Use and Characteristics of Herbicides for Non-crop Weed Control

PENN STATE
Department of Horticulture - College of Agricultural Sciences

Uses and Characteristics of Herbicides for Non-crop Weed Control

Prepared by:

Art Gover
Department of Horticulture
The Pennsylvania State University

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 instructions or directions for use. Directions for use for any pesticide product are contained only in the 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's label, then this document is in error, and the incorrect information must be disregarded (and hopefully brought to the attention of the author).

To the best of the author's knowledge, the information in this document is current as of May, 2000. Although the intent is for this document to be exhaustive, there are surely products that have been omitted through ignorance - not intent. Inclusion or omission of a product in this document does not constitute a recommendation, or lack of a recommendation regarding the use of that product.

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Introduction

The term 'non-cropland' covers a wide range of settings - pretty much any area not supporting food, feed, fiber, forest, or nursery plantings. We can divide non-crop areas into those requiring non-selective control, and those requiring selective control.

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 vegetative cover is desired. In some instances, the intent is to preserve vegetation that was planted, such as turf along a limited-access highway. The alternate scenario is an area where only certain vegetation is undesirable, and is selectively removed from the desirable, or non-problem vegetation. An electric ROW is a common example of this, as trees that could grow to contact the conductors are eliminated, while most shrubs, and herbaceous plants are desirable.

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 inputs.

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

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

Cultural - methods that enhance the growth or vigor of desirable species.

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 rights-of-way 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; and increasing the height and reducing the frequency of mowing of utility turf.

Mechanical

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

Biological

Biological control is the use of other organisms to control pest species. The leaf-feeding beetle *Galerucella* has been introduced into North America to feed on the highly-invasive purple loosestrife (*Lythrum salicaria*). Establishing a competitive groundcover that suppresses undesirable species is another example of biological control.

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. Being selective in our chemical control, we enhance biological 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'. Overapplying herbicides in a bare ground setting increases the possibility of the material moving off-site, causing unanticipated damage.

Method Integration

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

Mowing roadside turf high and infrequently improves turf vigor, 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 biological control 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 regrowth 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. An IVM approach stresses using 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.

An application 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 a 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, a guiding principle of the management program must be-

IVM is a balance between preserving desirable vegetation and controlling undesirable vegetation.

Targets and Thresholds

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 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.

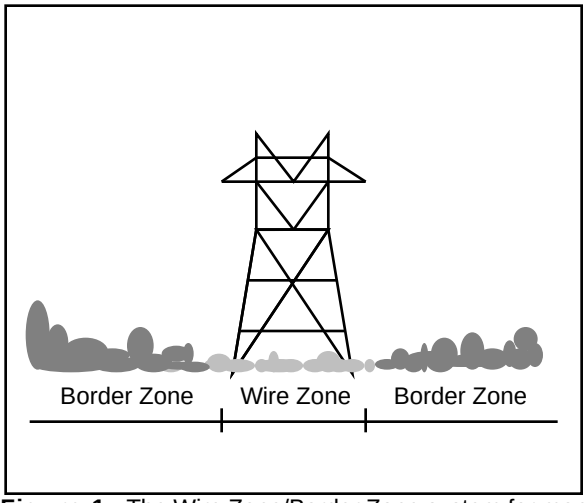

Figure 1: The Wire Zone/Border Zone system for managing transmission ROWs. The Wire Zone, the area directly beneath the conductors, is maintained as herbaceous and very low growing shrubs. This maximizes line clearance and improves movement along the ROW and access to the towers. The Border Zone is composed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

