructions or directions for use. Directions for use for any pesticide product are contained in the product label. Do not use any pesticide without carefully reading the label. If information in this document is in conflict with the information in a product label, then disregard that information in this document (and notify the author).

To the best of the author's knowledge, the information in this document is current as of December 2008. Most of the herbicides used in non-crop settings are off patent ('generic'). Therefore, most active ingredients are available in a number of products, and some herbicides, such as *glyphosate*, are available in dozens of essentially identical products. This publication will try to identify all of the available formulations of a given herbicide, but not every brand of that particular formulation. Most trade name examples cited will be the original, patented product. Herbicide product active ingredients will be indicated in italics (e.g. *glyphosate),* and trade names will be indicated in single quotes ('Rodeo'), rather than being identified with the '®' symbol.

Prepared by Art Gover, 2008. The contents of this work reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of The Pennsylvania State University at the time of publication.

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Introduction

The term 'non-cropland' covers a wide range of settings - pretty much any area not supporting food, feed, fiber, timber, or nursery crops. Within the realm of non-crop sites, a distinction we can make is between areas requiring non-selective control, and those requiring selective control measures.

Examples of areas where non-selective control, or total vegetation control is practiced include fencelines, highway guiderails, railroad ballast, unpaved parking or storage areas, electric sub-stations, petroleum tank farms, and the grounds surrounding industrial facilities.

Some of the reasons for practicing total vegetation control include ease of maintenance, ease of access, visibility, maintaining surface drainage, reducing fire hazard, and eliminating cover for vermin.

Selective control is practiced in any non-crop area where some form of vegetative cover is desired. These settings will range from utilitarian – such as electric rights-of-way (ROW) or roadsides – to natural areas such as parks, amenity forests, preserves, and refuges.

Regardless of the non-crop setting, the principles of Integrated Pest Management should be followed.

Integrated Pest Management and Integrated Vegetation Management

Integrated Pest Management (IPM) is a means to take a structured approach to common sense-, or preventive pest control. IPM stresses using all methods that are practically available, in a coordinated, or *integrated* manner, to manage pests.

The stress is on the concept of *management*. Any ecosystem has many natural forces interacting in a constantly changing manner. IPM stresses encouraging or enhancing the natural forces that work to our benefit, and trying as much as possible to allow these natural processes to work in concert with our management inputs.

A fundamental principle of IPM is knowing the biology of the pest. If you understand the life cycle of the pest, you will know when it is most vulnerable to management tools at your disposal.

IPM brings together varied control methods, the concept of pest thresholds, scouting, monitoring, and record keeping.

Methods available to manage pests can be grouped into the following categories:

Cultural – 'indirect' pest control, including methods that enhance the growth or vigor of desirable species, and preventive practices such as sanitation to prevent movement of pest propagules.

Mechanical - physical processes that exclude, damage, or remove pests.

Biological - using one organism to control another.

Chemical - the use of pesticides.

A pest threshold is the level at which a pest becomes damaging enough to warrant control efforts. In a commodity setting, this threshold is economic - it is the level where the yield loss caused by a pest is equal to the cost of controlling it. It does not make economic sense to implement a control practice that costs more than the damage a pest is going to cause.

When pest thresholds have been set, scouting is required to determine if pest levels are approaching the threshold. Once a pest management effort has been made, it is necessary to monitor the pest population to determine if the control has been successful. Keeping effective records of your scouting, control, and monitoring efforts provides the information you need to anticipate pest problems and gather the necessary resources in advance.

Integrated Vegetation Management

Integrated Vegetation Management (IVM) is simply adopting the IPM approach and targeting it specifically at the management of troublesome vegetation. This is appropriate in ROW and other non-crop sites because vegetation is typically the only pest. The following section describes examples of control practices specific to vegetation management.

Cultural

Cultural methods are practices to enhance the growth and vigor of desirable species. When the desired species is more vigorous, it can withstand more pest pressure before there is a negative effect. Some examples of cultural practices include proper seedbed preparation, adequate fertilization, and timely seeding of groundcovers; increasing the height and reducing the frequency of mowing of utility turf; or cleaning equipment after it is used on an infested site to prevent movement of seed, plant parts, or soil that contains pest seed.

Mechanical

Mechanical controls physically remove, exclude, or harm target vegetation. Pulling, mowing, cutting, or digging weeds, or using barrier mats are examples of mechanical methods.

Biological

Biological control is the use of other organisms to control pest species.

'Classical' biological control is use of an organism to target one pest species. The leaf-feeding beetle *Galerucella* has been introduced into North America to feed on the highly invasive purple loosestrife (*Lythrum salicaria*).

The term ‘ecological control’ has been used to describe planting or promoting desirable, competing vegetation that suppresses pest plants. This concept could be considered a cultural method, as well.

Chemical (Herbicidal)

When managing vegetation, chemical control refers to the use of herbicides. Perhaps the key concept of herbicide use in IVM is *selectivity*. This concept is easily applied to situations where desirable and undesirable vegetation occur together. If we can injure the weeds while leaving the desirable vegetation intact, the desirable vegetation can fill in the space where the weed species was. If you are selective with your chemical control, you enhance ‘ecological’ control - desirable vegetation is left intact to compete with and suppress the undesirable vegetation.

The concept of selectivity is less obvious in industrial settings where bare ground is maintained. In this instance, 'selective' is more along the lines of 'use only what is needed to control the target'. Over-applying herbicides in a bareground setting increases the possibility of the material moving off-site, causing non-target damage.

Method Integration

When used in a coordinated fashion, control methods are complementary.

Reducing mowing frequency and increasing the height of cut improves the vigor of roadside turf, reducing weed pressure and the need to use herbicides - judicious use of herbicides controls established weeds, and therefore the reduces the tendency to mow to 'clip' weeds, reducing stress to the turf, which allows the turf to be more competitive - reducing weeds.

Treating brush selectively when it is small reduces damage to adjacent desirable vegetation. The adjacent vegetation fills in, providing competition so that brush cannot re-establish, which reduces the need chemically treat brush.

When large brush is mechanically treated, either by mowing, or cutting with a chain saw, following-up with a cut-stubble or cut stump application reduces regrowth from the tree root systems. This allows the area to be re-established to desirable vegetation, either naturally or by reseeding. The competition further inhibits reestablishment of the brush.

IVM and Total Vegetation Control

It may seem that IVM has no practical application in creating bare ground for the entire growing season. Although there are fewer elements of IVM involved in total vegetation control, there is ample need for an IVM approach. IVM uses the proper material at the proper rates based on the conditions at the site. The less material you can use to achieve the goal of bare ground, the less likely you are to have off-site movement of herbicide and non-target damage.

An example of IVM in total vegetation control is dividing treatment sites into three control categories, based on vegetation present: Normal, Sensitive, and Difficult.

'Normal' areas would be those where a typical industrial treatment including herbicides with considerable soil activity could be used with comparatively little risk, and would be effective on the vegetation present.

'Sensitive' areas would be those areas where non-targets are in close proximity to the treatment area, or site conditions favor off-site herbicide movement, and the risk of causing damage with highly soil-active herbicides is unacceptable. Sensitive area treatments would not include herbicides with broad-spectrum soil activity.

Areas designated 'Difficult' would contain plant species that would not be controlled with a typical bare ground herbicide mix, such as brush, or herbaceous species such as Japanese knotweed (*Polygonum cuspidatum*). Rather than treating the entire site with an herbicide mixture potent enough to control extremely difficult species, it is better to spot-treat the difficult species, and use a less potent mixture on the bulk of the area.

IVM and Selective Vegetation Management

Trying to selectively manage vegetation provides an opportunity for a much fuller implementation of IVM.

In a selective management setting, IVM is a balance between preserving desirable vegetation and controlling undesirable vegetation.

The first step in a selective management program is to determine what the targets are, and set a threshold defining the level of infestation that is tolerable. Quite often, *where* a plant is determines if it is a target more than *how many* there are.

Figure 1 shows a cross-section of an electric transmission ROW, demonstrating the 'Border Zone-Wire Zone' concept. In this scheme, the area directly under the conductors, the 'Wire Zone', is maintained as herbaceous vegetation and low growing shrubs. This ensures clearance below the wires, and improves access through the ROW and to the towers. Between the Wire Zone and the edge of the ROW is the 'Border Zone'. Here, herbaceous plants, shrubs, and even small trees such as redbud would be allowed to grow. In the Border Zone, the primary target is tall growing trees that could potentially grow to contact the wires.

Figure 2 demonstrates the management zone concept on a limited access roadside setting. The roadside is divided into three vegetation management zones, the 'Non-selective Zone', where no vegetation is

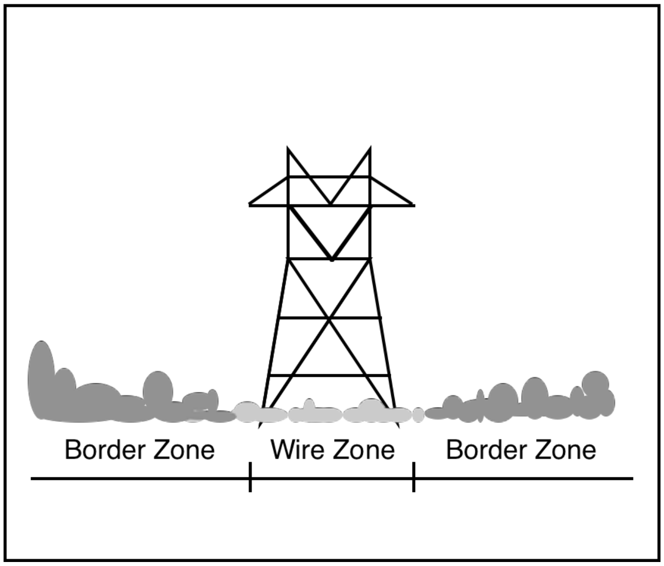

Figure 1: The Wire Zone/Border Zone system for managing transmission ROWs. The Wire Zone, the area directly beneath the conductors, is maintained as herbaceous and very low growing shrubs. This maximizes line clearance and improves movement along the ROW and access to the towers. The Border Zone is composed of grasses and forbs, shrubs, and small trees.

tolerated; the 'Safety Clear Zone' where no woody vegetation is permitted to provide motorists an obstacle free recovery area; and the 'Selective Zone', where tall growing tree species are controlled to prevent them from shading or falling into the roadway.

Summary

When carried out in a manner true to the intent of IVM, vegetation management is specifically targeted, preserves desirable vegetation, and is preventive rather than reactive.

A simple way to describe the objective of an IVM program is that the area should be free of undesirable vegetation, yet *look* as if it's being managed by Nature.

Herbicide Characteristics

Herbicides can be classified in many ways. We can classify herbicides into chemical families based on their structure and activity. Though useful to scientists and technicians in the field of weed science, this detailed a knowledge of herbicides is not necessary to use them effectively. 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 1 provides a brief definition of each of these terms.

The terms we commonly use to describe herbicides are not exclusive, or 'either-or'. Many herbicides fall into several categories.

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 distinction between contact and systemic activity is not clear-cut. All herbicides move within the treated plant to *some* extent. *Hexazinone* ('Velpar') moves through the plant via the xylem tissue, which transports water and soil nutrients upwards in the plant. A *hexazinone* application the contacts only the tops of a target plant will 'burn off' the top and likely not injure the untreated portion of the plant.

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 high rate of a single product. However, a poorly chosen

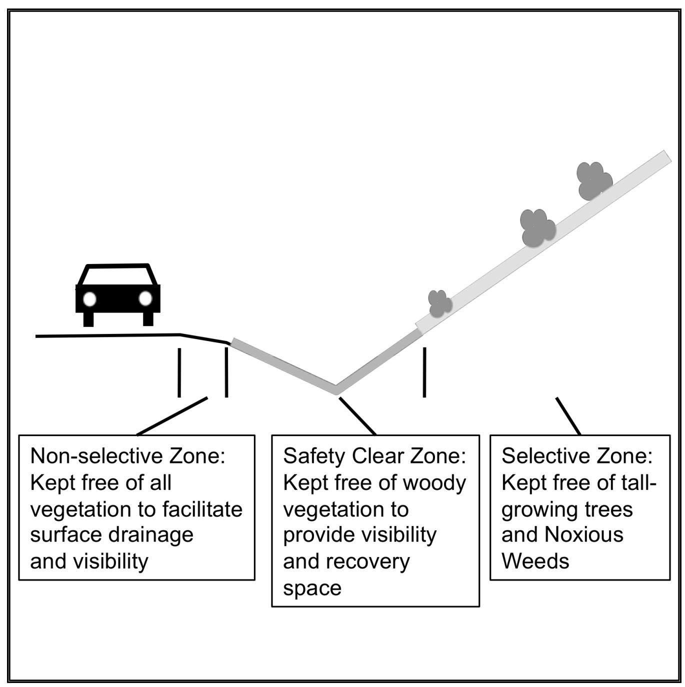

Figure 2: Application of the Management Zone concept to a highway ROW. The Non-selective Zone is kept free of vegetation to facilitate surface drainage from the travel lanes. The Safety Clear Zone is kept free of woody vegetation to allow recovery for vehicles that have left the roadway. The Selective Zone is kept free of tall growing trees that could eventually fall into the roadway.

Table 1: A brief definition of terms used to distinguish herbicides and application methods. Many herbicides fall into several categories.

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 herbicide - soil active herbicides that act on weeds as they germinate.

Preemergence application – an application made prior to emergence of the target weed. In crop settings, preemergence means prior to emergence of the crop.

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

Postemergence application – an application made after the target weed has emerged.

Selective herbicide- an herbicide that does not control all vegetation. It can be used to control one type of plant, while not harming another. Selectivity can be a function of application rate.

Selective application – an application relying on placement of the herbicide or timing of the application to injure only the target weed.

Non-selective - an herbicide or herbicide mixture that injures all contacted vegetation.

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

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

Broadcast - an application that is made to an entire area.

Spot treatment- applications made to localized targets within a management area. This is a common approach when target weeds are scattered.

mixture could actually be less effective than using the individual products by themselves.

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, or selectivity.

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 contacting 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 ester-formulated herbicides (see Formulations section) 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. The thick cuticle of southern pine (e.g. loblolly pine) species allows target weeds and hardwood species to be controlled using *glyphosate* while the pines are not injured.

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 the term '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 dissolved or suspended in water.

Leaf retention - the quality often referred to as 'sticking', or having the droplet of spray adhere to the leaf rather than bounce off 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 of the leaves keep water in, and provide a considerable barrier to substances trying to enter the plant as well.

Table 2. Simple herbicide categorizations are not typically 'either-or' designations. The examples below illustrate that herbicides can exhibit several characteristics.

Product	Soil Active	Foliar	Pre-emergence	Post-emergence	Selective	Non-Selective	Contact	Systemic
glyphosate		■		■		■		■
imazapyr	■	■	■	■	■	■		■
triclopyr		■		■	■			■
picloram	■	■	■	■	■			■
metsulfuron	■	■	■	■	■			■
glufosinate		■		■		■	■	■
diquat		■		■		■	■	
hexazinone	■	■	■	■	■	■		■
flumioxazin	■	■	■	■	■		■	
pendimethalin	■		■		■		■	

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 solubility less than one part per million, such as *pendimethalin* ('Pendulum') or *oryzalin* ('Surflan') can be taken up by roots.

Herbicide Movement in the Plant

The most general description of mode of action is how much an herbicide moves within a plant after application. *Systemic* herbicides move throughout the plant, or *translocate*, after they enter it. *Contact* herbicides act on the plant close to the point where they enter (Figure 3). The difference between systemic and contact is mostly a matter of degree, rather than being a cut-and-dried difference.

Systemic herbicides move in the plant's conductive tissue, and have two available paths of movement in the plant - through the *xylem*, or through the *phloem*.

The xylem is the tissue that carries water and soil nutrients from the roots to the leaves. Water and minerals move *upward* through the xylem, essentially 'pulled' upwards by the evaporation of water through pores in leaves called stomates. Herbicides that are only xylem-mobile can therefore only move upwards from the point of absorption.

Phloem is the plant conductive tissue that transports sugars and other organic molecules synthesized by the plant. Movement in the phloem is not a case of 'up or down', but rather 'source-to-sink'. The source is where the plant's energy source, sugar, is stored or produced; and the sink is the tissue that needs the sugars right now. Different parts of the plant can store sugars, but only the leaves can produce sugars from energy captured from sunlight.

Different parts of the plant are sinks at different times of year. Leaves are sinks until they are fully expanded, which is when they begin to export sugars to fuel growth in other parts of the plant. The roots must be fed by the leaves. When leaves are not present, or early in the season when there are not enough leaves to support the roots, the roots must rely on stored sugars to grow. Rhizome and stolon growth is an energy sink. Flowers and seeds are energy sinks.

The labels for phloem-mobile systemic herbicides recommend that applications to perennial weeds be delayed until a certain amount of growth has occurred, and that the plants are actively growing. The source-

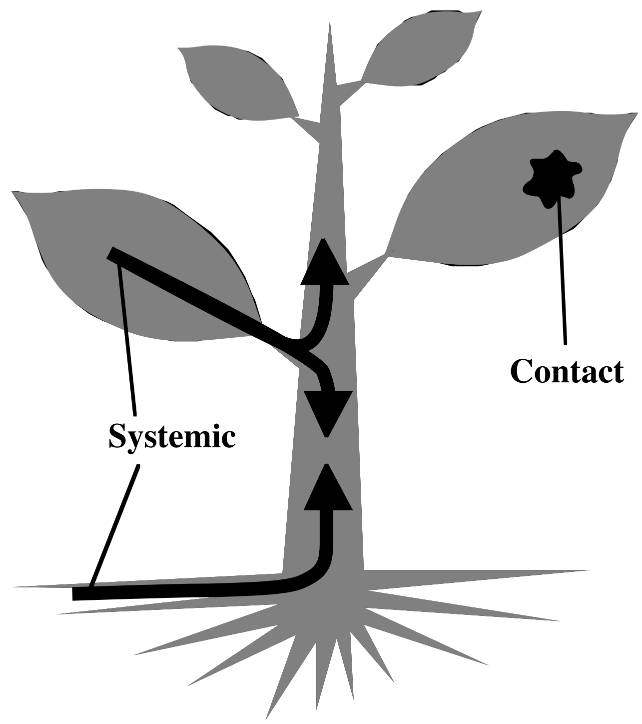

Figure 3. Systemic herbicides can move through the plant, either through the phloem, or upwards from the roots through the xylem tissue. Contact herbicides act rapidly, and do not move far from where they contacted the plant.

sink concept helps explain this. Early in the season, the energy driving the growth of perennial plants is from reserves stored the previous season. The flow of energy is from the storage tissue in the crown and roots, and stems of woody plants, to the new leaves and stems. Applying a systemic herbicide that moves with the sugars at this point in the season will only damage the shoot of the plant. None of the herbicide will move into roots because the flow in the phloem tissue is from the roots to the shoots.

Later in the growing season, when there are enough leaves to provide a surplus of energy for top-growth, sugars begin to move down to the root system. This is when systemic herbicides will provide control of the entire plant.

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 be 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* (‘Vanquish’) or *triclopyr* (‘Garlon’) mimic the activity of the plant hormone *auxin*, and may have several molecular 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 where these herbicides bind – and this is the only site of activity.

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 their 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. Even though *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 complex. 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 Formulations

When you purchase an herbicide, only a portion of the package contents is active ingredient. Typically, the purified active ingredient of an herbicide product would not be easy to work with. Pesticides are *formulated* with various inert ingredients to make them easier to use.

Herbicide formulations can be categorized as liquid or dry, and concentrate or ready-to-use.

A point that can be confusing is the difference between *active ingredient* (ai), and *acid equivalent* (ae). In their pure state, many herbicides are weak, organic acids. In this acid form, the herbicide is not particularly soluble, or easy to mix. To make this acid molecule easier to mix, chemical 'tails' are added which increase the solubility of the molecule. When formulating a water-soluble product, an amine salt form of the molecule is used. When an oil soluble product is desired, an ester form of the herbicide molecule is used. The salt or ester form of the herbicide molecule is the *active ingredient* of a product.

Different chemical tails make the size and weight of the herbicide molecule different. To allow the user to compare different formulations on an equal basis, the label details the *acid equivalent*.

An example: ‘Roundup Pro’ contains 41 percent by weight, or 4.0 lbs per gallon of the isopropylamine salt of *glyphosate*. However, each gallon contains only 3.0 pounds of the acid, *glyphosate*. ‘Roundup ProMax’ contains 49 percent by weight, or 5.5 lbs/gallon of the potassium salt of *glyphosate*, or 4.5 lbs per gallon of the acid equivalent. To make a clear comparison between the two products, which have different active ingredients (or different salts of *glyphosate*), we must compare them on an acid equivalent basis. On an acid equivalent basis, one gallon of ‘Roundup Pro’ provides the same amount of *glyphosate* as 2/3 gallon of ‘Roundup ProMax’.

Listed below are examples of available herbicide formulations, in liquid and dry forms.

Liquid Herbicide Formulations

Soluble Concentrate (S) – Water-based formulations that go into solution - the mixture remains essentially clear, as when sugar or table salt is mixed with water. The active ingredient is commonly an amine salt. Typically these formulations contain 2 to 4 lb ae per gallon. Product examples include ‘Arsenal’, ‘Roundup Pro’, ‘Garlon 3A’, and ‘Vanquish’.

Emulsifiable Concentrate (EC) - This type of formulation includes emulsifiers that allow oil and water to form a stable mixture. These products cause water to turn ‘milky’. Typically these products feature an oil-soluble ester form of the herbicide acid that is intended to be mixed in water, such as ‘Garlon 4 Ultra’. ‘Stalker’ is an example of a water-soluble active ingredient intended to be mixed in oil.

Flowable (L) - A thick formulation that is *suspended* in water when it is mixed. Flowables are produced by adding a suspending agent to a wettable powder. Product examples include ‘Diuron 4L’, and ‘Surflan AS’.

Oil-soluble Concentrate (OS) - Herbicides that can be mixed only in an oil carrier. Never a common formulation, there are currently no available product examples. An example was ‘Banvel 520’, a *2,4-D* plus *dicamba* mixture.

Ready-to-Use (RTU) - Applied without further mixing. These can be oil or water-based. For non-crop uses, these formulations are used for cut surface or basal bark applications. ‘Pathfinder II’ (oil-based) and ‘Pathway’ (water-based) are examples.

Dry Herbicide Formulations

Wettable Powder (W, WP) - Active ingredient is mixed with a clay carrier, for mixing in water. Constant agitation is needed to prevent settling in the spray tank. Concentrations are typically 50 to 80 percent. Very dusty, and unpleasant to handle while mixing. Most wettable powders have been replaced with easier-to-use DF or DG formulations. ‘Hyvar X’ is one of the few products still available in this form.

Dry Flowable (DF) - The active ingredient and the dry carriers are formed into small, bead-like aggregates that disperse in water. Nearly dust free. Once mixed, they are just like wettable powders - constant agitation is necessary. Examples include ‘Karmex DF’, ‘Krovar I DF’, and ‘Spike 80 DF’.

Dispersible Granule, Water Dispersible Granule (DG, WDG) - Essentially identical to the dry flowable. The granule is usually manufactured by extrusion, and looks like a tiny 'rabbit pellet'. Concentrations range from 60 to 75 percent ai. A very common dry formulation. Examples include ‘Endurance WDG’, ‘Overdrive’, and products identified as ‘XP’ formulations such as ‘Escort XP’.

Soluble Powder (SP) - Unlike a wettable powder, dry flowable, or dispersible granule, a soluble powder *dissolves* in water, leaving a clear mixture. ‘Roundup Pro Dry’ is an example that contains 71 percent ai.

Granule (G) - A low-concentration, ready-to-use product intended for application to the soil surface. Examples of carrier materials include limestone or quartz. Concentrations range from 0.5 to 25 percent ai. Product examples include ‘Arsenal 0.5 G’, ‘Pendulum 2G’, and ‘Pronone 25 G’.

Pellet (P) **-** A ready-to-use product that has been formed into easy-to-handle pellets. Intended for spot or broadcast applications to the soil surface. Concentrations range from 20 to 98 percent ai. The most common example is ‘Spike 20P’.

Herbicide Mode of Action

It is not necessary to be a plant physiologist to effectively use herbicides, but knowledge of how an herbicide works definitely assists the decision making process when selecting herbicides for a particular application. How an herbicide affects a plant is known as its 'mode of action'.

Herbicide mode-of-action categories describe the biochemical process that is interrupted within the plant, or the result of that biochemical interruption. Mode-of-action is then described by ‘site of action’ because herbicides acting on different molecular sites within the plant can cause similar effects. A good example of this is within the seedling growth inhibitor mode-of-action. Some herbicides prevent cell division by interfering with the function of the *microtubules*, which pull the newly divided chromosomes apart so that the cell can divide. Other seedling growth inhibitor herbicides work by preventing the cell from forming new cell wall so that the

Table 3. The benzoic acid, phenoxy-, pyridine-, and quinoline-carboxylic acid families are synthetic auxins. The semicarbazone herbicide diflufenzopyr interferes with auxin transport in the plant.

Growth Regulator Herbicide Families	
Herbicide	Product Example
Benzoic Acid (synthetic auxin)	
dicamba	‘Vanquish’
Phenoxy Carboxylic Acid (synthetic auxin)	
2,4-D	‘Hi-Dep’
dichlorprop (or 2,4-DP)	‘Patron DP-4’
Pyridine Carboxylic Acid (synthetic auxin)	
aminopyralid	‘Milestone VM’
clopyralid	‘Transline’
fluroxypyr	‘Vista’
picloram	‘Tordon K’
triclopyr	‘Garlon 3A’
Quinoline Carboxylic Acid (synthetic auxin)	
quinclorac	‘Paramount’
Semicarbazone (auxin transport inhibitor)	
diflufenzopyr	‘Overdrive’

single cell cannot become two separate cells.

Within the categories of mode-of-action and site-of-action, herbicides are classified by chemical family, which describes chemical structure of the herbicide.

The most common modes of action of herbicides used in non-crop areas include growth regulators, photosynthetic inhibitors, amino acid synthesis inhibitors, lipid biosynthesis inhibitors, seedling growth inhibitors, and membrane disrupters.

Growth Regulator Herbicides

Herbicides that mimic the activity of the plant hormone *auxin* are referred to as growth regulator herbicides (Table 3) because they prevent a plant from being able to regulate its own growth. These herbicides are typically used to control dicot weeds and are often simply called 'broadleaf herbicides'.

These herbicides are readily absorbed through foliage, and are most commonly used for postemergence applications. These chemicals tend to be mobile in soil, and can be root absorbed. *Picloram* ('Tordon K') in particular, has considerable soil activity. *Dicamba* has significant soil activity, *2,4-D* much less, and *triclopyr* has very little soil activity at typical use rates. Any of these herbicides applied at extreme rates have significant soil activity.

The plant hormone auxin plays many roles in plant growth, and plants are very sensitive to it in very minute concentrations. Additionally, plants regulate auxin concentration very tightly - it is synthesized and broken down rapidly. When herbicides that mimic auxin are applied at typical use rates, the plant is confronted with concentrations that may be hundreds or thousands of times greater - and sensitive plants are unable to quickly break down these synthetic molecules. Plants lose the ability to control, or regulate their growth, causing lethal malformations as now-rapidly expanding cells fail to differentiate into functional tissue. Stems twist, leaves curl, and tumor-like masses of undifferentiated cells form (Figure 4).

Figure 4. The dicot, or 'broadleaf' weed poison hemlock shows the twisted stems and foliage typical after treatment with a growth regulator herbicide. The surrounding grass shows no signs of injury.

Table 4. Herbicide families that are photosynthetic inhibitors include benzothiadiazoles, triazines, triazinones, ureas, and uracils. In addition, the pigment inhibiting pyridiazinone family is included.

Photosynthetic Inhibitor Herbicide Families	
Herbicide	Product Example
Benzothiadiazole	
bentazon	'Basagran T/O'
Triazine	
atrazine	'AAtrex'
simazine	'Princep'
prometon	'Pramitol 25E'
Triazinone	
hexazinone	'Velpar DF'
Urea	
diuron	'Karmex XP'
tebuthiuron	'Spike 20P'
Uracil	
bromacil	'Hyvar X'
Pyridazinone (pigment inhibitor)	
norflurazon	'Predict'

Another variation of the growth regulator herbicide is the auxin transport inhibitor. *Diflufenzopyr* ('Overdrive') is an example of an herbicide that interferes with the plant's ability to transport auxin, causing it to accumulate at growing points. When combined with a synthetic auxin (such as *dicamba* in 'Overdrive'), the effect is to amplify the activity of the herbicide.

The term 'growth regulator' is used frequently in the plant sciences, and in vegetation management in particular, often with apparently different meanings. The definitions below attempt to distinguish the different uses of the term.

Growth Regulator Herbicide: as described above, these are herbicides that mimic the action of the plant hormone auxin, and are lethal to plants because they prevent plants from controlling, or regulating, their growth.

Plant Growth Regulator: some chemicals are applied to plants to alter their growth without significantly injuring them – usually to shorten plant stems. *Paclobutrazol* ('Bonzi') is applied to landscape shrubs to limit stem elongation and reduce trimming. *Mefluidide* ('Embark 2S') inhibits cell division and is used on turfgrass to reduce or eliminate seedhead production.

Some herbicides have labeling for low-rate application to suppress grass growth ('chemical mowing') without causing unacceptable injury. Examples include *chlorsulfuron* ('Telar XP'), *glyphosate* ('Roundup Pro'), and *imazapic* ('Plateau').

Photosynthetic Inhibitors

These herbicides disrupt the plant's ability to capture energy from sunlight and convert it into chemical energy. Herbicides in this grouping prevent the transfer of energy between the chlorophyll pigment molecule that initially captures the light energy, to the protein molecules that facilitate the conversion of this captured light energy into certain high-energy molecules. These high-energy molecules provide the energy needed to synthesize complex carbon compounds such as sugars, using carbon dioxide present in the air we breathe.

This is problematic to the plant because the 'fuel' that drives the chemical processes that fix atmospheric carbon dioxide into sugars is shut off - the plant begins to starve. However, the 'side-effects' of disrupting electron transfer kill the plant long before it starves. The energy from sunlight is normally transferred as a high-energy electron through a cascade of complex proteins (enzymes) that transfer the captured light energy into the formation of high-energy molecules. When the transfer is interrupted, the high-energy electrons 'spill' out of the 'pipeline' and form *free radicals*, high-energy 'rogue molecules' which damage the membranes within the plant cell, causing cell contents to leak, resulting in cell death, and eventually death of the plant.

Most photosynthetic inhibitors are root absorbed, and xylem-mobile. Therefore, they do not move effectively from the foliage to the roots, so postemergence applications provide contact, rather than systemic activity. They are widely used for preemergence applications. Postemergence activity is variable. *Hexazinone* ('Velpar DF') is an effective burn-down material, while *tebuthiuron* ('Spike 80DF') and *bromacil* ('Hyvar X') have little foliar activity.

The chemical families that are photosynthetic inhibitors are listed in Table 4, along with some familiar herbicides no longer used in non-crop situations. *Norflurazon* ('Predict') is included in this grouping, but its mode of action is somewhat different. *Norflurazon* inhibits the synthesis of accessory pigments called carotenoids that surround chlorophyll and quench the excess energy of free radicals that naturally form during photosynthesis. Without carotenoids present to 'mop up', the free radicals would damage both the chlorophyll molecule and cell membranes. *Norflurazon*-affected seedlings turn white because the chlorophyll is damaged, then die.

Inhibitors of Amino Acid Synthesis

By themselves, amino acids are simple, small molecules. There are 20 amino acids found in plants. What makes amino acids amazing is that they are the building blocks, or the 'alphabet' of proteins. Although proteins serve many functions, their most important role is that of *enzymes*, which make the billions of chemical reactions that take place in an organism possible.

An enzyme is large molecule with a very complex shape, typically made up of thousands of amino acids. On this complex surface of the enzyme, the components of a chemical reaction nestle into specific berths, and the necessary reaction occurs. These chemical reactions would not occur if the two reacting components were floating free in the cell solution. Enzymes are necessary to *catalyze* these crucial chemical reactions. The very specific shape of an enzyme is due to the exact sequence of the amino acids. One amino acid cannot substitute for another. If a plant is unable to produce even 1 of the 20 amino acids, the plant will not be able to synthesize enzymes. No enzymes, no life.

All organic molecules are formed by sequences of chemical reactions. Herbicides that prevent the synthesis of amino acids are able to attach themselves to a key enzyme in the chain of chemical reactions that forms an amino acid (it takes enzymes to form amino acids to form more enzymes). The herbicide binds to a specific location on the surface of the enzyme where one of the reacting molecules would bind. The result is that

Table 5. Amino acid synthesis inhibitor herbicides act on the acetolactase synthase (ALS) or enolpyruvylshikimate-3-phosphate (EPSP) synthase enzymes to inhibit production of amino acids.

Amino Acid Synthesis Inhibitor Herbicide Families	
Herbicide	Product Example
Glycine (EPSP synthase inhibitors)	
glyphosate	'Roundup Pro'
Imidazolinone (ALS-inhibitors)	
imazamox	'Clearcast'
imazapic	'Plateau'
imazapyr	'Arsenal Powerline'
imazethapyr	'Stronghold'
Sulfonylurea (ALS-inhibitors)	
chlorsulfuron	'Telar XP'
metsulfuron-methyl	'Escort XP'
sulfometuron-methyl	'Oust XP'

Table 6. Seedling growth inhibitor herbicides interfere with the emerging plant's ability to complete cell division. Dinitroanalines interfere with synthesis of microtubules, which are the 'strands' in the cell that pull the newly divided chromosomes apart. Benzamides and nitriles interfere with synthesis of new cell walls. The specific site of activity of chloroacetamide herbicides is unknown.

Seedling Growth Inhibitor Herbicide Families	
Herbicide	Product Example
Benzamide (cell wall synthesis)	
isoxaben	'Gallery'
Dinitroanaline (microtubule synthesis)	
oryzalin	'Surflan AS'
pendimethalin	'Pendulum Aquacap'
prodiamine	'Endurance'
trifluralin	'Trifluralin 10G'
Chloroacetamide (unknown)	
S-metolachlor	'Pennant Magnum
Nitrile (cell wall synthesis)	
dichlobenil	'Casoron 4G'

the chain of chemical reactions stops. There is no chemical 'detour', no other chemical pathway to make the amino acid. Plant growth stops quickly, followed by the slow death of the plant.

Table 5 lists the herbicide families that are amino acid synthesis inhibitors.

Amino acid synthesis inhibiting herbicides act on two different enzymes, which interfere with production of either branched-chain or aromatic amino acids. Herbicides in the imidazolinone and sulfonylurea families interfere with the enzyme *acetolactase synthase* (ALS) to block production of branched-chain amino acids - leucine, isoleucine, and valine. Herbicides in the glycine family interfere with the function of *enolpyruvylshikimate-3-phoshate* (EPSP) synthase to block production of the aromatic amino acids phenylalanine, tryptophan, and tyrosine (Table 4).

Seedling Growth Inhibitors

This is a broad term that covers several sites-of-action and chemical families. Most herbicides in this category are effective only on seedlings, and therefore are used as preemergence herbicides. Table 6 provides a summary of the chemical families and herbicides in this group.

The most common herbicides in this category are the *dinitroanilines*, often referred to as 'root inhibitors'. These are the 'yellow' herbicides. The most commonly used is *pendimethalin* ('Pendulum Aquacap'), which is labeled in corn, soybeans, turf, ornamental, and non-crop settings. They are highly water-insoluble herbicides that stay very close to the soil surface after application. These herbicides must be in the soil when the weed seed germinates to be effective. Once absorbed by the growing root tip, these herbicides inhibit the formation of the cell's microtubules – the internal 'skeleton', which is instrumental in the movement of the cell components during cell division. Cells duplicate chromosomes and cell components, but never physically divide.

Isoxaben and *dichlobenil* prevent synthesis of new cell walls. *Dichlobenil* is somewhat unique in this mode-of-action group because it has also has activity against perennial plants, such as Canada thistle and mugwort.

The other chemical family in this category is the *chloroacetamides*. The precise activity of these herbicides is not known, but they prevent the development of roots and shoots of susceptible seedlings, and affected seedling dies before emergence.

Inhibitors of Lipid Synthesis

These herbicides selectively control grasses and are often called *graminicides*. They must be applied postemergence, and after absorption translocate to the growing points. The herbicide binds to a critical enzyme in the fatty acid synthesis process, preventing production of the lipids essential for the formation of cell membranes. Growth stops quickly, and the plant then dies over a 1 to 3 week period. There are two different chemical families with this mode-of-action that act on the same site (Table 7).

Broadleaf species are tolerant to these herbicides because they possess a different form of the enzyme - it performs the same function, but has a different chemical structure.