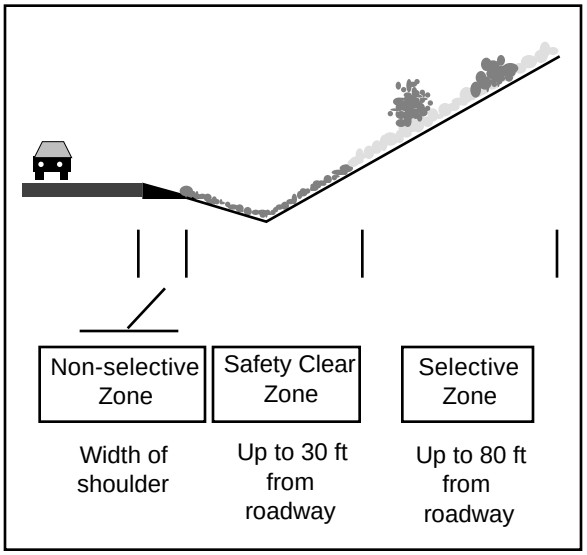

Figure 2: Application of the Management Zone concept to a highway ROW. The Non-selective Zone is kept free of vegetation to facilitate surface drainage from the travel lanes. The Safety Clear Zone is kept free of woody vegetation to allow recovery for vehicles that have left the roadway. The Selective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

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 Use Properties

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. A problem with simpler categorizations such as these is that sometimes a herbicide can fall into both categories. For example, imazapyr has both soil (root uptake) and foliar activity, and can be used pre- or postemergence. Whether an herbicide is selective or not is often dependent on application rate. The term 'Selective' becomes further complicated because we must distinguish between a selective herbicide, and a selective application - a non-selective herbicide can be selectively applied. Additionally, the distinction between contact and systemic activity is not always clear cut.

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 - soil active herbicides that are applied prior to emergence, and act on weeds as they germinate.
Postemergence - herbicides that control weeds after they emerge. They can be foliar and/or soil active.
Selective - an herbicide that does not control all vegetation. It can be used to control one type of plant, while not harming another. Selectivity is not necessarily an inherent chemical character of an herbicide - selectivity can be also be due to application rate, placement, or timing.
Non-selective - an herbicide or herbicide mixture that injures all vegetation.
Contact - an herbicide that injures only the portion of the plant it contacts.
Systemic - an herbicide that moves throughout the plant, able to cause injury away from where it contacted the plant.
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.

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 active state, many herbicides are weak, organic acids. In this acid form, the herbicide is not particularly soluble, nor easy to formulate. To make this acid molecule easier to use, 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: Glypro Plus contains, by weight, 41 percent of the isopropylamine salt of glyphosate. This salt comprises four pounds of each gallon of product. However, each gallon contains only three pounds of the acid, glyphosate. Roundup Pro Dry contains 71 percent, by weight, of the monoammonium salt of glyphosate, or 65 percent, by weight, 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 4.6 pounds of Roundup Pro Dry.

Listed below are examples of available herbicide formulations.

Liquid 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 ai per gallon. Product examples include Arsenal, Roundup Pro, Garlon 3A, and Vanquish.

Emulsifiable Concentrate (EC) - This type of formulation includes emulsifiers which allow oil and water to form a stable mixture. These products cause water to turn white. Typically these formulations feature oil-soluble esters of the active ingredient that are intended to be mixed in water, such as Garlon 4. 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 - the mixture is cloudy. 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. Not common, in fact none of the products listed in this handbook are OS formulations.

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 or Veteran CST (water-based) are examples.

Dry Formulations

Wettable Powder (W, WP) - Finely ground active ingredient is mixed with a clay carrier, that are suspended 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. Spike 80 W is the only non-crop product 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 Dispersable 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, Escort, and Telar.

Soluble Powder (SP) - Unlike a wettable powder, dry flowable, or dispersible granule; a soluble powder *dissolves* in water, leaving a clear mixture. Velpar and Roundup Pro Dry are examples. Concentrations range from 75 to 90 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 SpraKil 26, 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.

Herbicide Application

Due to the many different properties of herbicides, there are many different ways to use them. The following sections will attempt to illustrate the varied ways herbicides can be used in the management of vegetation, by illustrating the concepts of application to soil or plant, selective compared to non-selective, and preemergence compared to postemergence.

Soil Applications

Selective Preemergence

In non-crop settings, this application is most commonly used to control annual weeds in established vegetation, such as landscape plantings or turfgrass. Herbicides that are suitable for this use are typically low in solubility, and stay quite close to the soil surface. These herbicides also do not translocate readily. This allows the established plants to be essentially unaffected while germinating seedlings are injured.

This type of application is very common in row crops such as corn or soybeans. In this setting, the crop is able to germinate and grow either because

the crop species is tolerant to the herbicide, or the germinating crop seed is below the herbicide and its root system does not contact the herbicide until the plant is well established.