The graminicides have been observed to be antagonized by several herbicides used for broadleaf weed control, such as *2,4-D, dicamba, bentazon*, and the *sulfonylurea* family (Table 3). The antagonism occurs on the plant surface, or inside the plant, rather

Table 7. Lipid synthesis inhibitors prevent formation of fatty acids necessary for production of cell membranes. The herbicides in this group only injure grasses.

Lipid Synthesis Inhibitor Herbicide Families	
Herbicide	Product Example
Aryloxyphenoxy proprionate	
fenoxaprop-P	'Acclaim Extra'
fluazifop-P	'Fusilade II'
quizalofop-P	'Assure II'
Cyclohexandione	
clethodim	'Envoy Plus'
sethoxydim	'Sethoxydim E-Pro'

Table 8. The chemical families grouped as membrane disrupter herbicides – or 'contact' herbicides - have three sites-of-action: photosystem I, protoporphyrinogen oxidase (PPO), and the inhibition of glutamine synthetase. Photosystem I and PPO-inhibitors cause reactions that lead to extremely reactive molecules (radicals) that destroy cell membranes. Glufosinate is not a 'true' membrane disrupter, but it is fast acting and is used in the same manner as membrane disrupters.

Membrane Disrupter Herbicide Families	
Herbicide	Product Example
Bipyridilium (photosystem I)	
diquat	'Reward LS'
paraquat	'Gramoxone Inteon'
Diphenylether (PPO)	
oxyfluorfen	'Goal 2XL'
N-phenylphthalimide (PPO)	
flumioxazin	'Payload'
Phenylpyrazole (PPO)	
pyraflufen-ethyl	'Edict'
Phosphinic Acid (glutamine synthetase)	
glufosinate	'Finale'
Triazolinone (PPO)	
carfentrazone-ethyl	'Quicksilver'
sulfentrazone	'Portfolio'

than in the spray tank. The labels of the different grass herbicides indicate which tank mixes are discouraged, as well as tank mix partners that are not antagonistic.

Membrane Disrupters

These are commonly referred to as 'contact' herbicides. They work quickly, and do not translocate significant distances within the plant. These herbicides usually affect the plant where they are applied.

The term 'contact' is misleading - these herbicides do not cause damage upon contacting the plant. Just as a systemic herbicide would, they diffuse through the waxy cuticle surrounding the leaf, then pass through the cell's outer membrane, and pass through at least one more set of membranes before they reach the site of their activity. Many of these herbicides are active in the *chloroplast*, the structures inside plant cells where photosynthesis occurs. Table 8 summarizes the chemical families and herbicides classified as membrane disrupters, as well as *glufosinate,* which is not a true membrane disrupter but is used in the same manner as 'burndown' herbicides such as *paraquat* and *diquat.*

Once inside the chloroplast, these molecules cause the formation of *free radicals* - dangerously reactive molecules that attack chemical bonds in the fatty acids that make up cell membranes. Once the membranes are damaged and their contents begin to leak out, the cell can no longer function, and dies.

Once they enter the plant, membrane disrupters work quickly, usually showing symptoms within a few days, if not sooner. This fast activity prevents them from being translocated, and is the primary reason these herbicides are not effective on perennial plants. The top growth of plants is often killed by membrane disrupters, but roots, rhizomes and stolons are not.

The fast activity of membrane disrupter herbicides is the reason why they are not tank-mixed with systemic postemergence herbicides - the plant tissue would be damaged before a systemic herbicide could enter the plants transport system.

Paraquat, *diquat*, *carfentazone-ethyl,* and *glufosinate* are applied postemergence only. *Flumioxazin*, *oxyfluorfen*, and *sulfentrazone* are primarily soil-applied but have significant activity on emerged seedlings.

Unclassified Herbicides

There are a few herbicides that defy categorization. In the non-crop sector the most prominent example is *fosamine* ('Krenite S'). *Fosamine* is widely used as a brush control agent on roadsides and utility ROW. Susceptible woody plants fail to leaf-out the spring following application, but how this occurs is unknown.

Herbicide Resistance

Repeated use of the same herbicide, or combination of herbicides year after year can result in what is generally known as 'resistance'.

Before discussing herbicide resistance, a distinction needs to be made between *tolerance* and *resistance*.

Tolerance is when a species is not controlled by an herbicide, and never has been. Grasses are not controlled by growth regulator herbicides such as *2,4-D* or *triclopyr* - grasses are tolerant to these herbicides.

The term resistance is used when a species that was originally controlled by a product is no longer controlled at rates that were previously effective. This effect was first widely observed with the herbicides *atrazine* and *simazine*.

Resistance occurs when there are sub-populations, or *biotypes*, within a species that are affected much less by an herbicide than the rest of the population. After repeated use of an herbicide, the resistant biotype makes up a larger portion of the population.

Selecting Tolerant Populations

Repeated use of a particular herbicide or combination of herbicides can cause a shift in the weed species present on a site. When the herbicides are first used and observed to be effective, this is because the vast majority of the species present are susceptible to the herbicide. Consider an industrial site or highway guiderail that is treated every year to keep the site free of vegetation. If only a few plants of tolerant species establish during the growing season, they are not noticed. If these plants complete their life cycle and drop seed, next year there will be more plants. Each year the number of plants increases until finally the site is heavily populated with resistant vegetation. The herbicide combination has not become ineffective because of a loss of activity - instead we have selected, or 'released' weed species that were never susceptible to the treatment, and caused a species shift on the site. In southeastern PA, this situation has been observed with the grass species *Leptochloa fascicularis* in both industrial and guiderail sites. This once barely-noticed species has become more common due to repeated use of herbicide mixes that do not control it.

Selecting Resistant Biotypes

In the scenario outlined above, a predominant population of susceptible species are eliminated, and replaced with a species tolerant to the herbicide treatment. The same situation can occur *within* a single species. Sometimes these differences within a species take the form of slightly different structures of the same enzyme. In the case of triazine herbicides such as *atrazine* or *simazine*, the difference between a susceptible biotype and resistant biotype was a single amino acid substitution in the protein where the triazine herbicide was bound. However, the resistant biotypes are less vigorous, and originally made up a very small portion of the population. It took many years of repeated use of triazine herbicides before the resistant biotypes became apparent. Table 9 illustrates how a resistant biotype making up just 0.1 percent of a species can increase because of repeated use of an herbicide. In this case, it takes eight to nine years before the population shift is noticeable in terms of weed control. Also notice that the noticeable shift comes over just a two-to-three year period, after several years of build-up. This is why many instances of triazine herbicide resistance *seemed* sudden.

Table 9. Hypothetical growth of a population of herbicide resistant plants. The resistant plants are less vigorous than the susceptible plants, and make up only 0.1 percent of the population initially. For this example, use of the herbicide allows the resistant population to double each year. After 10 years, the herbicide is rendered ineffective.

Years of Herbicide Use	Resistant Population	Susceptible Population
	(%)	(%)
1	0.1	99.9
2	0.2	99.8
3	0.4	99.6
4	0.8	99.2
5	1.6	98.4
6	3.2	96.8
7	6.4	93.6
8	12.8	87.2
9	25.6	74.4
10	51.2	48.8

In the example in Table 8 the resistant biotype is less vigorous than the susceptible biotype, and comprises a very small portion of the population. Recently, species in western part of the US, such as kochia and prickly lettuce have shown resistance to the ALS-inhibitor herbicides *chlorsulfuron, metsulfuron methyl, sulfometuron methyl*, and *imazapyr*. The resistant biotypes were not less vigorous, and made up a larger portion of the existing population. They were able to increase their population to levels rendering herbicides ineffective much more quickly than the less vigorous biotypes of triazine-resistant weeds. In the case of the ALS-inhibitor herbicides, the weed control failures occurred after a few seasons.

Preventing Resistance

You prevent herbicide resistance by using mixtures of herbicides with different modes-of-action, and occasional rotation to alternate mixtures as well.

Be aware of the mode-of-action of herbicides when developing alternate mixes. Different herbicide families can have identical modes of action. For example, replacing *sulfometuron methyl* (‘Oust XP’) as the broad-spectrum component of a bareground mixture with *imazapyr* (‘Arsenal’) would not be effective resistance management. Both herbicides have the exact same mode-of-action. A biotype that is resistant to ‘Oust XP’ may also be resistant to ‘Arsenal’.

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 life cycles are classified as annual, biennial, or perennial.

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 behave as a summer annual, a biennial, or a perennial. The listings below describe how these plants typically grow.

Knowing the life cycle of weeds gives you key information in deciding how to manage them. Consider two different plants at the end of the growing season, each bearing ripe seed. One is an annual, and one is a rhizomatous perennial. An annual already bearing seed cannot be controlled – the damage is done. The rhizomatous perennial bearing seed is still a viable control target. Late growing-season applications with systemic herbicides are one the most effective methods to control perennial species. The seeds may be a viable propagule, but the rhizomes are a bigger concern.

Annuals

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 (Figure 5). Winter annuals germinate in the fall, overwinter, and 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 Annuals	
kochia	*Kochia scoparia*
mile-a-minute	*Polygonum perfoliatum*
common ragweed	*Ambrosia artimisiifolia*
giant foxtail	*Setaria faberi*
Japanese stiltgrass	*Microstegium vimineum*
Winter Annuals	
shepherdspurse	*Capsella bursa-pastoris*
yellow rocket	*Barbarea vulgaris*
common groundsel	*Senecio vulgaris*
downy brome	*Bromus tectorum*

The key to managing annual weeds is to prevent seed production.

Biennials

Biennials are plants that live for two growing seasons and reproduce only by seed. Typically, biennials germinate in the spring, grow without stem elongation (rosette) the first season, overwinter, then elongate or 'bolt', flower, set seed and die (Figure 6). The distinction between what is a winter annual and what is a biennial is sometimes not clear. 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

Figure 5. The summer annual giant foxtail germinates in the spring, produces abundant seed in its characteristic bristly seedhead, and drops the seed at the end of summer. Winter annuals germinate in the late summer, overwinter, and flower and seed in the spring.

Figure 6. First-season growth of the biennial common burdock shows the rosette growth form. After overwintering, the stem will elongate - or 'bolt' - then flower. After seed set, the plant dies.

somewhat small. Examples of biennials are listed below.

garlic mustard	*Alliaria petiolata*
common burdock	*Arctium minus*
bull thistle	*Cirsium vulgare*
musk thistle	*Carduus nutans*
poison hemlock	*Conium maculatum*

Perennials

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 (Figure 7). Examples of vegetative propagation and species are listed below.

New Shoots from Spreading Roots	
Canada thistle	*Cirsium arvense*
tree-of-heaven	*Ailanthus altissima*
black locust	*Robinia pseudoacacia*
Rhizome (creeping, underground stems)	
quackgrass	*Elymus repens*
Johnsongrass	*Sorghum halepense*
Japanese knotweed	*Polygonum cuspidatum*
common reed	*Phragmites australis*
Stolon (creeping, above-ground stems)	
white clover	*Trifolium repens*
Bermudagrass	*Cynodon dactylon*
Bulb (enlarged stem bases)	
wild garlic	*Allium vineale*
star-of-Bethlehem	*Ornithogalium umbellatum*

Soil

The characteristics of a soil can have a profound impact on the effectiveness of different vegetation management methods. Soil is the growing medium for the plants, has an unavoidable impact on the vegetation present, and therefore, how the site 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 the seeded crownvetch (*Coronilla varia*), but that will still support growth of 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, or the site needs to be remediated to support competitive, desirable vegetation.

Figure 7. An exhumed 'crown' of the herbaceous perennial Japanese knotweed showing the root-like rhizomes, the emerging buds of this year's growth, and the clipped remains of last year's stems. New plants can grow from rhizome fragments smaller than 1-inch.

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 aquatic 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

The texture, or particle size of a surface plays a key role in determining how well herbicides can be *adsorbed*, or held onto the surface. Fine-textured soils have a greater surface area per given volume than coarse-textured soils, and are better able to retain herbicide.

Soil is composed of three size classes of particles - sand, silt, and clay (Figure 8). Listed below are the size ranges of the three types of soil particles, in millimeters (mm):

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

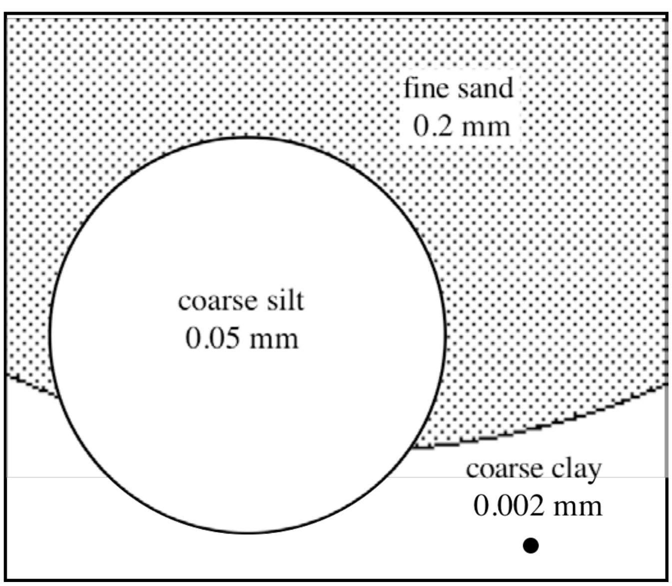

Figure 8. The spheres above depict the relative size difference between a particle of fine sand, coarse silt, and coarse clay. The largest particle of sand (2.0 mm) would be 10 times the diameter of the sand particle above.

Consider a cube-shaped stone that is 25 mm (1 inch) per side. It has six faces, each with a surface area of 1 square inch (in^2), for a total surface area of 6 in^2. If that same 1-inch cube was divided into sand-sized cubes, 1 mm to a side (approximately 25 mm per inch), it would have a total surface area of 150 in^2. If the 1-inch cube were composed of silt-sized cubes, 0.01 mm to a side, it would have a total surface area of 15,000 in^2 (104 square feet). Finally, if the 1-inch cube were made up of clay sized cubes 0.001 mm to a side, it would have a total surface area of 1,040 ft^2. Table 9 summarizes the relationship between soil particle size and surface area.

Table 9 provides an illustration of the effect of particle size on surface area, but it does not totally reflect the contribution of clay to soil surface area. The calculations in Table 10 are based on hypothetical cube-shaped particles. This is not unreasonable for sand and silt, which are usually small fragments of the soil's parent material. Clay particles, however, form as the soil is developing. Its components, silica, aluminum, oxygen, and hydrogen; form into thin, sheet-like particles that behave very differently than sand and silt particles.

Because clay particles are sheet-like, they have much more surface area than if they were more like spheres or cubes. Table 11 compares the effect of particle shape on surface area, using a sheet of 8-1/2 by 11 inch paper, 0.01 inch thick as the example. This piece of paper would have a volume of 0.94 cubic inches and a surface area of 187 square inches. A cube and sphere with the same volume would have surface areas of 5.7 and 4.6 square inches, respectively. This tremendous surface area explains why clay particles have such an impact on the physical and chemical properties of soil.

A more representative approximation of a clay particle would be to take the 0.001 mm sub-cube from Table 9 that was used to approximate a clay particle, and slice it into between 100 and 1000 sheets. This would increase the surface area of the soil in just that cube between 34 and 334 times.

The effect of clay on herbicide is not just increased surface area. Clays are also chemically reactive. Each individual layer of a clay particle is made up of a sandwich of positively charged silica or alumina ions between outer layers of oxygen or hydroxyl (oxygen plus a single hydrogen) ions that are negatively charged. The charges at the edges of these sheets are not balanced, as they are in the center of the sheets, so the edges tend to be negatively charged. In addition, as the sheets are forming, there is occasional insertion of alumina ions where silica ions should be, or magnesium substitutes for alumina. Alumina has less positive charge than silica, and magnesium has less positive charge than alumina. This substitution reduces the positive charge, and increases the net negative charge.

Table 10. Relationship between soil particle size and surface area. For each example, a 1-inch cube is subdivided into smaller cubes corresponding to particle sizes for sand, silt, and clay. Total surface area of the 1-inch cube composed of these smaller cubes is listed.

Particle Type	Particle Diameter mm	Particle Diameter inches	Total Surface Area in a 1-inch cube (square inches)
Stone	25	1	6
Sand	1	0.04	150
Silt	0.01	0.0004	15,000
Clay	0.001	0.00004	150,000

This net negative charge of clay particles is what creates the *Cation Exchange Capacity*, or *CEC*, of a soil. The CEC is a measure of a soil's ability to adsorb positively charged molecules. This is very important for soil fertility, because nutrients such as nitrogen in the form of ammonium, potassium, calcium, and magnesium are positively charged.

The other cause of CEC in a soil is organic matter, often referred to as *humus*. Humus is a general term that refers to a variety of organic molecules that result from the digestion and decomposition of organic residues. Humus is quite resistant to further decomposition, and has a net negative charge. It improves the structure of soil by encouraging the aggregation of smaller soil particles, and improves fertility by providing an adsorption site for positively charged nutrients.

We see then that fine textured soils high in clay, or organic matter have more capacity to bind herbicides in place. In fact, many soil herbicide labels recommend higher rates in fine textured soils because the soils reduce the availability of the herbicides for root pick up.

Most industrial sites, however, have coarse-textured soils, often having gravel surfaces, or even pavement. As can be seen in Table 9, stone has very little surface area per unit volume, and therefore very little capacity to adsorb herbicide. Yet, most total vegetation control applications rely on potent soil active herbicides at rates high enough to provide control for an entire growing season. Industrial weed control, then, is often the combination the herbicides most capable of causing off-site damage and the sites least capable of retaining these herbicides.

Table 11. Soil particle shape has a significant effect on the surface area. The comparison is based on a sheet of paper, 8.5 by 11 inches, and 0.01 inches thick as the 'Flat' particle dimensions. The 'flat' shape represents typical clay particles and demonstrates why they are so chemically reactive.

Particle Shape	Particle Volume (cubic inches)	Particle Surface Area (square inches)
Flat	0.94	187
Cube	0.94	5.7
Sphere	0.94	4.6

Therefore, it is critical to evaluate the surface of a site when determining what herbicides to use. If you are treating cracks or seams in asphalt or concrete, be aware that nearly all the herbicide that is deposited on the surface will wash off. Herbicide that does not wash into the cracks or seams will be carried to adjacent areas. The same is true of highway guiderail applications where the guiderail is very close to the pavement, or actually installed in the pavement. If herbicide is applied to the pavement, or to a thin layer of anti-skid material on top of pavement, these sites have little capacity to retain herbicide and much of it can be carried away.

Soil Permeability

Soil permeability describes the rate that 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 9). *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.

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).