Non-selective Preemergence

This application is intended to provide bare ground, or total vegetation control. This can be achieved by applying soil-active herbicides with broad spectrum activity, such as bromacil, hexazinone, imazapyr, prometon, or tebuthiuron. These herbicides will control existing vegetation via root uptake, and they will prevent weeds from establishing from seed.

Another variation of this application is to combine a non-selective postemergence herbicide with preemergence herbicides. The postemergence material controls existing vegetation, and the preemergence herbicides prevent weeds from establishing from seed.

Selective Postemergence

This is not a common approach for soil applications - though it is a very common foliar application.

After brush in a ROW is mechanically cleared, a cut-stubble application of picloram will control the woody plants through root uptake, while grasses will not be affected.

Non-selective Postemergence

At high application rates, broad spectrum residual herbicides with very little foliar uptake such as bromacil, or tebuthiuron will control most vegetation through root uptake, regardless of application timing.

Spot Concentrate

This is a form of non-selective postemergence application, but it is directed to individual plants as either a concentrated spray solution or as dry material. A practical technique for control of scattered brush.

Foliar (and Bark) Applications

Selective Postemergence

A very common application. Most often accomplished with selective herbicides. Examples include control of broadleaf weeds in grasses with herbicides such as 2,4-D, clopyralid, dicamba, picloram, or triclopyr; and control of grass weeds in broadleaf plantings with herbicides such as Assure II, Envoy, Fusilade II, or Vantage.

Selective control can be achieved by application placement. A low volume treatment can be applied to target brush without getting spray material on the non-target surrounding vegetation.

Another method of achieving selectivity is timing of application. Cool-season grasses (e.g. quackgrass, tall fescue) can be controlled in warm-season grasses (e.g. switchgrass, bluestems) with a non-selective herbicide such as Roundup Pro by applying early in the season when cool-season grasses are beginning to grow vigorously but warm-season grasses are still dormant. Another example would be preserving desirable herbaceous plants on a ROW by timing spray applications to occur after the desirable plant has flowered, set seed, and begun to senesce (die back) for the season.

Non-selective Postemergence

Can be achieved by using an herbicide that is active on all vegetation, or by combining herbicides together that become non-selective in combination. A critical element determining herbicide selection is whether or not soil activity is desired. At one extreme, a tank-mix can be assembled that will control existing vegetation through foliar uptake, and leave an active residue in the soil to provide bare ground for the remainder of the growing season. The other extreme would be a pre-plant application with no soil activity, made to control all weeds but leave no residue that would inhibit the subsequent seeding.

Summary

An applicator can tailor an herbicide application to almost any situation due to the wide variation of available herbicides, and the many ways to apply them to target vegetation. Through a careful consideration of the qualities of the application site and vegetation present, and the characteristics of available herbicides, it is possible to use herbicides in a manner that provides control of target species, while preserving desirable vegetation - a fundamental goal of Integrated Vegetation Management.

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'.

Systemic vs. Contact Herbicides

The most general description of mode of action is how much an herbicide moves in a plant after application. *Systemic* herbicides move throughout the plant, or *translocate*, after they enter it. *Contact* herbicides act on the plant at the point where they enter. 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 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 to grow. 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 be actively growing. The source-sink concept helps explain this. Early in the season, the energy driving the growth of plants is from reserves stored the previous season. The flow of energy is from the storage tissue in the crown and roots, 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.

Categorizing Mode of Action

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, and membrane disrupters.

Growth Regulator Herbicides

Herbicides that mimic the activity of the plant hormone *auxin* are referred to as growth regulator herbicides, although they are more commonly known as 'broadleaf herbicides'. Examples of this type of herbicide include 2,4-D, dicamba (Vanquish), and triclopyr (Garlon).

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) in particular, has considerable soil activity. Dicamba has significant soil activity, 2,4-D much less, and triclopyr has very little 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.

Their are three major groups of growth regulator herbicides used in non-crop settings.

Phenoxy Herbicides	*(Product Example)*
2,4-D	(Hi-Dep)
dichlorprop (2,4-DP)	(Patron DP-4)
Benzoic Acid Herbicides	
dicamba	(Vanquish)
Picolinic Acid Herbicides	
clopyralid	(Transline)
fluroxypyr	(Vista)
picloram	(Tordon K)
triclopyr	(Garlon)

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 (PGR): The line between regulating a plant's growth and killing the plant is often a fine one. Another way to look at is this - if 'dose makes the poison', then the difference between a PGR and an herbicide is application rate.

The chemicals paclobutrazol (Profile 2SC) and flurprimidol (Cutless Implants) only have labeled uses as PGRs. They reduce a plant's ability to synthesize the plant hormone gibberillic acid. This reduces cell elongation, which causes branches to be shorter and leaves to be smaller. It can be argued that these chemicals are 'true' PGRs.

Mefluidide (Embark) is arguably best described as an herbicide that is easier to use for suppressing growth than killing plants. Mefluidide inhibits cell division, which along with cell elongation (or expansion) is how growth occurs. It is very effective at preventing seedhead formation in grasses.

The herbicides chlorsulfuron (Telar), glyphosate (Roundup Pro, etc.), imazapyr (Arsenal), imazapic (Plateau), and metsulfuron methyl (Escort) are examples of herbicides with very-low-rate use provisions in their labels to suppress ('regulate') the growth of grasses.

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 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 form 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 usually kill the plant before it starves. The energy from sunlight is normally transferred through a cascade of complex proteins that channel the captured light energy into the formation of high energy molecules. When the transfer is interrupted, this unchanneled light energy forms *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.

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) is an effective burn-down material, while tebuthiuron (Spike) and bromacil (Hyvar) have very little foliar activity.

The chemical families that are photosynthetic inhibitors are listed below, along with some familiar herbicides not used in non-crop situations (any more). Norflurazon (Predict) is included in this grouping, but its mode of action is somewhat different. Norflurazon inhibits the synthesis of accessory pigments called carotenoid that surround chlorophyll and quench the excess energy of free radicals that naturally form during photosynthesis. Without carotenoids present, the free radicals damage both the chlorophyll molecule and cell membranes.

Triazine Herbicides	
atrazine	(AAtrex)
simazine	(Princep)

hexazinone(Velpar)

Substituted Urea Herbicides

diuron	(Karmex)
tebuthiuron	(Spike)

Uracil Herbicides

bromacil	(Hyvar)

Other

bentazon	(Basagran T/O)
norflurazon	(Predict)

Inhibitors of Amino Acid Synthesis

By themselves, amino acids are simple, little molecules. There 20 amino acids found in plants. What makes amino acids amazing is that they are the building blocks 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 one of the 20 amino acids, the plant will not be able to synthesize enzymes. No enzymes, no life.

Several herbicides prevent plants from producing amino acids. 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 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.

Glyphosate (Roundup Pro) inhibits the synthesis of three amino acids known as aromatic amino acids. Herbicides such as imazapyr (Arsenal) or sulfometuron methyl (Oust) inhibit the synthesis of three amino acids known as branched chain amino acids.

Unclassified

glyphosate	(Roundup Pro)

Imidazolinone Herbicides

imazapic	(Plateau)
imazapyr	(Arsenal)

Sulfonylurea Herbicides

chlorsulfuron	(Telar)
metsulfuron methyl	(Escort)
sulfometuron methyl	(Oust)

Growth Inhibitors

This is a broad term that covers several chemical families, although only two chemical families are labeled for non-crop uses. Most herbicides in this category are effective only on seedlings, and therefore are preemergence herbicides.

The most common herbicides in this category are the dinitroanilines, often referred to as root inhibitors. These are the 'yellow' herbicides. They are highly water-insoluble herbicides that stay very close to the soil surface. These herbicides must be in the soil prior to weed germination, or they are not effective. Once absorbed by the growing root tip, these herbicides inhibit the formation of the cell's 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. The cells become bulbous and misshapen, and the root tips become stubby and do not produce root hairs. Affected seedlings usually die before emergence.

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.

Dinitroanaline Herbicides

oryzalin	(Surflan)
pendimethalin	(Pendulum)
prodiamine	(Endurance)
trifluralin	(Treflan)

Chloroacetamide Herbicides

metolachlor	(Pennant Liquid)

Inhibitors of Lipid Synthesis

These herbicides selectively control grasses. They must be applied postemergence, and after absorption they 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.