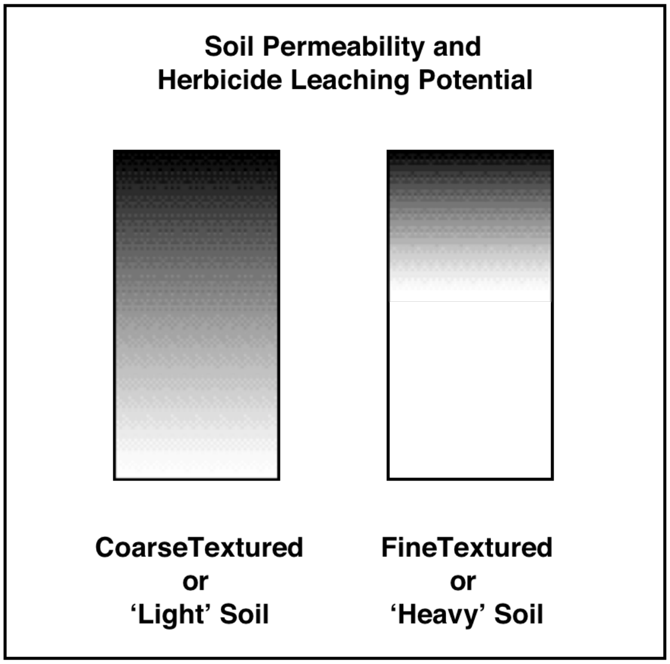

Figure 9. A demonstration of the role of soil texture on permeability, and resulting leaching of an herbicide. The herbicide, represented as black, has leached farther in the more permeable, coarse textured soil on the left.

Soil 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 that make it much easier for water to move through it.

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 groundwater 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 10). 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.

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

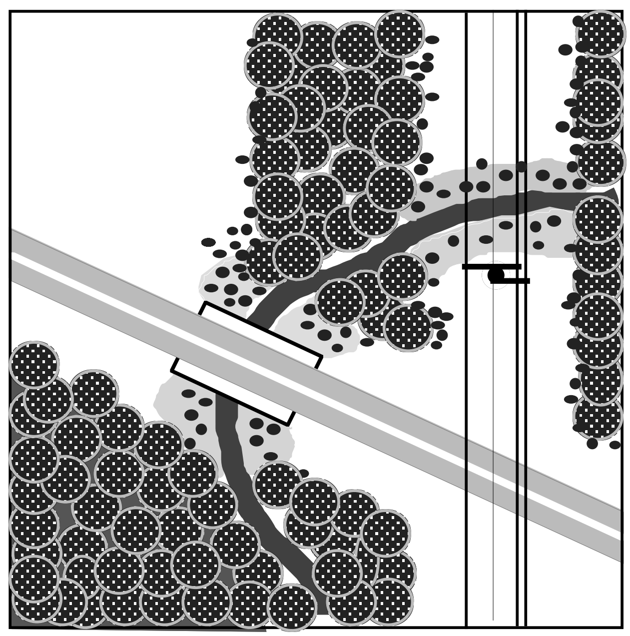

Figure 10. A bird's eye view of buffer zones, indicated by shading, next to a stream, crossing electric transmission and highway ROWs through a wooded area . The potential of contamination of the stream from herbicides or sediment is reduced by limiting broadcast spray or mowing operations. Undesirable 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.

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 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 a threat to non-target vegetation by misapplication, spray drift, volatilization, and root uptake (Figure 11). 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. 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.

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 aboveground 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 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.

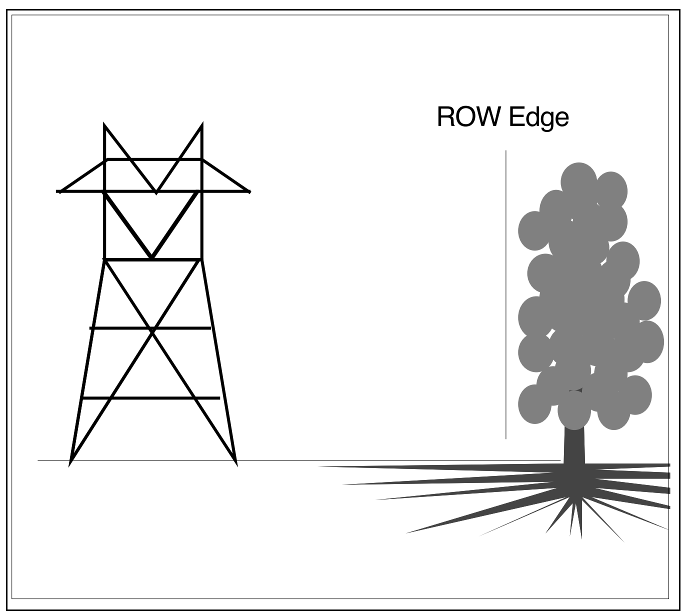

Figure 11: Although the branches of trees can be trimmed to the ROW boundary, the roots can extend a considerable distance - two to three times the width of the canopy. Herbicides that persist in the soil and can be picked by these roots can cause off-target injury.

Some species, such as boxelder maple (*Acer negundo*) drop their leaves quite early, often in September; while species such as black locust (*Robinia pseudoacacia*) and many of the exotic, invasive shrub species 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. Figure 12 shows a high volume application to tree-of-heaven, showing the advantage of high volume when treating dense targets.

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. You can treat targets ranging from scattered small brush to patches of 15 to 20-ft tall resprouts or dense thickets Japanese knotweed.

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.

Figure 12. A high volume foliar application is the most effective way to treat tall, dense targets.

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 – especially if the applicator is relying more on the ‘throw’ capabilities of the sprayer rather than his or her feet to get close to the target. Selectivity with a high volume application 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 3A’ (*triclopyr*), ‘Tordon K’ (*picloram*), or ‘Vanquish’ (*dicamba*) would leave much of the understory intact.

High volume applications of *glyphosate* 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 (Figure 13) equipped with adjustable cone nozzles; or swivel-body valves providing the applicator a choice of spray tips.

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 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.

Figure 13. Low volume application with a backpack sprayer provides mobility and selectivity.

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 throughout the 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 tree-of-heaven, black locust, or sumac 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. Ill-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 Ultra' (*triclopyr)*, 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 (Figure 14).

Since the introduction of low volume basal bark applications, this method has become the standard basal bark practice, and therefore is the convention. 'Conventional' basal bark is rarely used. Therefore, we will not further discuss 'conventional' basal bark, and will simply use the term basal bark for 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 an adjustable-nozzle spray wand. Ideally, the spray wand should be configured so that the shut-off is at the tip, to provide 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.

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

Figure 14. A basal bark treatment is made with an herbicide mixed in oil and applied to the complete circumference of the lower portion of the target stem.

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.

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 Ultra’ or ‘Pathfinder II’) is used, basal bark treatments can be used to control undesirable trees growing near desirable trees. *Triclopyr* has little soil activity, so as long as it is not applied to non-target plants, or not applied to a *lot* of targets very close to a desirable tree, there is little risk of non-target injury.

Timing flexibility is another advantage of basal bark treatments. The only situations when basal bark treatments cannot be made are 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 of year. Root suckering species should be treated during the summer 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 tree-of-heaven, the application becomes excruciating. Basal bark is best suited to low to moderate stem densities. Additionally, because it is an individual stem treatment, it is likely you will miss some stems when vegetation is dense.

Cut Surface Applications

The term 'cut surface' describes the treatment of exposed cambial tissue, by 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 (Figure 15). 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. ‘Eco 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 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

Figure 15. The ‘hack-and-squirt’ technique relies on application of small volumes of concentrated herbicide mixture to spaced cuts on woody stems.

environment to the herbicides. For this reason, these techniques can be used in 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 timing issues 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 second 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.

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 important 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.

The drawback to delaying treatment after cutting is locating the stumps amid the slash and debris and existing vegetation.

The other timing issue is the time of year the treatment is made. In the early spring when sap flow is heavy, some trees species, such as maples and birches, may 'bleed' enough they push the solution off the stump surface. In this situation, use an oil-based treatment and treat the bark of the stump.

Controlling Suckering Species

When you are trying to control root-suckering species such as tree-of-heaven or black locust, stump treatment is not an effective control measure. To control suckering species the herbicide has to move into the roots. If you remove the tree top, there is no longer any movement of herbicide to the roots.

To effectively control suckering species while including cutting as part of the operation, treat the stems during the late summer with foliar, basal bark, or hack-and-squirt treatments, then cut them after they are dead.

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 K' (*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 greatly reduced. 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 suggest that treatments should not begin until late winter - late February to early March.

Coverage is critical because herbicide movement via translocation is going to be minimal after the treatment.

Advantages

Dormant stem treatments provide another means to lengthen the application season. Dormant stem treatments can begin one to two months before typical 'spring' work begins. Additionally, susceptible non-targets are dormant and have no foliage – reducing the risk of off-target injury.

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 will be impacted. 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, the root system in suckering species is not controlled.

Applications to Soil

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

Selective Preemergence

When the target weeds are annuals in already established groundcover, there are herbicides that will prevent germination without injuring the existing groundcover. Examples include the dinitroanaline herbicides such as *pendimethalin;* as well as *metolachlor* or *isoxaben*. These herbicides can be used in naturalistic settings such as parks or meadows (Figure 16), as well as sites such as screen plantings around industrial sites. They will prevent new growth from seed of most weed species, but will not affect existing vegetation.

These herbicides must be in contact with the germinating seed to be effective. Therefore, they need to be applied in advance – at least two weeks, depending on surface residue – to allow rainfall to move them into the soil.

Advantages

Where you have known infestations of problem annuals or biennials where you have desirable vegetation, this is an ideal approach to preserve the existing vegetation. Postemergence applications, especially to desirable mixed species vegetation, are going to cause at least some injury to non-targets.

Where infestations are extensive, you can make a fixed-pattern broadcast application from a vehicle, particularly if you are working in an setting such as meadow.

Disadvantages

Where infestations are extensive, preemergence applications require more labor than postemergence applications. You will typically treat the known 'footprint' of the infestation, plus some additional buffer area. Additionally, if you are repeating a treatment from the season before, you may have no telltale signs of the target weeds. Where control is critical, you will come back with a postemergence clean-up treatment anyway. Sometimes it is more efficient to wait for emergence to know where the targets are, and do all the treatments postemergence.

Total Vegetation Control

Total vegetation control is practiced where bare ground is desired. Settings include industrial sites, petroleum tank farms, electric sub-stations (Figure 17), fence lines, unpaved parking lots, and highway guiderails and signposts (Figure 18). 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.

These treatments rely on a mixture of herbicides to provide season-long control. The mixture would typically include broad-spectrum residual (BSR), preemergence, and postemergence herbicides.

The BSR herbicides provide soil activity to prevent germination from seed, as well as root uptake to injure established plants. Examples of commonly used BSR herbicides include *sulfometuron methyl* ('Oust XP', 'Oust Extra', 'Landmark XP'), *imazapyr* ('Arsenal Powerline', 'Sahara DG') and *bromacil* ('Hyvar X', 'Krovar I'). *Sulfometuron* and *imazapyr* have foliar activity as well, to provide an additional means to control existing vegetation.

Preemergence herbicides are added primarily to prevent germination from seed. Preemergence herbicides pose less risk from off-site movement, so they are used at relatively higher rates than BSR herbicides. In this manner, you can minimize the dosage of BSR herbicides to simply provide the initial control, and let the higher dosage of the less-mobile preemergence herbicides provide the control of weeds from seed.

The most commonly used preemergence herbicide in bare ground applications is *diuron* ('Karmex XP'). *Diuron* is also an ingredient in the combination-product 'Krovar I'. Other preemergence herbicides include *sulfentrazone* ('Portfolio', 'Throttle XP')*, flumioxazin* ('Payload'), *imazapic* ('Plateau', 'Journey'), and dinitroanaline herbicides such as *prodiamine* ('Proclipse') or *pendimethalin* ('Pendulum').

The most common postemergence herbicide for total vegetation control is *glyphosate* ('Roundup Pro').

By combining herbicide types, you can control existing vegetation and achieve residual control while using moderate doses of potent BSR herbicides.

Soil Spot Treatments

Soil spot treatments describe the treatment of

Figure 16. Pendimethalin is applied as a selective preemergence treatment to control the annual weeds mile-a-minute and Japanese stiltgrass in a park setting. Pendimethalin does not affect established plants, and can be applied over existing woody and herbaceous plants.

Figure 17. A common industrial site application is made with a sprayer with several hundred feet of hose equipped with a handgun with an off-center spray tip allowing the applicator to treat an 8 to 10 ft swath.

localized infestations of established, undesirable species, whether it is scattered brush or problem species that grows in clumps or colonies. A persistent herbicide such as *tebuthiuron* ('Spike 20P'), *hexazinone* ('Velpar ULW'), or *bromacil* ('Hyvar') 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 pellets or granules.

The primary limitation of using soil spot treatment is selectivity. Spot treatments 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

A 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.

Cut stubble treatments are applied to recently mowed areas using a fixed pattern spray device on a vehicle. It is a very productive application.

Cut stubble applications reduce the vegetation that initally reestablishes.

As mentioned above, 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

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.

Figure 18. A non-selective herbicide mixture is applied to a highway guiderail to prevent weed growth. Herbicides in the mixture eliminate existing growth and prevent establishment of new weeds from seed.

Table 12 - Herbicides Available for Non-crop Use, by Trade Name. *Alphabetical listing of selected non-crop herbicides, by product name. Where multiple active ingredients are included, they are listed in order of prevalence in the mixture, or in alphabetical order when proportion is equal.*

Product Name	Active Ingredients
Acclaim Extra	fenoxaprop-p-ethyl
Aquamaster	glyphosate
Arsenal 0.5 G	imazapyr
Arsenal Powerline	imazapyr
Assure II	quizalafop P-ethyl
Basagran T/O	bentazon
Barrier	dichlobenil
BK 800	2,4-D + dichlorprop + dicamba
Casoron 4G	dichlobenil
Clearcast	imazamox
DMA 4 IVM	2,4-D
DiBro 2+2	bromacil + diuron
DiBro 4+2	diuron + bromacil
Edict 2SC	pyraflufen-ethyl
Embark 2S IVM	mefluidide
Endurance	prodiamine
Envoy Plus	clethodim
Escort XP	metsulfuron methyl
Finale	glufosinate ammonium
Fusilade II	fluazifop P-butyl
Fusion	fluazifop P-butyl + fenoxaprop P-ethyl
Gallery	isoxaben
Garlon 3A	triclopyr
Garlon 4 Ultra	triclopyr
Glyphomate 41	glyphosate
Gramoxone Inteon	paraquat dichloride
Hi-Dep IVM	2,4-D
Hyvar X	bromacil
Hyvar XL	bromacil
Journey	glyphosate + imazapic
Karmex XP	diuron
Krenite S	fosamine ammonium
Krovar I	bromacil + diuron
Landmark XP	sulfometuron methyl + chlorsulfuron
Lineage Clearstand	imazapyr + metsulfuron methyl
Lineage HWC	imazapyr + sulfometuron methyl + metsulfuron methyl
Lineage Prep	imazapyr + sulfometuron methyl + metsulfuron methyl
Milestone VM	aminopyralid
Milestone VM Plus	triclopyr + aminopyralid
Oust XP	sulfometuron methyl
Overdrive	dicamba + diflufenzopyr
Pathfinder II	triclopyr
Pathway	2,4-D + picloram
Patron 170	2,4-D + dichlorprop
Payload	flumioxazin
Pendulum 2G	pendimethalin
Pendulum 3.3 EC	pendimethalin
Pendulum Aquacap	pendimethalin
Pennant Magnum	S-metolachlor
Plateau	imazapic
Portfolio	sulfentrazone
Pramitol 5 PS	sodium metaborate + sodium chlorate + prometon + simazine
Pramitol 25E	prometon
Pramitol 4SC	prometon

Table 12 - Herbicides Available for Non-crop Use, by Trade Name (*continued*): Alphabetical listing of selected non-crop herbicides, by product name. Where multiple active ingredients are included, they are listed in order of prevalence in the mixture, or in alphabetical order when proportion is equal.