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 postemergence grass herbicides have been observed to be antagonized by several herbicides used for broadleaf weed control, such as 2,4-D, dicamba, bentazon, and the sulfonylureas. The antagonism occurs either on the plant surface, or inside the plant, rather 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.

Aryloxyphenoxy Herbicides

fenoxaprop-P-butyl	(Acclaim Extra)
fluazifop-P-butyl	(Fusilade II)
quizalifop-P-ethyl	(Assure II)

Cyclohexanedione Herbicides

clethodim	(Envoy)
sethoxydim	(Vantage)

Cell Membrane Disrupters

These are the herbicides commonly referred to as 'contact' herbicides. They work quickly, and do not translocate.

The term 'contact' is a little 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, through the watery interior of the cell (cytoplasm), and pass through at least one more set of membranes before they reach the site of their activity. These herbicides are active in the *chloroplast*, the structures inside plant cells where photosynthesis occurs.

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 - the phloem and xylem.

Membrane disrupters can be tank mixed with herbicides that provide activity through root uptake. The membrane disrupter herbicide would essentially burn down the top growth of the plant, and the soil active herbicide would control the regrowth by entering the plant through root uptake.

Paraquat, diquat, and glufosinate are applied postemergence only. Oxyfluorfen has postemergence activity on some species, but is most effectively applied to the soil surface to control seedlings as they emerge.

Bipyridylium Herbicides

diquat	(Reward)
paraquat	(Gramoxone Extra)

Diphenylether Herbicides

oxyfluorfen	(Goal)

Unclassified

glufosinate(Derringer)

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. In the case of the triazine herbicides, the triazine-resistant biotypes made up a very small portion of the population because they were not as vigorous as the triazine-susceptible population. It took many years of repeated use of triazine herbicides before the resistant-biotype had increased its portion of the population enough to be noticed.

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 a tolerant species establish towards the end of 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 vegetation. The herbicide combination has not become ineffective because of a loss of activity - instead we have selected, or 'released' a population of weeds tolerant to the treatment. In southeastern PA, this situation has been observed with the grass species sprangletop (*Leptochloa fascicularis*) in both industrial and guiderail sites.

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 tolerant species originally made up a minute fraction of the weed population. Through elimination of the abundant susceptible species, the tolerant species increases and becomes dominant. The same situation can occur *within* a single species. Within a given species, there are slightly different populations, or *biotypes* that occur. Sometimes these differences 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 2 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.

In the example in Table 2 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

Herbicide resistance is prevented by using mixtures of herbicides with different modes of action, and occasional rotation to alternate mixtures as well.

Table 2: 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 that the small population is resistant to allows it to double in size each year. After 10 years, the product is 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

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) as the broad spectrum component of a bare ground 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 may also be resistant to Arsenal.

Table 3 - Herbicides Available for Non-crop Use, by Trade Name. Alphabetical listing of 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
2,4-D 4 Amine	2,4-D
Accord	glyphosate
Arsenal 0.5 G	imazapyr
Arsenal	imazapyr
Assure II	quizalafop P-ethyl
Basagran SG	bentazon
Basagran T/O	bentazon
BareSpot Bareground BD	sodium metaborate + sodium chlorate + bromacil + diuron
BareSpot Monobor-Chlorate	sodium metaborate + sodium chlorate
BareSpot Ureabor	sodium metaborate + sodium chlorate + bromacil
BareSpot Weed & Grass	sodium metaborate + sodium chlorate + diuron
Barrier	dichlobenil
BK 800	2,4-D + dichlorprop + dicamba
Casoron	dichlobenil
Cutless	flurprimidol
DiBro 2+2	bromacil + diuron
Diuron 4L	diuron
Diuron 80	diuron
Embark	mefluidide
Endurance	prodiamine
Envoy	clethodim
Escort	metsulfuron methyl
Finale	glufosinate ammonium
Fusilade II	fluazifop P-butyl
Fusion	fluazifop P-butyl + fenoxaprop P-ethyl
Gallery	isoxaben
Garlon 3A	triclopyr
Garlon 4	triclopyr
Glyfos	glyphosate
Glypro	glyphosate
Glypro Plus	glyphosate
Goal	oxyfluorfen
Gramoxone Extra	paraquat dichloride
Hi-Dep IVM	2,4-D
Hyvar X	bromacil
Hyvar XL	bromacil
Karmex DF	diuron
Krenite S	fosamine ammonium
Krovar I	bromacil + diuron
Milestone	azafenidin
Ornamec	fluazifop P-butyl
Oust	sulfometuron methyl
Pathfinder II	triclopyr
Pathway	2,4-D + picloram
Patron 170	2,4-D + dichlorprop
Patron DP-4	dichlorprop
Pendulum 2G	pendimethalin
Pendulum 3.3 EC	pendimethalin
Pendulum WDG	pendimethalin
Pennant Liquid	metolachlor
Plateau	imazapic
Pramitol 5 PS	sodium metaborate + sodium chlorate + prometon + simazine

Table 3 - Herbicides Available for Non-crop Use, by Trade Name (*continued*): Alphabetical listing of 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
Pramitol 25E	prometon
Predict	norflurazon
Profile 2SC	paclobutrazol
Pronone 10G	hexazinone
Pronone 25G	hexazinone
Pronone Power Pellet	hexazinone
Reward LA	diquat dibromide
Reward LS	diquat dibromide
Rodeo	glyphosate
Roundup Pro	glyphosate
Roundup Pro Dry	glyphosate
Sahara	diuron + imazapyr
Scythe	pelargonic acid
Select 2 EC	clethodim
Snapshot TG	trifluralin + isoxaben
Solution IVM	2,4-D
Spike 20P	tebuthiuron
Spike 80W	tebuthiuron
SpraKil S-13	diuron + tebuthiuron
SpraKil S-26	diuron + tebuthiuron
SpraKil S-5	tebuthiuron
Staa-Free 2 + 2	bromacil + diuron
Stalker	imazapyr
Stronghold	mefluidide + imazethapyr + imazapyr
Surflan	oryzalin
Telar	chlorsulfuron
TopSite 2.5G	diuron + imazapyr
Tordon 101M	2,4-D + picloram
Tordon K	picloram
Transline	clopyralid
Treflan 5G	trifluralin
Vanquish	dicamba
Vantage	sethoxydim
Vegemec	prometon + 2,4-D
Velpar DF	hexazinone
Velpar L	hexazinone
Veteran 10G	dicamba
Veteran 720	2,4-D + dicamba
Veteran CST	dicamba
Weed Blast 4G	bromacil + diuron
XL 2G	benefin + oryzalin

Table 4 - Herbicides Available for Non-crop Use, by Active Ingredient. 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.

Ingredient	Products
2,4-D	2,4-D 4 Amine IVM BK 800 (dichlorprop; dicamba) Hi-Dep IVM Patron 170 (dichlorprop) Solution IVM Vegemec (prometon) Veteran 720 (dicamba)
azafenidin	Milestone
benefin	XL 2G (oryzalin)
bentazon	Basagran SG Basagran T/O Lescogran
bromacil	BareSpot Bareground BD (sodium metaborate + sodium chlorate, diuron) BareSpot Ureabor (sodium metaborate + sodium chlorate) DiBro 2+2 (diuron) Hyvar X Hyvar XL Krovar I (diuron) Staa-Free 2+2 (diuron) Weed Blast 4G (diuron)
chlorsulfuron	Telar
clethodim	Envoy Select 2 EC
clopyralid	Transline
dicamba	BK 800 (2,4-D; 2,4-DP) Vanquish Veteran 10G Veteran 720 Veteran 2010 (MCPA) Veteran CST
dichlobenil	Casoron 4G Barrier 4G
dichlorprop	BK 800 (2,4-D; dicamba) Patron 170 (2,4-D) Patron DP-4
diquat dibromide	Reward LA Reward LS
diuron	BareSpot Bareground BD (sodium metaborate + sodium chlorate, bromacil) BareSpot Weed & Grass (sodium metaborate + sodium chlorate) DiBro 2+2 (bromacil) Diuron 4L Diuron 80 Karmex DF Krovar I (bromacil) Sahara (imazapyr) SpraKil S-13 (tebuthiuron)

Table 4 - 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.