Product Name	Active Ingredients
Predict	norflurazon
Quicksilver T&O	carfentrazone-ethyl
Reward	diquat dibromide
Rodeo	glyphosate
Roundup Pro	glyphosate
Roundup Pro Concentrate	glyphosate
Roundup Pro Dry	glyphosate
Roundup ProMax	glyphosate
Sahara	diuron + imazapyr
Scythe	pelargonic acid
Sethoxydim E-Pro	sethoxydim
Snapshot TG	trifluralin + isoxaben
Spike 20P	tebuthiuron
Spike 80W	tebuthiuron
SpraKil S-13	diuron + tebuthiuron
SpraKil S-26	diuron + tebuthiuron
SpraKil S-5	tebuthiuron
Stalker	imazapyr
Stronghold	mefluidide + imazethapyr + imazapyr
Surflan AS	oryzalin
Telar XP	chlorsulfuron
Throttle XP	sulfentrazone + sulfometuron methyl + chlorsulfuron
TopSite 2.5G	diuron + imazapyr
Tordon 101M	2,4-D + picloram
Tordon K	picloram
Transline	clopyralid
Trifluralin 10G	trifluralin
Vanquish	dicamba
Vegemec	prometon + 2,4-D
Velpar DF	hexazinone
Velpar L	hexazinone
Veteran 720	2,4-D + dicamba
XL 2G	benefin + oryzalin
Weed Blast 8G	bromacil + diuron

Table 13 - Herbicides Available for Non-crop Use, by Active Ingredient. Alphabetical listing of selected non-crop herbicides, by active ingredient. Where products are a mixture of herbicides, the other active ingredients are indicated in parentheses, in order of prevalence. Products in **boldface** type are the trade names used in the herbicide product summary section.

active ingredient	product examples
2,4-D	**DMA 4 IVM** 2,4-D LV4 Ester 2,4-D LV6 Ester BK 800 (dichlorprop, dicamba) Patron 170 (dichlorprop) Tordon 101M (picloram) Vegemec (prometon) Veteran 720 (dicamba)
aminopyralid	**Milestone VM** Milestone VM Plus (triclopyr)
benefin	XL 2G (oryzalin)
bentazon	**Basagran T/O**
bromacil	**Hyvar X** DiBro 2+2 (diuron) DiBro 4+2 (diuron) Hyvar XL Krovar I (diuron) Weed Blast 8G (diuron)
carfentrazone-ethyl	**Quicksilver T&O**
chlorsulfuron	**Telar XP** Throttle XP Landmark XP
clethodim	**Envoy Plus**
clopyralid	**Transline**
dicamba	**Vanquish** BK 800 (2,4-D; 2,4-DP) Overdrive (diflufenzopyr) Veteran 720 (2,4-D)
dichlobenil	**Casoron 4G** Barrier 4G Barrier 50W Veto
dichlorprop	BK 800 (2,4-D; dicamba) Patron 170 (2,4-D)
diflufenzopyr	Overdrive (dicamba)
diquat dibromide	**Reward**
diuron	**Karmex XP** DiBro 2+2 (bromacil) Diuron 4L Krovar I (bromacil) Sahara (imazapyr) SpraKil S-13 (tebuthiuron) SpraKil S-26 (tebuthiuron) Topsite 2.5G (imazapyr) Weed Blast 8G (bromacil)
fenoxaprop-P-ethyl	**Acclaim Extra** Fusion

Table 13 - Herbicides Available for Non-crop Use, by Active Ingredient (*continued*). Alphabetical listing of non-crop herbicides, by active ingredient. Where products are a mixture of herbicides, the other active ingredients are indicated in parentheses, in order of prevalence. Products in **boldface** type are the trade names used in the herbicide product summary section.

active ingredient	product examples
fluazifop P-butyl	**Fusilade II** Ornamec Fusion
flumioxazin	**Payload**
fosamine ammonium	**Krenite S**
glufosinate	**Finale**
glyphosate	**Roundup Pro** Glyphomate 41 Rodeo Roundup Pro Concentrate Roundup Pro Dry Roundup Pro Max
hexazinone	**Velpar DF** Velpar L Velpar ULW Westar (sulfometuron methyl)
imazamox	**Clearcast**
imazapic	**Plateau** Journey (glyphosate)
imazapyr	**Arsenal Powerline** Arsenal 0.5 G Lineage Clearstand (metsulfuron methyl) Lineage HWC (metsulfuron methyl, sulfometuron methyl) Lineage Prep (metsulfuron methyl, sulfometuron methyl) Sahara (diuron) Stalker Stronghold (mefluidide, imazethapyr) TopSite 2.5 G (diuron)
imazethapyr	Stronghold (mefluidide, imazapyr)
isoxaben	**Gallery 75 DF** Snapshot TG (trifluralin)
mefluidide	**Embark 2S IVM** Stronghold (imazethapyr, imazapyr)
S-metolachlor	**Pennant Magnum**
metsulfuron methyl	**Escort XP** Lineage Clearstand (imazapyr) Lineage HWC (imazapyr, sulfometuron methyl) Lineage Prep (imazapyr, sulfometuron methyl) Oust Extra (sulfometuron methyl)
norflurazon	**Predict**
oryzalin	**Surflan** XL 2G (benefin)
oxyfluorfen	Goal 2XL
paraquat dichloride	**Gramoxone Inteon**
pelargonic acid	**Scythe**

Table 13 - Herbicides Available for Non-crop Use, by Active Ingredient (*continued*). Alphabetical listing of non-crop herbicides, by active ingredient. Where products are a mixture of herbicides, the other active ingredients are indicated in parentheses, in order of prevalence. Products in **boldface** type are the trade names used in the herbicide product summary section.

active ingredient	product examples
pendimethalin	**Pendulum Aquacap** Pendulum 2G Pendulum 3.3 EC Pendulum WDG
picloram	**Tordon K** **Pathway (2,4-D)** **Tordon 101M (2,4-D)**
prodiamine	**Endurance**
prometon	**Pramitol 25E** Pramitol 2.2 L Pramitol 5 PS (sodium metaborate + sodium chlorate, simazine) Pramitol 4SC Vegemec (2,4-D)
pyraflufen-ethyl	**Edict 2 SC**
quizalofop P-ethyl	**Assure II**
simazine	**Simazine 90 DF** Simazine 4L Pramitol 5 PS (sodium metaborate + sodium chlorate, prometon)
sulfentrazone	**Portfolio** Throttle XP (sulfometuron methyl, chlorsulfuron)
sulfometuron methyl	**Oust XP** Landmark XP (chlorsulfuron) Lineage HWC (imazapyr, metsulfuron methyl) Lineage Prep (imazapyr, metsulfuron methyl) Oust Extra (metsulfuron) Throttle XP (chlorsulfuron, sulfentrazone)
tebuthiuron	**Spike 80 DF** Spike 20P SpraKil S-5 SpraKil S-13 (diuron) SpraKil S-26 (diuron)
triclopyr	**Garlon 3A** Garlon 4 Ultra Pathfinder II Milestone VM Plus (aminopyralid)
trifluralin	**Trifluralin 10G** Snapshot TG (isoxaben)

Table 14 - Herbicide Toxicity and Reaction to Inorganic Materials. Summary of acute toxicity of non-crop herbicides, and affect on inorganic materials. Unless indicated, the toxicities are for the technical grade active ingredient. LD_{50} is the dose, in mg/kg, or parts per million, that kills 50 percent of a test population. LC_{50} is the concentration in the air, in mg/liter, that kills 50 percent of a test population. Affect on inorganics is for the formulated product.

Example Product	Active Ingredient	Acute Oral LD_{50} (Rat) (mg/kg)	Acute Dermal LD_{50} (Rabbit) (mg/kg)	4 hour Inhalation LC_{50} (Rat) (mg/L)	Affected Inorganics
Hi-Dep	*2,4-D*	639	>2,000	2.0	noncorrosive
Milestone VM	*aminopyralid*	>5,000	>2,000	>5.3	non-corrosive
Basagran T/O	*bentazon*	1,100	>2,500	5.0	non-corrosive
Hyvar	*bromacil*	5,175	>5,000	>4.8	X-non-corrosive, XL-aluminum
Telar	*chlorsulfuron*	5,545	3,400	>5.9	non-corrosive
Envoy Plus	*clethodim*	>1,360	>5,000	>3.9	non-corrosive
Transline	*clopyralid*	4,300	>2,000	1.0	brass, copper, zinc, aluminum
Vanquish	*dicamba*	1,707	>2,000	>9.6	non-corrosive
Casoron	*dichlobenil*	4,460	>2,000	>0.25	non-corrosive
BK 800	*dichlorprop*	800	1,400[1/]	n/a	n/a
Reward	*diquat*	230	>400	n/a	concentrate-aluminum
Karmex DF	*diuron*	3,400	>2,000[2/]	>5.0	non-corrosive
Fusion	*fenoxaprop-P*	3,310	>2,000	4.0	non-corrosive
Fusilade II	*fluazifop-P*	2,721	>2420	>0.54[2/]	non-corrosive
Krenite S	*fosamine*	24,400	>1683	3.3[2/]	brass and copper
Finale	*glufosinate*	1,910	1,380	4.0	non-corrosive
Roundup Pro	*glyphosate*	5,600	>5,000	>3.2[2/]	iron, galvanized steel
Velpar L	*hexazinone*	1,690	>6,000	>7.48	non-corrosive
Plateau	*imazapic*	>5,000	>2,000	>4.83	brass, iron, mild steel
Arsenal	*imazapyr*	>5,000	>2,000	>1.3	iron, mild steel, brass
Gallery	*isoxaben*	>10,000	>2,000	>2.68	non-corrosive
Embark	*mefluidide*	>4000	>4,000	>8.5[2/]	slight corrosion to metallic parts
Escort	*metsulfuron*	>5,000	>2,000	>5.3	non-corrosive
Surflan	*oryzalin*	>5,000	>2,000	>3.0	non-corrosive
Goal 2XL	*oxyfluorfen*	>5,000	>5,000	>4.8[2/]	non-corrosive
Gramoxone Inteon	*paraquat*	112	240	n/a	aluminum
Scythe	*pelargonic acid*	>5,000	>2,000	>5.3[2/]	non-corrosive
Pendulum	*pendimethalin*	>5,000	>2,000	>5.3[2/]	non-corrosive
Tordon K	*picloram*	4,012	>2,000	>0.035	slightly-mild steel
Endurance	*prodiamine*	>5,000	>2,000	>0.26	non-corrosive
Pramitol 25E	*prometon*	1,518	>2,000	>3.26	non-corrosive
Assure II	*quizalofop-P*	1,480	>5,000	6.0	concentrate-painted surfaces
Vantage	*sethoxydim*	2,676	>5,000	6.0	non-corrosive
Oust	*sulfometuron*	>5,000	>2,000	>5.0	non-corrosive
Spike	*tebuthiuron*	644	>200	1.0	non-corrosive
Garlon	*triclopyr*	713	>2,000	n/a	slight corrosion to aluminum
Trifluralin 10 G	*trifluralin*	>5,000	>5,000	>4.8	non-corrosive

[1/] Toxicity to mice

[2/] Toxicity of formulated product

Table 15 - Herbicide Behavior in Soils. Abridged Version of the Oregon State University Extension Pesticide Properties Database[1/]. Columns include a 'Pesticide Movement Rating' derived from the typical soil half-life value, the solubility of the herbicide in water, and the soil sorption coefficient. The movement rating provides a sense of the potential for a given herbicide to move towards groundwater, rather than a precise characterization that could be used for comparative purposes. There are too many variable factors that influence soil half-life and soil sorption to allow for a precise prediction of the behavior of an herbicide in the soil.

Common Name	Pesticide Movement Rating[2/]	Soil Half-life (days)	Water Solubility[3/] (mg/L or ppm)	Sorption Coefficient[4/] (soil K_{OC})
2,4-D acid	Moderate	10	890	20
2,4-D dimethylamine salt	Moderate	10	796,000	20
2,4-D esters or oil sol. amines	Moderate	10	100	100
Aminopyralid	Low	26	203	1000
Benefin	Extremely Low	40	0.1	9000
Bentazon sodium salt	High	20	2,300,000	34
Bromacil acid	Very High	60	700	32
Bromacil lithium salt	Very High	60	700	32
Carfentrazone-ethyl	Low	4	12	866
Clethodim	Low	3	5,400	10
Clopyralid amine salt	Very High	40	300,000	6
Dicamba salt	Very High	14	400,000	2
Dichlobenil	Moderate	60	21.2	400
Dichlorprop (2,4-DP) ester	Low	10	50	1000
Diflufenzopyr	Low	4	5850	87
Diquat dibromide salt	Extremely Low	1000	718,000	1,000,000
Diuron	Moderate	90	42	480
Fenoxaprop-ethyl	Extremely Low	9	0.8	9490
Fluazifop-P-butyl	Very Low	15	2	5700
Flumioxazin	Low	15	2	2240
Fosamine ammonium	Low	8	1,790,000	150
Glufosinate ammonium salt	Low	7	1,370,000	100
Glyphosate isopropylamine salt	Extremely Low	47	900,000	24,000
Hexazinone	Very High	90	33,000	54
Imazamox	High	50	45,000	62
Imazapyr acid	High	90	11,000	100
Imazapyr isopropylamine salt	High	90	500,000	100
Imazethapyr	Very High	90	200,000	10
Isoxaben	Low	100	1	1400
Mefluidide	Low	4	180	200
Metolachlor	High	90	530	200
Metsulfuron-methyl	High	30	9500	35
Norflurazon	Low	30	28	700
Oryzalin	Low	20	2.5	600
Oxyfluorfen	Extremely Low	35	0.1	100,000
Paclobutrazol	High	200	35	400
Paraquat dichloride salt	Extremely Low	1000	620,000	1,000,000
Pendimethalin	Very Low	90	0.275	5000
Picloram salt	Very High	90	200,000	16

Table 15 - Herbicide Behavior in Soils (*continued*). Abridged Version of the Oregon State University Extension Pesticide Properties Database[1/]. Columns include a 'Pesticide Movement Rating' derived from the typical soil half-life value, the solubility of the herbicide in water, and the soil sorption coefficient. The movement rating provides a sense of the potential for a given herbicide to move towards groundwater, rather than a precise characterization that could be used for comparative purposes. There are too many variable factors that influence soil half-life and soil sorption to allow for a precise prediction of the behavior of an herbicide in the soil.

Common Name	Pesticide Movement Rating[2/]	Soil Half-life (days)	Water Solubility[3/] (mg/L or ppm)	Sorption Coefficient[4/] (soil K_{OC})
Prodiamine	Extremely Low	120	0.013	13,000
Prometon	Very High	500	720	150
Quizalofop-ethyl	Moderate	60	0.31	510
Sethoxydim	Low	5	4390	100
Simazine	High	60	6.2	130
Sodium chlorate	Very High	200	100,000	10
Sulfentrazone	High	541	400	104
Sulfometuron-methyl	Moderate	20	70	78
Tebuthiuron	Very High	360	2500	80
Triclopyr amine salt	Very High	46	2,100,000	20
Triclopyr ester	Low	46	23	780
Trifluralin	Very Low	60	0.3	8000

1/ P.A. Vogue, E.A. Kerle, and J.J. Jenkins. For the unedited pesticide listing, go to http://npic.orst.edu/ppdmove.htm. Additional data derived from the USDA-NRCS Pesticide Properties Database, available at http://www.wsi.nrcs.usda.gov/products/W2Q/pest/WinPST.html#pst%20ppd.

2/ The Pesticide Movement Rating is categorically derived from the Groundwater Ubiquity Score (GUS), which is $GUS = \log_{10}(\text{half-life}) \times [4 - \log_{10}(K_{OC})]$. Movement ratings range from 'Extremely Low' to 'Very High'. Pesticides with a GUS less than 1.0 are considered to have an extremely low potential to move toward groundwater. Values of 1.0-2.0 are low, 2.0-3.0 are moderate, 3.0-4.0 are high, and values greater than 4.0 have a very high potential to move toward groundwater.

3/ Water solubility describes the amount of pesticide that will dissolve in a known amount of water. Most of the values reported were determined at room temperature (20° C or 25° C). The higher the solubility value, the more likely the pesticide will be removed from the soil in runoff or by leaching.

4/ The sorption coefficient (K_{OC}) describes the tendency of a pesticide to bind to soil particles. Sorption retards movement of the pesticide through soil, and may also increase persistence (increase the half-life) because the pesticide is protected from degradation processes. The higher the K_{OC} value, the greater the tendency for a pesticide to bind to the soil.

Table 16. Non-crop herbicide labeled uses. *Selective Pre* - applications intended to control weeds from seed in established plantings. *Selective Post* – applications that remove weeds from plantings of designated species. *Non-selective Pre* - applications used to maintain bare ground. *Non-selective Post* – applications to control or suppress all existing vegetation. *Weed Control under Pavement* - applications to the prepared road base immediately prior to paving. *Low Volume Basal Bark* - herbicide is diluted in an oil carrier and applied to the lower bark of woody plants. *Cut Surface* – application to a cut stump, exposed cambium, or woody stem injection treatments. *Spot Concentrate* - application of material to the soil at the base of target brush. Granular products with a low percentage of active ingredient are not included in this category. *Cut Stubble* - broadcast application of a soil active herbicide after brush has been mowed, to prevent resprouting. *Growth Regulation* - Products labeled to suppress growth of target plants. This also includes herbicides labeled for growth suppression of utility turfgrasses. *Aquatic* - Control of weeds in water.

Product	Selective Pre	Selective Post	Non-selective Pre	Non-selective Post	Under Pavement	Basal Bark	Cut Surface	Soil Spot	Cut Stubble	Growth Regulation	Aquatic
Acclaim Extra		■									
Arsenal Powerline		■	■	■	■		■			■	
Arsenal 0.5 G			■	■							
Assure II		■									
Basagran T/O		■									
BK 800		■				■	■				
Casoron	■		■		■						
Clearcast		■									■
DiBro 2 + 2			■	■							
DiBro 4 + 2			■	■							
Diuron 4L			■								
DMA 4 IVM		■					■				■
Edict 2 SC		■									
Embark 2S IVM										■	
Endurance	■										
Envoy Plus		■									
Escort XP		■						■		■	
Finale				■							
Fusilade II		■									

Table 16. Non-crop herbicide labeled uses (continued).

Product	Selective Pre	Selective Post	Non-selective Pre	Non-selective Post	Under Pavement	Basal Bark	Cut Surface	Soil Spot	Cut Stubble	Growth Regulation	Aquatic
Fusion		■									
Gallery	■										
Garlon 3A		■					■				■
Garlon 4 Ultra		■				■	■				
Glyphomate 41		■		■			■			■	■
Gramoxone Inteon				■							
Hyvar X			■	■				■			
Hyvar XL			■	■				■			
Journey	■		■	■						■	
Karmex XP			■								
Krenite S		■					■				
Krovar I			■	■							
Landmark XP		■	■	■	■					■	
Lineage Clearstand		■		■			■			■	
Lineage HWC			■	■							
Lineage Prep			■	■							
Milestone VM		■									
Milestone VM Plus		■					■				
Ornamec		■									
Oust XP		■	■	■						■	
Overdrive		■									
Pathfinder II						■	■				
Pathway							■				
Patron 170		■				■	■				

Table 16. Non-crop herbicide labeled uses (continued).

Product	Selective Pre	Selective Post	Non-selective Pre	Non-selective Post	Under Pavement	Basal Bark	Cut Surface	Soil Spot	Cut Stubble	Growth Regulation	Aquatic
Pendulum 2G	■										
Pendulum Aquacap	■										
Pendulum WDG	■										
Pennant Magnum	■										
Plateau	■	■								■	
Pramitol 5 PS			■	■							
Pramitol 25E			■	■							
Pramitol 4 SC			■	■							
Predict	■										
Reward				■							■
Rodeo		■		■			■			■	■
Roundup Pro		■		■			■			■	
Roundup Pro Concentrate		■		■			■			■	
Roundup Pro Dry		■		■						■	
Roundup Pro Max		■		■						■	
Sahara			■	■	■						
Scythe				■							
Sethoxydim E-Pro		■									
Snapshot TG	■										
Spike 20P			■	■				■			
Spike 80 DF			■	■	■			■			
SpraKil S-13			■	■							
SpraKil S-26			■	■							

Table 16. Non-crop herbicide labeled uses (continued).

Product	Selective Pre	Selective Post	Non-selective Pre	Non-selective Post	Under Pavement	Basal Bark	Cut Surface	Soil Spot	Cut Stubble	Growth Regulation	Aquatic
SpraKil S-5			■	■							
Stalker					■	■	■		■		
Stronghold										■	
Surflan AS	■										
Telar XP		■								■	
TopSite 2.5 G			■	■							
Tordon 101M		■					■		■		
Tordon K		■				■			■		
Transline		■					■				
Trifluralin 10G	■										
Vanquish		■					■				
Vegemec			■	■							
Velpar DF		■		■							
Velpar L		■		■							
Velpar ULW		■		■							
Veteran 720		•									
Weed Blast 8G			■	■							
XL 2G	■										

Herbicide Product Summaries

This section summarizes the products, uses, application rates for herbicides labeled for non-crop uses. The products listed under each heading represent unique formulations or unique labeling for a formulation. Many herbicides are available in a number of products with identical formulations. We do not attempt to list them here.