Ingredient	Products
diuron (*continued*)	SpraKil S-26 (tebuthiuron) Staa-Free 2+ 2 (bromacil)
	Topsite 2.5G (imazapyr) Weed Blast 4 G (bromacil)
fenoxaprop P-ethyl	Fusion (fluazifop P-butyl)
fluazifop P-butyl	Fusilade II Fusion (fenoxaprop P-ethyl)
flurprimidol	Cutless Implants
fosamine ammonium	Krenite S
glufosinate	Derringer
glyphosate	Accord Glyfos Glypro Glypro Plus Rodeo Roundup Pro Roundup Pro Dry
hexazinone	Pronone 10G Pronone 25G Pronone Power Pellet Velpar Velpar DF Velpar L
imazapic	Plateau
imazapyr	Arsenal Arsenal 0.5 G Sahara (diuron) Stalker Stronghold (mefluidide, imazethapyr) TopSite 2.5 G (diuron)
imazethapyr	Stronghold (mefluidide, imazapyr)
isoxaben	Gallery Snapshot TG (trifluralin)
mefluidide	Embark Stronghold (imazethapyr, imazapyr)
metolachlor	Pennant Liquid
metsulfuron methyl	Escort
norflurazon	Predict
oryzalin	Surflan XL 2G (benefin)
oxyfluorfen	Goal
paclobutrazol	Profile 2SC
paraquat dichloride	Gramoxone Extra
pelargonic acid	Scythe

Table 4 - 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.

Ingredient	Products
pendimethalin	Pendulum 2G Pendulum 3.3 EC Pendulum WDG
picloram	Pathway (2,4-D) Tordon K Tordon 101M (2,4-D)
prodiamine	Endurance
prometon	Pramitol Pramitol 5 PS (sodium metaborate + sodium chlorate, simazine) Vegemec (2,4-D)
quizalofop P-ethyl	Assure II
sethoxydim	Vantage
simazine	Pramitol 5 PS (sodium metaborate + sodium chlorate, prometon)
sodium metaborate + sodium chlorate	BareSpot Bareground BD (bromacil, diuron) BareSpot Monobor-Chlorate BareSpot Ureabor (bromacil) BareSpot Weed&Grass (diuron) Pramitol 5 PS (prometon, simazine)
sulfometuron methyl	Oust
tebuthiuron	Spike 20P Spike 80W SpraKil S-5 SpraKil S-13 (diuron) SpraKil S-26 (diuron)
triclopyr	Garlon 3A Garlon 4 Pathfinder II
trifluralin	Snapshot TG (isoxaben) Treflan 5G

Table 5 - Herbicide Toxicity and Reaction to Inorganic Materials. Summary of acute toxcity 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
Milestone	*azafenidin*	>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	*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
2,4-DP	*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 Extra	*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
Treflan 5G	*trifluralin*	>5,000	>5,000	>4.8	non-corrosive
Hi-Dep	*2,4-D*	639	>2,000	2.0	noncorrosive

[1/] Toxicity to mice

[2/] Toxicity of formulated product

Table 6 - 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
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
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
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
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
Imazapyr acid	High	90	11,000	100
Imazapyr isopropylamine salt	High	90	500,000	100
Imazaquin acid	Very High	60	60	20
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
Prodiamine	Extremely Low	120	0.013	13,000
Prometon	Very High	500	720	150
Quizalofop-ethyl	Moderate	60	0.31	510

Table 6 - 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})
Sethoxydim	Low	5	4390	100
Simazine	High	60	6.2	130
Sodium chlorate	Very High	200	100,000	10
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://ace.orst.edu/info/nptn/ppdmove.htm.

[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 0.1 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 7: Non-crop herbicides and labeled uses. **Selective Pre** - preemergence applications intended to control weeds from seed in established plantings. **Selective Post** - herbicides that would act selectively on broadleaf weeds, or grasses, but not both. **Non-selective Pre** - Materials used to maintain bareground. **Non-selective Post** - Products that will injure all existing vegetation. **Weed Control under Pavement** - Materials applied to the road base immediately prior to paving. **Low Volume Basal Bark** - A brush control treatment where the herbicide is diluted in an oil carrier and applied to the lower bark of woody plants. **Cut Surface** - Brush control treatments that include treating a cut stump, exposed cambium, or injection treatments. **Spot Concentrate** - The 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** - A 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 Weed Control** - Control of weeds in water.