Acclaim Extra
(fenoxaprop-P-ethyl) **Producer: Bayer**

Application Rate: 0.071 to 0.17 lbs ai/acre.

Formulation	per/acre
Acclaim Extra (0.57 EC)	16 to 39 oz/acre

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage. Must be applied postemergence to target grasses.

Fenoxaprop-P is a lipid synthesis inhibitor. It binds to and inactivates an enzyme that is critical to the synthesis of fatty acids. Growth ceases quickly, but susceptible plants may take several weeks to die.

Sites: Terrestrial applications only. Do not use near water.

Uses: Selective control of Johnsongrass and weedy annual grasses in roadside stands of Kentucky bluegrass, perennial ryegrass, fineleaf fescues or tall fescue. Acclaim Extra is also labeled for use in landscape beds and ornamental turf.

Notes: Grass control is most effective when they are less than 6 inches tall. Treatments to annual grasses in seedhead are largely ineffective. Acclaim Extra can be tank mixed with broadleaf herbicides without loss of control.

Combination Products

Fusion [2.56 E] *(24% fluazifop-P-butyl, 7% fenoxaprop-P-ethyl) – Control of annual grasses and Johnsongrass on roadsides. Use for selective grass control in common Bermudagrass, fineleaf fescues, perennial ryegrass, smooth brome, and tall fescue.*

Arsenal Powerline
(*imazapyr*) **Producer: BASF**

Application Rate: 0.002 to 1.5 lbs ai/acre.

Formulation	per/acre
Arsenal Powerline (2 S)	2 oz to 6 pints
Arsenal 0.5 G	200 to 300 lbs
Habitat (2S)	1 to 6 pints
Stalker (2 EC)	1 to 6 pints

Several manufacturers offer 2 S formulations of imazapyr for non-crop or aquatic applications, as well as 4 S formulations for forestry use.

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage, stems, or roots. Can be applied pre- or postemergence, to plant or soil.

Imazapyr binds to and inactivates the enzyme acetolactase synthase (ALS), preventing synthesis of essential amino acids. Affected plants cease growth quickly, but complete control of treated plants may take several weeks.

Sites: uplands, non-tidal wetlands where surface water is not present, non-irrigation ditchbanks, and ditch bottoms where only isolated puddles of surface water occur. 'Habitat' is labeled for aquatic sites.

Uses: selective weed control in unimproved Bermuda- and bahiagrass, herbaceous weed control, foliar brush control, cut surface, basal bark, total vegetation control, seedhead suppression of unimproved Bermudagrass and cool-season turfgrasses, aquatic weed control.

Notes: selectivity largely determined by application rate. Legumes tend to be more tolerant than other plant species. Higher application rates provide persistent soil activity, so use caution when applying near the roots of desirable plants. Due to relatively slow nature of activity, tank mixing with fast acting herbicides such as 2,4-D is not recommended. Relatively low application rates increase activity in tank mixes with herbicides such as fosamine ammonium, glyphosate, or triclopyr. Biotypes of kochia (*Kochia scoparia*) have been found to be resistant to imazapyr and other ALS-inhibiting herbicides.. Be certain to practice resistance-management (see *Herbicide Resistance* in this document).

Combination Products

Lineage Clearstand [73 DG] (*63% imazapyr, 10% metsulfuron methyl*)

Lineage HWC [74 DG] (*38% imazapyr, 28% sulfometuron methyl, 8% metsulfuron methyl*)

Lineage Prep [74 DG] (*55% imazapyr, 15% sulfometuron methyl, 4% metsulfuron methyl) The Lineage product line is for use in conifer forestry for site-prep or herbaceous weed control,* *and in non-crop sites for brush control, herbaceous weed control, total vegetation control, and selective weeding in some utility turf settings.*

Sahara DG *(62% diuron, 8% imazapyr) -Pre- or postemergence to maintain bare ground on industrial sites, or weed control under paved surfaces.*

Stronghold [1.8 S] *(16% mefluidide, 3.9% imazethapyr, 0.1% imazapyr) - Seedhead and/or vegetative growth suppression of bahiagrass, Kentucky bluegrass, orchardgrass, smooth bromegrass, or tall fescue. For use on utility/commercial turf, not residential lawns or manicured grounds.*

TopSite 2.5 G *(2% diuron, 0.5% imazapyr) - Control of herbaceous weeds on sites where bare ground is desired. Most effective when applied preemergence.*

Assure II

(quizalofop P-ethyl) **Producer: DuPont**

Application Rate: 0.034 to 0.082 lbs ai/acre.

Formulation	per/acre
Assure II 0.88 EC	4 to 18 oz/acre

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage. Must be applied postemergence to target grasses.

Quizalofop-P is a lipid synthesis inhibitor. It binds to and inactivates an enzyme that is critical to the synthesis of fatty acids. Growth ceases quickly, but susceptible plants may take several weeks to die.

Sites: Terrestrial applications only. Do not use near water.

Uses: Control of weedy grasses in non-crop sites, including roadside flower seedings. Not to be used in landscape beds.

Notes: Grass control is most effective when they are less than 6 inches tall. Treatments to grasses in seedhead are largely ineffective. Tank mixes with broadleaf herbicides may reduce grass control.

Basagran T/O

(bentazon) **Producer: BASF**

Application Rates: 0.75 to 2.0 lbs ai/acre.

Formulation	per/acre
Basagran T/O (4 S)	1.5 to 4 pts/acre

Mode of Action: Systemic to a limited extent. Translocation tends to be localized. Readily absorbed through leaves. Must be applied postemergence to target weeds.

Bentazon is a photosynthetic inhibitor. Electron flow is interrupted during the conversion of light energy to high-energy chemical compounds. This causes formation of free radicals causing protein and lipid damage, leading to cell membrane damage and desiccation.

Sites: Terrestrial applications only. Do not use near water

Uses: Control of broadleaf weeds and sedges in turf and non-crop areas. Over-the-top applications are labeled for some ornamentals.

Notes: Due to limited translocation, good coverage of target weeds is important. One of the few selective controls for yellow nutsedge. Most effective on broadleaf weeds when only a few inches tall. Provides effective burndown of Canada thistle. Perennials such as thistle or nutsedge may require retreatment two weeks after initial treatment.

Casoron 4G

(dichlobenil) **Producer: Uniroyal**

Application Rate: 2.0 to 10 lbs ai/acre.

Formulation	per/acre
Barrier 4 G	100 to 300 lbs
Casoron 4 G	50 to 250 lbs
Veto (1.4 ME)	1.4 to 5.7 gal

Mode of Action: Systemic. Moves to growing points after root absorption. Readily absorbed by roots or foliage. Granular products are soil applied for preemergence control.

Dichlobenil is quite volatile, and moves readily through soil. Accumulates at growing points of roots and shoots, inhibiting cell division.

Sites: For terrestrial use only. Do not use near water.

Uses: Preemergent weed control in woody ornamentals, herbaceous weed control in non-crop areas, and weed control under asphalt.

Notes: Dichlobenil is quite volatile, and must either be applied during late fall or early spring, when soil temperatures are less than 50 degrees F, or incorporated. 'Veto' is an encapsulated liquid formulation designed to release the herbicide after soil infiltration. Due to high mobility and leachability, should not be applied where the water table is high, or where movement of surface water is anticipated. Do not apply to frozen soils. Dichlobenil is one of the few materials that can be used for preemergence control of established perennial weeds such as Canada thistle and mugwort in woody landscapes.

Clearcast
(*imazamox*) **Producer: BASF**

Application Rate: 0.06 to 0.5 lbs ai/acre.

Formulation	per/acre
Clearcast (1 S)	8 to 64 oz/acre

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage, stems, or roots. Can be applied pre- or postemergence, to plant or soil.

Imazamox binds to and inactivates the enzyme acetolactase synthase (ALS), preventing synthesis of essential amino acids. Affected plants cease growth quickly, but complete control of treated plants may take several weeks.

Sites: uplands, non-tidal wetlands where surface water is not present, non-irrigation ditchbanks, and ditch bottoms where only isolated puddles of surface water occur, and aquatic sites.

Uses: herbaceous weed control in terrestrial and aquatic settings.

Notes: Marketed primarily, at least initially, as an aquatic herbicide. Currently Clearcast shows promise against phragmites and reed canarygrass. Its aquatic labeling would make it a useful tool in riparian settings against species such as mile-a-minute, Japanese stiltgrass, or Japanese hops.

DMA 4 IVM
(*2,4-D*) **Producer: Dow AgroSciences**

Application Rate: 0.24 to 7.6 lbs ae/acre.

Formulation	per/acre
DMA 4 IVM (3.8 S)	8 oz to 2 gallons
2,4-D LV 4 Ester (3.8 E)	1 qt to 1 gallon
2,4-D LV 6 Ester (5.5 E)	21 oz to 6 pts

2,4-D products are offered by many manufacturers. The 3.8 S formulation is the most common. Ester formulations provide better penetration of leaf cuticle but are more volatile. The ‘low volatile’ (LV) designation simply means the ester used is less volatile than other esters.

Mode of Action: Systemic. Translocates throughout the plant. Entry primarily through foliage, limited uptake by roots. Apply postemergence to actively growing weeds.

2,4-D mimics the activity of the plant hormone auxin. Auxin is involved to a certain extent in most plant growth processes. At herbicidal doses, 2,4-D causes profound disturbances in plant growth, particularly the control, or regulation, of growth. Symptoms of 2,4-D injury are seen most acutely in actively growing tissue, and includes cupping, curling, and rolling of leaves; twisting of stems; and malformed development of plant organs. Onset of injury is rapid, often visible within hours.

Sites: DMA 4 IVM is labeled for terrestrial and aquatic use.

Uses: Postemergence broadleaf weed and brush control, woody plant injection.

Notes: 2,4-D does not injure grasses, and can be used to selectively remove broadleaf weeds. This herbicide is active on all broadleaf plants, but not necessarily lethal. Due to low cost and broad spectrum, 2,4-D can be a useful tank-mix ingredient, but has a limited control spectrum if applied alone. Rapid activity can cause 2,4-D to be antagonistic to other slow-acting herbicides, particularly grass herbicides such as Assure II, Envoy, Fusilade II, Fusion, and Vantage.

Combination Products

BK 800 [4.5 EC] (22% 2,4-D; 22% dichlorprop; 5% dicamba) -Control of broadleaf weeds in turf, and non-crop weed and brush control. Brush applications can be to foliage, cut surface, or basal bark.

Pathway [1.27 S] *(11.2% 2,4-D acid; 3.0% picloram acid) - Ready-to-use formulation for injection and cut surface treatment of undesirable woody plants.*

Patron 170 [3.7 EC] *(22 % dichlorprop, 21% 2,4-D) - Control of broadleaf weeds in turf, and brush using foliar, cut surface, or basal bark treatment.*

Tordon 101 Mixture [2.54 S] *(21.2% 2,4-D; 5.7% picloram) - Control of broadleaf weeds and brush using foliar, broadcast cut stubble, and cut surface applications.*

Vegemec [0.38 EC] *(3.6% prometon, 1.0% 2,4-D) - Non-selective, residual control of vegetation. 2,4-D provides quick knockdown, prometon provides soil activity. Do not use where roots of desirable plants are present.*

Veteran 720 [2.9 S] *(20% 2,4-D; 11% dicamba) - Broadleaf weed control in turf, and non-crop weed and brush control.*

Edict 2 SC
(*pyraflufen-ethyl*) **Producer: Nichino**

Application Rate: 0.013 to 0.031 lb ai/acre

Formulation	per/acre
Edict 2 SC (0.18 SC)	0.7 to 4 oz/acre

Mode of Action: Contact. Edict 2 SC provides selective control of broadleaf weeds

Pyraflufen-ethyl inhibits the enzyme protoporphyrinogen oxidase (PPO), allowing the accumulation of free radicals within the cell, causing membrane damage and cell desiccation.

Sites: Terrestrial sites.

Uses: Postemergence control of broadleaf weeds. Edict 2 SC provides rapid control without antagonizing other broadleaf herbicides.

Notes: Research trials have shown that Edict 2 SC hastens burndown of species such as Japanese knotweed when tank-mixed with 'Vanquish' or 'Garlon 3A'.

Embark 2S IVM
(mefluidide) **Producer: PBI/Gordon**

Application Rate: 0.125 to 1.0 lb ai/acre.

Formulation	per/acre
Embark 2S IVM	8 to 64 oz/acre

Mode of Action: Systemic. Translocates to growing points, but more so in shoots than roots. Entry is through foliage, must be applied postemergence.

The specific action of mefluidide is not known. At the rates used on grasses it stops cell division at growing points, providing growth regulation.

Sites: Terrestrial applications only. Do not use near water.

Uses: Seedhead and vegetative growth inhibition of tall fescue, Kentucky bluegrass, perennial ryegrass, smooth bromegrass, orchardgrass, reed canarygrass, and common Bermuda grass on roadsides, airfields, plant sites, military posts, or ROW.

Notes: In mixed-species stands of turf, results may be variable. For seedhead suppression, must be applied prior to seedhead emergence. Inhibits grass growth only - where broadleaf weeds are present, a broadleaf herbicide should be added. Can be tank-mixed with low rates of Arsenal, Escort, or Telar to broaden the growth regulator effect, though phytotoxicity may increase.

Combination Products:

Stronghold [1.8 S] *(16% mefluidide, 3.9% imazethapyr, 0.1% imazapyr) - Seedhead and/or vegetative growth suppression of bahiagrass, Kentucky bluegrass, orchardgrass, smooth bromegrass, or tall fescue. For use on utility/commercial turf, not residential lawns or manicured grounds.*

Endurance
(*prodiamine*) **Producer: NuFarm**

Application Rate: 0.65 to 1.5 lbs ai/acre

Formulation	per/acre
Endurance 65 WG	1.0 to 2.3 lb/acre

Mode of Action: Localized. Activity usually limited to root tips of germinating seeds. Taken up by roots, must be applied to soil prior to seed germination.

Prodiamine inhibits cell division and differentiation at the growing point of the root. Roots become stubby, thickened, and fail to produce root hairs. Susceptible seedlings usually die before shoot emergence occurs.

Sites: Terrestrial use only. Do not apply near water.

Uses: Preemergence control of seedling grass and selected broadleaf weeds in bareground areas of industrial sites and ROW. Can also be used for preemergence weed control in established perennial and wildflower plantings.

Notes: Controls most annual grasses, some broadleaf species from seed. No activity on established plants. Very low solubility - moves into soil very slowly. Should be applied in advance of germination. Useful for maintaining bare ground near desirable plants.

Envoy Plus
(*clethodim*) **Producer: Valent**

Application Rate: 0.0625 to 0.25 lb ai/acre

Formulation	per/acre
Envoy Plus [0.97 E]	9 to 32 oz/acre

Envoy Plus can be applied up to 64 oz/ac per year, but no more than 32 oz/ac per application.

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage. Must be applied postemergence to target grasses.

Clethodim is an lipid synthesis inhibitor. It binds to, and inactivates an enzyme that is critical to the synthesis of fatty acids. Growth ceases quickly, but susceptible plants may take several weeks to die.

Sites: Terrestrial applications only. Do not apply near water.

Uses: Selective control of annual and perennial grasses in non-crop areas. Envoy can also be used for selective control of grasses in ornamentals.

Notes: When treating in ornamentals with Envoy Plus, use a non-ionic surfactant to reduce the potential for injury. Where no ornamentals are present, use a crop oil concentrate with Envoy Plus. Like most other selective grass herbicides, *clethodim* is not effective on fineleaf fescues. Grass control may be reduced if *clethodim* is tank-mixed with other herbicides.

Escort XP

(*metsulfuron methyl*) **Producer: DuPont**

Application Rate: 0.012 to 0.15 lb ai/acre

Formulation	per/acre
Escort XP (60 DG)	0.33 to 4.0 oz/acre

Metsulfuron methyl is available from several manufacturers as a 60 percent dry formulation.

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage, or roots. Generally applied postemergence, but does have preemergence activity.

Metsulfuron is an amino acid synthesis inhibitor that binds to and inactivates the enzyme acetolactase synthase (ALS), preventing synthesis of essential amino acids. Affected plants cease growth quickly, but complete control of treated plants may take several weeks.

Sites: Terrestrial applications. Escort XP can be applied to floodplains, terrestrial areas of deltas, and drained areas of low-lying areas where there may be isolated puddles.

Uses: General weed and brush control in non-crop areas and unimproved turf, growth and seedhead suppression of unimproved cool-season grasses such as tall fescue and Kentucky bluegrass, spot concentrate soil applications for control of multiflora rose, and weed control in established and seedling native grasses.

Notes: Escort XP is primarily active on broadleaf species, and especially active on multiflora rose. It will cause visible injury to some grasses, which is why it can be used at low rates to suppress grass growth and seedheads. If grass is to be seeded where Escort XP has been applied, there is a one to four month replant interval after treatment, depending on grass species.

Combination Products:

Lineage Clearstand [73 DG] (*63% imazapyr, 10% metsulfuron methyl*)

Lineage HWC [74 DG] (*38% imazapyr, 28% sulfometuron methyl, 8% metsulfuron methyl*)

Lineage Prep [74 DG] (*55% imazapyr, 15% sulfometuron methyl, 4% metsulfuron methyl) The Lineage product line is for use in conifer forestry for site-prep or herbaceous weed control, and in non-crop sites for brush control, herbaceous weed control, total vegetation control, and selective weeding in some utility turf settings.*

Oust Extra [71 DG] (*56% sulfometuron methyl, 15% metsulfuron methyl) – Herbaceous weed control and site prep in conifer forestry; and herbaceous weed control and selective weed control in certain utility turf settings.*

Finale

(*glufosinate ammonium*) **Producer: Bayer**

Application Rate: 0.5 to 1.5 lb ai/acre

Formulation	per/acre
Finale (1.0 S)	2 to 6 qt/acre

Mode of Action: Limited systematic activity. Uptake is strictly through foliage. Although some perennial species may be susceptible, this material should be regarded as a contact herbicide. Applications must be postemergence.

Glufosinate inhibits the activity of the enzyme glutamine synthetase, disrupting nitrogen metabolism, leading eventually to formation of free radicals that damage cell membranes.

Sites: Terrestrial use only. Do not apply near water.

Uses: Non-selective, postemergence weed control in non-crop areas.

Notes: Finale will provide effective control of seedling weeds. Perennial weeds will usually regrow from underground propagules. There is no soil activity. Provides a measure of selectivity for annual weed control in established vegetation, as perennial vegetation will recover from the application.

Fusilade II

(*fluazifop P-butyl*) **Producer: Syngenta**

Application Rate: 0.25 to 0.38 lb ai/acre

Formulation	per/acre
Fusilade II 2 EC	16 to 24 oz/acre
Ornamec 0.5 EC	64 to 96 oz/acre

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage. Must be applied postemergence to target grasses.

Fluazifop P-butyl is an lipid synthesis inhibitor. It binds to, and inactivates an enzyme that is critical to the synthesis of fatty acids. Growth ceases quickly, but susceptible plants may take several weeks to die.

Sites: Terrestrial applications only. Do not apply near water.

Uses: Selective control of grasses in non-crop areas and ornamental plantings.

Notes: Control of annual grasses is more effective when they are only a few inches tall. Like most other selective grass herbicides, fluazifop P-butyl is not effective on fineleaf fescues. The label recommends applying other herbicides 5 days prior to, or after the application of Fusilade II, to avoid herbicide antagonism and resulting loss of control.

Combination Products

Fusion [2.56 E] *(24% fluazifop-P-butyl, 7% fenoxaprop-P-ethyl) – Control of annual grasses and Johnsongrass on roadsides. Use for selective grass control in common Bermudagrass, fineleaf fescues, perennial ryegrass, smooth brome, and tall fescue.*

Gallery 75 DF

(*isoxaben*) **Producer: Dow AgroSciences**

Application Rate: 0.5 to 1.0 lb ai/acre.

Formulation	per/acre
Gallery 75 DF	0.66 to 1.33 lb/acre

Mode of Action: Limited systemic activity. Will translocate from roots to leaves. Very little entry through foliage. Isoxaben provides preemergence control of broadleaf weeds.

Isoxaben inhibits the formation of the plant cell wall. Affected tissue is malformed, roots are stubby and short with few root hairs. Susceptible plants are usually killed prior to emergence.

Sites: Terrestrial uses only. Do not use near water.

Uses: In non-crop settings, Gallery can be used to maintain bare ground near desirable plantings, and in turf, ornamentals, and nursery areas.

Notes: Gallery is more effective on broadleaf weeds than grasses. Gallery should be combined with preemergence herbicides effective on grasses such as Endurance, Pendulum, Pennant, or Surflan to provide broad-spectrum preemergence control near desirable plantings.

Combination Products

Snapshot 2.5 TG *(2.0% trifluralin, 0.5% isoxaben) Preemergence control of annual broadleaf and grass weeds. Best results occur if 0.5 inch of rainfall occurs within 3 days.*

Garlon 3A

(*triclopyr*) **Producer: Dow AgroSciences**

Application Rate: 0.75 to 9.0 lb ae/acre

Formulation	per/acre
Garlon 3A (3 S)	1 qt to 3 gal/acre
Garlon 4 Ultra (4 EC)	1 qt to 2 gal/acre
Pathfinder II	ready-to-use

Triclopyr products are available from several manufacturers in the 3 S and 4 E formulations.

Mode of Action: Systemic. Translocates throughout the plant. Readily taken up by foliage. Garlon 4 and Pathfinder II formulations penetrate bark.

Triclopyr acts on the plant in a manner similar to 2,4-D, mimicking the activity of the plant hormone auxin. Regulation of growth is severely disturbed and actively growing tissue becomes malformed, with symptoms such as leaf curling and stem twisting. Triclopyr is only active on broadleaf species.

Sites: Upland sites, non-irrigation ditchbanks, and seasonally dry wetlands, floodplains, deltas, transition areas between uplands and wetlands, and aquatic sites.

Uses: Selective broadleaf weed control, control of brush with foliar, basal bark, and cut surface and injection treatments, and control of emergent aquatic weeds.

Notes: Triclopyr has very little soil activity, and must be applied directly to the target plant. Dormant season basal bark applications are very effective on treated stems, but have limited effect on the root system of suckering tree species such as sumac, tree-of-heaven, black locust, or sassafras.

Combination Products

Milestone VM Plus [1.1 S] *(12% triclopyr, 1.1% aminopyralid) – Selective control of broadleaf* *weeds in utility turf, broadleaf weed and brush control in non-crop sites.*

Gramoxone Inteon
(*paraquat*) **Producer: Syngenta**

Application Rate: 0.62 to 0.94 lb ai/acre

Formulation	per/acre
Gramoxone Inteon (2 S)	2.5 to 4 pints/acre

Mode of Action: Contact. Gramoxone Inteon causes rapid injury to treated foliage and herbaceous tissue. Postemergence activity only.

Paraquat disrupts electron transfer in Photosystem I, causing the formation of free radicals within the plant cell, damaging the cell membrane, leading to leakage of cell contents and desiccation.

Sites: Terrestrial use only. Do not apply near water.

Uses: Rapid, non-selective burndown of weeds in non-crop areas.

Notes: Gramoxone Inteon provides control of top growth of most weeds in 1 to 2 days. Perennials and well-established annuals usually regrow. Tank mixing a broad-spectrum residual herbicide is necessary to control perennial weeds. Paraquat is tightly bound to soil particles, so there is no soil activity. Due to its rapid activity, Gramoxone is antagonistic to other foliar-applied systemic herbicides. Tank mix partners should be limited to soil active herbicides.

Hyvar X
(*bromacil*) **Producer: DuPont**

Application Rate: 2.4 to 12 lb ai/acre

Formulation	per/acre
Hyvar X (80 W)	2 to 15 lbs/acre
Hyvar XL (2 S)	0.75 to 12 gal/acre

Mode of Action: Systemic. Bromacil moves upwards in the plant via the xylem, following the water stream from roots to leaves. Uptake is primarily through the roots.

Bromacil is a photosynthetic inhibitor. Electron flow is interrupted during the conversion of light energy to high-energy chemical compounds. This causes formation of free radicals causing protein and lipid damage, leading to cell membrane damage and desiccation.

Sites: Terrestrial applications only. Do not use near water

Uses: Non-selective control of weeds and brush with pre- or postemergence applications. Can be broadcast, or applied as a spot concentrate to brush. Hyvar X-L can be used to prevent weed growth under pavement and pond liners.

Notes: Bromacil is a broad spectrum, residual herbicide with long-term soil residual. Applications should not be made near the roots of desirable plants. Onset of visible effects from postemergence treatments to established vegetation will be slow. For quicker results, a burn-down herbicide should be added to the spray mixture.

Combination Products - all products listed below are used for total vegetation control in non-crop and industrial sites.

DiBro 2+2 [4 G] *(2% bromacil, 2% diuron)*

DiBro 4+2 [6 G] *(4% bromacil, 2% diuron)*

Krovar I DF [80 DF] *(40% bromacil, 40% diuron*

Weed Blast [8 G] *(4% bromacil, 4% diuron*

Karmex XP
(*diuron*) **Producer: DuPont**

Application Rate: 4 to 12 lb ai/acre

Formulation	per/acre
Direx 4L	1 to 3 gal/acre
Karmex XP (80 DG)	5 to 15 lb/acre

Diuron is available from many manufacturers as an 80 percent dry or 4 L formulation.

Mode of Action: Systemic. Diuron moves upwards in the plant through the xylem, following the water stream from root to leaves. Uptake is through both roots and foliage.

Diuron is a photosynthetic inhibitor. Electron flow is interrupted during the conversion of light energy to high-energy chemical compounds. This causes formation of free radicals causing protein and lipid damage, leading to cell membrane damage and desiccation.

Sites: Uplands, and ditches when water is not present. Irrigation ditches can only be treated in the non-crop season.

Uses: Typically used in tank mixes to provide total vegetation control.

Notes: Diuron is used primarily as a preemergence herbicide, although there is postemergence activity on seedlings. Where perennial vegetation is present, tank mixes with broad-spectrum residual herbicides such as bromacil, imazapyr, or sulfometuron methyl are needed.

Combination Products - all products listed below are used for total vegetation control in non-crop and industrial sites.

DiBro 2+2 [4 G] *(2% bromacil, 2% diuron)*

DiBro 4+2 [6 G] *(4% bromacil, 2% diuron)*

Krovar I DF [80 DF] *(40% bromacil, 40% diuron*

Sahara DG *(62% diuron, 8% imazapyr*

SpraKil S-13 [4 G] *(3% diuron, 1% tebuthiuron)*

SpraKil S-26 [8 G] *(6% diuron, 2% tebuthiuron*

TopSite 2.5 G *(2% diuron, 0.5% imazapyr)*

Weed Blast [8 G] *(4% bromacil, 4% diuron*

Krenite S

(*fosamine ammonium*) **Producer: DuPont**

Application Rate: 6 to 24 lb ai/acre

Formulation	per/acre
Krenite S (4 S)	1.5 to 6 gal/acre

Mode of Action: Systemic. Although fosamine will translocate throughout plant, best results occur when entire target plant is treated. Localized applications result in side trimming.

The mechanism of fosamine activity is not known. When fully expanded leaves are treated late in the growing season, symptoms are often limited to partial discoloration, which is often masked by fall coloration of surrounding vegetation. Treated branches of susceptible species do not leaf out the following season, though scraping the bark reveals the tissue to be alive.

Sites: In addition to upland sites, Krenite can be applied to seasonally dry wetlands, or low-lying areas with scattered puddling.

Uses: Krenite is primarily a brush control agent. It is particularly useful for 'low-profile' applications, as late season applications produce limited symptoms. Susceptible brush does not leaf out the following spring, or the leaves are stunted and clustered.

Notes: Herbicidal effects are more pronounced on the treated part of the plant. For this reason, Krenite is often used a side-trim agent at the edge of ROW. When herbicides such as Arsenal are tank mixed with Krenite, the species spectrum is broadened, but the side-trim effect is diminished and damage to untreated portions of the plant are more likely. Krenite is not selective, and will damage contacted herbaceous plants.

Milestone VM

(*aminopyralid*) **Producer: Dow AgroSciences**

Application Rate: 0.047 to 0.11 lb ae/acre

Formulation	per/acre
Milestone VM (2 S)	3 to 7 oz/acre

Mode of Action: Systemic. Translocates throughout the plant. Readily taken up by foliage.

Aminopyralid acts on the plant in a manner similar to 2,4-D, mimicking the activit of the plant hormone auxin. Regulation of growth is severely disturbed and actively growing tissue becomes malformed, with symptoms such as leaf curling and stem twisting. Aminopyralid is only active on broadleaf species.

Sites: Upland sites, non-irrigation ditchbanks.

Uses: Selective broadleaf weed control, control of brush with foliar treatments.

Notes: Milestone VM is very active against plants in the Aster family, such as Canada thistle; and legumes. Conversely, it is weak against plants in the mustard family, and should be tank-mixed with another herbicide for broad-spectrum broadleaf weed control.

Combination Products

Milestone VM Plus [1.1 S] *(12% triclopyr, 1.1% aminopyralid) – Selective control of broadleaf weeds in utility turf, broadleaf weed and brush control in non-crop sites.*

Oust XP

(*sulfometuron methyl*) **Producer: DuPont**

Application Rate: 0.047 to 0.38 lb ai/acre

Formulation	per/acre
Oust XP (75 DG)	1 to 8 oz/acre

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage or roots. Can be applied pre- or postemergence, to plant or soil.

Sulfometuron is an amino acid synthesis inhibitor that binds to and inactivates the enzyme acetolactase synthase (ALS), preventing synthesis of essential amino acids. Affected plants cease growth quickly, but complete control of treated plants may take several weeks.

Sites: Do not apply near open water.

Uses: Selective weed control in, and growth suppression of Bermudagrass, bahiagrass, centipedegrass, smooth brome, and crested wheatgrass;

non-selective weed control on non-cropland sites; and weed control under pavement.

Notes: For selective weed control, do not add additional surfactant. For non-selective weed after weeds have emerged or resumed active growth, surfactant is recommended. Biotypes of kochia, Russian thistle, and prickly lettuce have been confirmed to be resistant to sulfometuron and other ALS-inhibitors. When targeting these species, include herbicides with a different mode of action in the tank mix (see *Herbicide Resistance* section).

Combination Products:

Landmark XP [75 DG] (*50% sulfometuron methyl, 25% chlorsulfuron) – Herbaceous weed control in non-crop sites, selective weed control in certain utility turfgrasses.*

Lineage HWC [74 DG] (*38% imazapyr, 28% sulfometuron methyl, 8% metsulfuron methyl*)

Lineage Prep [74 DG] (*55% imazapyr, 15% sulfometuron methyl, 4% metsulfuron methyl) The Lineage product line is for use in conifer forestry for site-prep or herbaceous weed control, and in non-crop sites for brush control, herbaceous weed control, total vegetation control, and selective weeding in some utility turf settings.*

Oust Extra [71 DG] (*56% sulfometuron methyl, 15% metsulfuron methyl) – Herbaceous weed control and site prep in conifer forestry; and herbaceous weed control and selective weed control in certain utility turf settings.*

Throttle XP [75 DG] (*48% sulfentrazone, 18% sulfometuron methyl, 9% chlorsulfuron) – Herbaceous weed control in non-crop sites.*

Westar [75 DG] (*69% hexazinone, 6% sulfometuron methyl) – Herbaceous weed control in non-crop settings.*

Payload
(*flumioxazin*) **Producer: Valent**

Application Rate: 0.26 to 0.38 lb ai/acre

Formulation	per/acre
Payload (51 DG)	8 to 12 oz/acre

Mode of Action: Contact. Can be applied preemergence to soil or early postemergence.

Flumioxazin inhibits the enzyme protoporphyrinogen oxidase (PPO), allowing the accumulation of free radicals within the cell, causing membrane damage and cell desiccation.

Sites: Terrestrial sites.

Uses: Maintaining bare ground in non-crop sites. Payload is effective against kochia, and can be used as an alternative to diuron as part of a resistance management program.

Notes: Add a surfactant when weeds have emerged.

Pendulum Aquacap
(*pendimethalin*) **Producer: BASF**

Application Rate: 2 to 4 lb ai/acre

Formulation	per/acre
Pendulum 2G	100 to 200 lb/acre
Pendulum 3.3 EC	2.4 to 4.8 qt/acre
Pendulum Aquacap (3.8 ME)	2.1 to 4.3 qt/acre

Mode of Action: Localized. Activity usually limited to root tips. Taken up by roots, must be applied to soil prior to seed germination.

Pendimethalin inhibits cell division and differentiation at the growing point of the root. Roots become stubby, thickened, and fail to produce root hairs. Susceptible seedlings usually die before shoot emergence occurs.

Sites: Terrestrial use only. Do not apply near water.

Uses: Preemergence control of seedling grass and selected broadleaf weeds in bare ground areas of industrial sites and rights-of-way. Can also be used for preemergence weed control in forests, established perennial and wildflower plantings.

Notes: Controls most annual grasses, some broadleaf species from seed. No activity on established plants. Very low solubility - moves into soil very slowly. Should be applied in advance of germination. Useful for maintaining bare ground near desirable plants, and providing selective preemergence control Japanese stiltgrass or mile-a-minute in natural areas.

Pennant Magnum
(*S-metolachlor*) **Producer: Syngenta**

Application Rate: 1.2 to 2.5 lb ai/acre

Formulation	per/acre
Pennant Magnum (7.6 EC)	1.3 to 2.6 pints/acre

Mode of Action: Localized. Taken up by roots and shoots of germinating weeds. Susceptible species fail to emerge. Must be applied preemergence.

The exact mechanism of activity of metolachlor and related herbicides is not known. At some level, it interferes with the production of several key plant compounds.

Sites: Terrestrial use only.

Uses: Preemergence weed control in many established ornamental species, and preemergent weed control in warm-season turf.

Notes: Metolachlor is more effective on grasses than broadleaves. Metolachlor is also unique in its ability to provide selective preemergence control of established yellow nutsedge. Pennant can be used in sensitive areas where ornamental plants such as screen plantings are grown near industrial sites.

Plateau
(*imazapic*) **Producer: BASF**

Application Rate: 0.031 to 0.19 lb ai/acre

Formulation	per/acre
Plateau (2 S)	2 to 12 oz/acre

The 2 S formulation of imazapic is available from several manufacturers.

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage or roots. Can be applied pre- or postemergence, to plant or soil.

Imazapic is an amino acid synthesis inhibitor that binds to and inactivates the enzyme acetolactase synthase (ALS), preventing synthesis of essential amino acids. Affected plants cease growth quickly, but complete control of treated plants may take several weeks.

Sites: Terrestrial use only.

Uses: Selective weed control in certain established grasses, crownvetch, and wildflowers; weed control in seedings of native prairie grasses and wildflowers; seedhead and growth suppression of certain grasses; and maintenance of bare ground on industrial and similar sites.

Notes: Selectivity is both a function of species and rate. Crownvetch and Bermudagrass can tolerate the highest application rate, while tall fescue is significantly suppressed at very low rates, and killed at the high rate. As with Arsenal, which is in the same chemical family, legumes tend to be tolerant. Plateau provides control of many annual grasses and broadleaf weeds during establishment of native grasses such a big bluestem, little bluestem, and Indiangrass; but is quite injurious to switchgrass. Biotypes of species such as kochia, Russian thistle, and prickly lettuce have been identified for herbicides such as Arsenal, Escort, Oust, and Telar; which have the same mode of action as Plateau. Practice resistance management when using Plateau or similar herbicides (see *Herbicide Resistance* section).

Combination Products:

Journey [2.25 S] *(22% glyphosate,8% imazapic) – Preemergence weed control in tolerant native plantings, non-selective herbaceous weed control, seedhead suppression of certain utility grasses.*

Portfolio
(*sulfentrazone*) **Producer: Wilbur-Ellis**

Application Rate: 0.25 to 0.38 lb ai/acre

Formulation	per/acre
Portfolio (4 L)	8 to 12 oz/acre

Mode of Action: Contact. Can be applied preemergence to soil or early postemergence.

Sulfentrazone inhibits the enzyme protoporphyrinogen oxidase (PPO), allowing the accumulation of free radicals within the cell, causing membrane damage and cell desiccation.

Sites: Terrestrial sites.

Uses: Maintaining bare ground in non-crop sites. Portfolio is effective against kochia, and can be used as an alternative to diuron as part of a resistance management program.

Notes: Most use of sulfentrazone will likely be as the combination product 'Throttle XP', which is a combination of sulfentrazone plus 'Landmark XP'.

Combination Products:

Throttle XP [75 DG] (*48% sulfentrazone, 18% sulfometuron methyl, 9% chlorsulfuron) – Herbaceous weed control in non-crop sites.*

Pramitol 25 E
(*prometon*) **Producer: UAP**

Application Rate: 8 to 20 lb ai/acre

Formulation	per/acre
Pramitol 25 E (2 E)	4 to 10 gal/acre
Pramitol 4 SC	1 to 3 gal/acre

Several manufacturers produce prometon under the name of 'Pramitol 25 E'.

Mode of Action: Systemic. Prometon moves upwards in the plant after being absorbed by the roots. Downward movement after foliar absorption is limited.

Prometon is a photosynthetic inhibitor. Electron flow is interrupted during the conversion of light energy to high-energy chemical compounds. This causes formation of free radicals causing protein and lipid damage, leading to cell membrane damage and desiccation.

Sites: Terrestrial use only. Do not apply near water.

Uses: Pre- or postmergent non-selective weed control on non-cropland sites.

Notes: Pramitol has considerable soil activity, and should not be used where the roots of desirable plants extend. For quicker control from postemergence applications, tank mix a burn-down herbicide.

Combination Products - all products listed below are used for total vegetation control on non-crop and industrial sites.

Pramitol 5 PS [96 P] *(50% sodium metaborate, 40% sodium chlorate, 5% prometon, 0.75% simazine)*

Vegemec [0.38 EC] *(3.6% prometon, 1.0% 2,4-D)*

Predict
(*norflurazon*) **Producer: Syngenta**

Application Rate: 2 to 4 lb ai/acre

Formulation	per/acre
Predict (80 DF)	2.5 to 5 lb/acre

Mode of Action: Systemic. Moves readily upwards after root absorption. Applications must be made prior to germination. Affected seedlings are often white.

Norflurazon inhibits the synthesis of carotenoids, which are accessory pigments that aid the function of chlorophyll. In the absence of carotenoids, free radicals form, causing destruction of chlorophyll and cell membranes.

Sites: Terrestrial uses only. Do not apply near water.

Uses: Preemergence control of certain grass and broadleaf weeds from seed.

Notes: Can be used as a preemergence ingredient in bareground applications. Is not labeled for use in plantings, therefore cannot be used for weed control in areas such as screen plantings adjacent to bareground areas.

Quicksilver T&O
(*carfentrazone-ethyl*) **Producer: FMC**

Application Rate: 0.013 to 0.031 lb ai/acre

Formulation	per/acre
Quicksilver T&O (1.9 E)	0.9 to 2.1 oz/acre

Mode of Action: Contact. Quicksilver provides selective control of broadleaf weeds

Sulfentrazone inhibits the enzyme protoporphyrinogen oxidase (PPO), allowing the accumulation of free radicals within the cell, causing membrane damage and cell desiccation.

Sites: Terrestrial sites.

Uses: Postemergence control of broadleaf weeds. Quicksilver provides rapid control without antagonizing other broadleaf herbicides.

Notes: Carfentrazone-ethyl is mixed with other broadleaf herbicides for rapid weed control in turf. On some species of weeds however, carfentrazone-ethyl does antagonize the activity of glyphosate.

Reward
(*diquat*) **Producer: Syngenta**

Application Rate: 0.25 to 0.5 lb ai/acre

Formulation	per/acre
Reward	1 to 2 pts/acre

Mode of Action: Contact. Reward causes rapid injury to treated foliage and herbaceous tissue. Postemergence activity only.

Diquat inhibits electron transport in Photosystem I, causing the formation of free radicals within the plant cell, damaging the cell membrane, leading to leakage of cell contents and desiccation.

Sites: When making terrestrial applications, do not apply near water. Reward is labeled for certain aquatic applications.

Uses: Non-selective, postemergence control of the top growth of emerged weeds. Well-established annuals, and biennials and perennials will likely regrow.

Notes: Diquat is very fast acting - complete burndown is usually seen within two to three days. Because of this rapid activity, Reward products should not be tank mixed with slower acting herbicides - the plant tissue will be desiccated before the systemic herbicide can translocate.

Combination Products

QuikPro [76 SP] (*73% glyphosate, 3% diquat) – Non-selective burndown in non-crop and landscape sites.*

Roundup Pro
(*glyphosate*) **Producer: Monsanto**

Application Rate: 0.094 to 7.5 lb ae/acre

Formulation	per/acre
Roundup Pro (3 S)	4 oz to 10 qts/acre
Roundup Pro Concentrate (3.7 S)	
Roundup Pro Dry (65 SP)	2.4 oz to 12 lb/acre
Roundup Pro Max (4.5 S)	
Rodeo (4 S)	3 oz to 7.5 pts/acre
Glyphomate 41 (2.8 S)	

Glyphosate is the most widely available herbicide in the world. There are seemingly countless products available from seemingly countless manufacturers. The most common products are partial-load and surfactant-loaded 3 S formulations, and the surfactant-free 4 S formulations. The original 'Roundup' is no longer available, at least by name, but 3 S formulations with a 'Warning' signal word are likely the identical formulation.

Mode of Action: Systemic. Moves throughout the plant after uptake through foliage or stems. There is no soil activity. Must be applied to actively growing herbaceous plants, or freshly exposed cambial tissue of woody plants.

Glyphosate is an amino acid synthesis inhibitor. It inactivates an enzyme that is critical to the synthesis of three amino acids. Plant growth ceases quickly, but symptoms may not begin to show for several days. Complete control may take two weeks.

Sites: Terrestrial and aquatic sites. Aquatic-labeled products have terrestrial site labeling as well.

Uses: Weed suppression ('Chemical Mowing'), seedhead and vegetation suppression of certain perennial turfgrasses, selective weed control in certain perennial turfgrasses, pre-plant weed control, and non-selective control of herbaceous and woody plants in non-crop areas.

Notes: Glyphosate is active to some extent on all plants. Selectivity is a function of the species and the rate applied. Glyphosate is unique in that it is non-selective, systemic, but has no soil activity. Other non-selective, non-residual herbicides may provide quicker control of top growth, but none have the same effectiveness on a broad spectrum of perennial species. Glyphosate is available as surfactant-loaded, partial surfactant load, and surfactant-free formulations.

Formulations with the 'old' surfactant – polyoxyethyleneamine (POEA) – are lethal to many aquatic organisms. Use only aquatic-labeled products near water. Do not mix glyphosate solutions in galvanized or unlined steel tanks, as hydrogen gas, which is extremely explosive, is released. Use stainless steel, or non-metallic tanks only.

Combination Products

Journey [2.25 S] *(22% glyphosate,8% imazapic) – Preemergence weed control in tolerant native plantings, non-selective herbaceous weed control, seedhead suppression of certain utility grasses.*

QuikPro [76 SP] (*73% glyphosate, 3% diquat) – Non-selective burndown in non-crop and landscape sites.*

Scythe
(*pelargonic acid*) **Producer: Dow AgroSciences**

Application Rate: 9.4 to 84 lb ai/acre

Formulation	per/acre
Scythe (4.2 EC)	2.25 to 20 gal/acre

Mode of Action: Contact. Plant injury may be visible in minutes. Strictly postemergence - there is no soil activity.

Once pelargonic acid penetrates the waxy cuticle surrounding the leaf, leakage of cell contents occurs rapidly.

Sites: Terrestrial use only.

Uses: Non-selective burn-down of herbaceous weeds.

Notes: Scythe is effective on seedling weeds. Well-established weeds will need to be retreated, or the spray mixture will need to include a broad spectrum, soil-active herbicide. The use of Scythe as a synergist at rates of 1 to 3 percent, by volume, in mixtures with glyphosate has been patented. The user should be aware this effect is limited to certain weed species. Scythe at the same concentration will antagonize the activity of glyphosate on perennial species, including tall fescue.

Spike 80 DF
(*tebuthiuron*) **Producer: Dow AgroSciences**

Application Rate: 1 to 6 lb ai/acre

Formulation	per/acre
Spike 20 P	5 to 30 lb/acre
Spike 80 DF	1.25 to 5 lb/acre
SpraKil S-5 (5 G)	40 to 120 lb/acre

Mode of Action: Systemic. Tebuthiuron moves upwards in the plant via the xylem, following the water stream from root to leaves. Uptake is primarily through the roots.

Tebuthiuron is a potent photosynthetic inhibitor. Electron flow is interrupted during the conversion of light energy to high-energy chemical compounds. This causes formation of free radicals causing protein and lipid damage, leading to cell membrane damage and desiccation.

Sites: Terrestrial use only.

Uses: Long term total vegetation control, spot applications to low density brush.

Notes: Spike has an extremely long half-life in the soil - about 360 days. Control of target plants is largely guaranteed, but treated areas may not support vegetation until the second growing season after application. Because of its potency and long-term soil activity, it is imperative that applicators be certain the roots of nearby desirable trees do not extend into the treated area.

Combination Products - all products listed below are used for total vegetation control on non-crop and industrial sites.

SpraKil S-13 [4 G] *(3% diuron, 1% tebuthiuron)*

SpraKil S-26 [8 G] *(6% diuron, 2% tebuthiuron)*

Surflan A.S.

(*oryzalin*) **Producer: United Phosphorous**

Application Rate: 2 to 6 lb ai/acre

Formulation	per/acre
Surflan A.S. (4 L)	2 to 6 qts/acre
Surflan WDG (85%)	2.4 to 7.1 lb/acre

Mode of Action: Localized. Activity usually limited to root tips. Taken up by roots, must be applied to soil prior to seed germination.

Oryzalin inhibits cell division and differentiation at the growing point of the root. Roots become stubby, thickened, and fail to produce root hairs. Susceptible seedlings usually die before shoot emergence occurs.

Sites: Terrestrial use only. Do not apply near water.

Uses: Preemergence control of seedling grass and selected broadleaf weeds in bare ground areas of industrial sites and ROW. Can also be used for preemergence weed control in landscape areas.

Notes: Controls most annual grasses, some broadleaf species from seed. No activity on established plants. Very low solubility - moves into soil very slowly. Should be applied in advance of germination. Useful for maintaining bare ground near desirable plantings that may border industrial sites such as screen plantings around electrical sub-stations.

Combination Products

XL 2G *(1% benefin, 1% oryzalin) - Preemergence control of most grasses and many broadleaf weeds from seed.*

Telar XP

(*chlorsulfuron*) **Producer: DuPont**

Application Rate: 0.012 to 0.14 lb ai/acre

Formulation	per/acre
Telar XP (75 DG)	0.25 to 3 oz/acre

Mode of Action: Systemic. Translocates throughout the plant. Entry through foliage, or roots. Generally applied postemergence, but does have preemergence activity.

Chlorsulfuron is an amino acid synthesis inhibitor that binds to and inactivates the enzyme acetolactase synthase (ALS), preventing synthesis of essential amino acids. Affected plants cease growth quickly, but complete control of treated plants may take several weeks.

Sites: Terrestrial applications.

Uses: General weed control in non-crop areas and unimproved turf, and growth and seedhead suppression of unimproved cool-season grasses such as tall fescue and Kentucky bluegrass.

Notes: Telar is primarily active on broadleaf species. It will cause visible injury to some grasses, which is why it can be used at low rates to suppress grass growth and seedheads. If grass is to be seeded where Telar has been applied, there is a one to six month replant interval after treatment, depending on grass species and application rate.

Combination Products

Landmark XP [75 DG] (*50% sulfometuron methyl, 25% chlorsulfuron) – Herbaceous weed control in non-crop sites, selective weed control in certain utility turfgrasses.*

Throttle XP [75 DG] (*48% sulfentrazone, 18% sulfometuron methyl, 9% chlorsulfuron) – Herbaceous weed control in non-crop sites.*

Tordon K

(*picloram*) **Producer: Dow AgroSciences**

Application Rate: 0.12 to 1.0 lb ae/acre

Formulation	per/acre
Tordon K (2 S)	8 oz to 2 qt/acre

Mode of Action: Systemic. Translocates throughout the plant. Readily taken up by foliage and roots.

Picloram acts on the plant in a manner similar to 2,4-D, although the specific site of its activity is not known. Regulation of growth is severely disturbed and actively growing tissue becomes malformed, with symptoms such as leaf curling and stem twisting. Picloram is only active on broadleaf species.

Sites: Terrestrial applications. Should not be used where conditions favor off-site movement due to leaching or run-off.

Uses: Selective broadleaf weed control in grasses, control of brush with foliar, basal bark, cut stubble, and cut surface and injection treatments.

Notes: Picloram is a Restricted Use Product, and has considerable soil activity. It is quite water soluble, and prone to leaching through highly permeable soils, and can be carried away in run-off. Addition of Tordon K to basal bark applications of Garlon 4 will broaden the control spectrum and can reduce resprouting of suckering tree species such as sumac, tree-of-heaven, black locust, or sassafras.

Combination Products

Pathway [1.27 S] *(11.2% 2,4-D acid; 3.0% picloram acid) - Ready-to-use formulation for injection and cut surface treatment of undesirable woody plants. NOT a Restricted Use product.*

Tordon 101 Mixture [2.54 S] *(21.2% 2,4-D; 5.7% picloram) - Apply at 2 to 8 qts/acre for control of broadleaf weeds and brush using foliar, broadcast cut stubble, and cut surface applications. Restricted Use product.*

Transline
(*clopyralid*) **Producer: Dow AgroSciences**

Application Rate: 0.09 to 0.5 lb ae/acre

Formulation	per/acre
Transline (3 S)	4 to 21.3 oz/acre

Mode of Action: Systemic. Translocates throughout the plant. Readily absorbed through foliage.

Clopyralid acts on the plant in a manner similar to 2,4-D, mimicking activity of the plant hormone auxin. Regulation of growth is severely disturbed and actively growing tissue becomes malformed, with symptoms such as leaf curling and stem twisting. Clopyralid is only active on broadleaf species.

Sites: Terrestrial applications only.

Uses: Selective broadleaf weed control in non-crop areas, including certain areas used for livestock grazing.

Notes: Transline is not recommended for use on highly permeable soils with a high water table. Transline tends to be highly active on plants in the Aster family, such as thistles; as well as legumes.

Trifluralin 10 G
(*trifluralin*) **Producer: Loveland Products, Inc.**

Application Rate: 4 to 16 lb ai/acre

Formulation	per/acre
Trifluralin 10 G	40 to 160 lb/acre

Mode of Action: Localized. Activity usually limited to root tips. Taken up by roots, must be applied to soil prior to seed germination.

Trifluralin inhibits cell division and differentiation at the growing point of the root. Roots become stubby, thickened, and fail to produce root hairs. Susceptible seedlings usually die before shoot emergence occurs.

Sites: Terrestrial use only. Do not apply near water.

Uses: Preemergence control of seedling grass and selected broadleaf weeds in bare ground areas of industrial sites and ROW. Can also be used for preemergence weed control in landscape areas, and weed control under pavement.

Notes: Controls most annual grasses, some broadleaf species from seed. No activity on established plants. Very low solubility - moves into soil very slowly. Should be applied in advance of germination. Trifluralin is less stable on the soil surface than similar herbicides such as Endurance, Pendulum, or Surflan, and should be rainfall-incorporated within 3 days of application for best results. Useful for maintaining bare ground near desirable plantings that may border industrial sites such as screen plantings around electrical sub-stations.

Combination Products

Snapshot 2.5 TG *(2.0% trifluralin, 0.5% isoxaben) Preemergence control of annual broadleaf and grass weeds.*

Vanquish
(*dicamba*) **Producer: NuFarm**

Application Rate: 0.25 to 2.0 lb ae/acre

Formulation	per/acre
Vanquish (4 S)	0.5 to 4 pts/acre

Mode of Action: Systemic. Translocates throughout the plant. Readily absorbed through foliage or roots.

Dicamba acts on the plant in a manner similar to 2,4-D, mimicking the activity of the plant hormone auxin. Regulation of growth is severely disturbed and actively growing tissue becomes malformed, with symptoms such as leaf curling and stem twisting. Dicamba is only active on broadleaf species.

Sites: Upland sites and non-irrigation ditchbanks.

Uses: Foliar applications to control broadleaf weeds and brush in non-crop areas, including certain areas used for livestock grazing; and cut-surface and injection treatments for brush control.

Notes: Though dicamba has a short half-life in the soil, it is quite mobile. It should not be used where the roots of desirable trees extend. Vanquish is less volatile than the 'Banvel' formulations of dicamba formerly used in non-crop areas.

Combination Products

BK 800 [4.5 EC] *(21.5% 2,4-D; 21.5% dichlorprop; 5.4% dicamba) - Control of broadleaf weeds in turf, and non-crop weed and brush control. Brush applications can be to foliage, cut surface, or basal bark.*

Overdrive [70 DG] (*50% dicamba, 20% diflufenzopyr) – Selective broadleaf weed control.*

Veteran 720 [2.9 S] *(20% 2,4-D; 11% dicamba) - Broadleaf weed control in turf, and brush control.*

Velpar DF
(*hexazinone*) **Producer: DuPont**

Application Rate: 0.75 to 8 lb ai/acre

Formulation	per/acre
Velpar DF (75 DF)	1 to 10.7 lb/acre
Velpar L (2 S)	3 pt to 4 gal/acre
Velpar ULW (75 SP)	2.3 to 10.7 lb/acre

Mode of Action: Systemic. Hexazinone moves upwards in the plant, following the water stream from root to leaves. Uptake is through roots or foliage.

Hexazinone is a photosynthetic inhibitor. Electron flow is interrupted during the conversion of light energy to high-energy chemical compounds. This causes formation of free radicals causing protein and lipid damage, leading to cell membrane damage and desiccation.

Sites: Terrestrial use only.

Uses: General weed and brush control on non-crop sites, spot applications to low density brush, selective control of Canada thistle in crownvetch, and selective weed control in Bermudagrass and bahiagrass pastures and unimproved turf.

Notes: Most effective applied preemergence or early postemergence. Brush control applications to soils may take several weeks for symptoms to show. Affected trees may defoliate and refoliate before dying. Applications to Canada thistle in crownvetch provide effective control of top-growth, but resprouting will occur later in the season. Velpar ULW is applied as a granule for weed and brush control.

Combination Products

Westar [75 DG] (*69% hexazinone, 6% sulfometuron methyl) – Herbaceous weed control in non-crop settings.*

Vista
(*fluroxypyr*) **Producer: Dow AgroSciences**

Application Rate: 0.12 to 0.25 lb ae/acre

Formulation	per/acre
Vista (1.5 EC)	0.67 to 1.33 pts/acre

Mode of Action: Systemic. Translocates throughout the plant. Readily absorbed through foliage.

Fluroxypyr acts on the plant in a manner similar to 2,4-D, mimicking the activity of the plant hormone auxin. Regulation of growth is severely disturbed and actively growing tissue becomes malformed, with symptoms such as leaf curling and stem twisting. Fluroxypyr is only active on broadleaf species.

Sites: Terrestrial applications, including non-irrigation ditchbanks.

Uses: Selective broadleaf weed control in non-crop areas.

Notes: Vista is quite active on kochia, including biotypes resistant to other herbicides.