Product	Selective Pre	Selective Post	Non-selective Pre	Non-selective Post	Weed Control under Pavement	Basal Bark	Cut Surface	Spot Concentrate	Cut Stubble	Growth Regulation	Aquatic Weed Control
2,4-D 4 Amine		●					●				●
Accord				●			●				●
Arsenal		●	●	●	●		●			●	
Arsenal 0.5 G			●	●							
Assure II		●									
BareSpot Bareground BD			●	●							
BareSpot Monobor-Chlorate			●	●							
BareSpot Ureabor			●	●							
BareSpot Weed&Grass			●	●							
Barrier	●		●		●						
Basagran SG		●									
Basagran T/O		●									
BK 800		●				●	●				
Casoron	●		●		●						
Cutless										●	
DiBro 2 + 2			●	●							
Diuron 4L			●								
Diuron 80			●								
Embark										●	
Endurance	●										
Envoy		●									
Escort		●						●		●	
Finale				●							
Fusilade II		●									
Fusion		●									
Gallery	●										

TABLE 7: Non-crop herbicides and labeled uses (*continued*). **Selective Pre** - preemergence applications intended to control weeds from seed in established plantings. **Selective Post** - herbicides that would act selectively on broadleaf weeds, or grasses, but not both. **Non-selective Pre** - Materials used to maintain bareground. **Non-selective Post** - Products that will injure all existing vegetation. **Weed Control under Pavement** - Materials applied to the road base immediately prior to paving. **Low Volume Basal Bark** - A brush control treatment where the herbicide is diluted in an oil carrier and applied to the lower bark of woody plants. **Cut Surface** - Brush control treatments that include treating a cut stump, exposed cambium, or injection treatments. **Spot Concentrate** - The 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** - A 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 Weed Control** - Control of weeds in water.

Product	Selective Pre	Selective Post	Non-selective Pre	Non-selective Post	Weed Control under Pavement	Basal Bark	Cut Surface	Spot Concentrate	Cut Stubble	Growth Regulation	Aquatic Weed Control
Garlon 3A		●					●				
Garlon 4		●				●	●				
Glyfos		●		●			●			●	
Glypro		●		●			●			●	●
Glypro Plus		●		●			●			●	
Gramoxone Extra				●							
Hi-Dep IVM		●					●				
Hyvar X			●	●				●			
Hyvar XL			●	●				●			
Karmex DF			●								
Krenite S		●					●				
Krovar I			●	●							
Milestone			●								
Ornamec		●									
Oust		●	●	●						●	
Pathfinder II						●	●				
Pathway							●				
Patron 170		●				●	●				
Patron DP-4		●									
Pendulum 2G	●										
Pendulum 3.3 EC	●										
Pendulum WDG	●										
Pennant Liquid	●										
Plateau	●	●									
Pramitol 5 PS			●	●							
Pramitol 25E			●	●							
Predict	●		●								
Profile 2SC										●	

TABLE 7: Non-crop herbicides and labeled uses (*continued*). **Selective Pre** - preemergence applications intended to control weeds from seed in established plantings. **Selective Post** - herbicides that would act selectively on broadleaf weeds, or grasses, but not both. **Non-selective Pre** - Materials used to maintain bareground. **Non-selective Post** - Products that will injure all existing vegetation. **Weed Control under Pavement** - Materials applied to the road base immediately prior to paving. **Low Volume Basal Bark** - A brush control treatment where the herbicide is diluted in an oil carrier and applied to the lower bark of woody plants. **Cut Surface** - Brush control treatments that include treating a cut stump, exposed cambium, or injection treatments. **Spot Concentrate** - The 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** - A 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 Weed Control** - Control of weeds in water.

Product	Selective Pre	Selective Post	Non-selective Pre	Non-selective Post	Weed Control under Pavement	Basal Bark	Cut Surface	Spot Concentrate	Cut Stubble	Growth Regulation	Aquatic Weed Control
Pronone Power Pellet			●	●							
Pronone 10G			●	●							
Pronone 25G			●	●							
Reward LA				●							●
Reward LS				●							
Rodeo		●		●			●			●	●
Roundup Pro		●		●			●			●	
Roundup Pro Dry		●		●						●	
Sahara			●	●	●						
Scythe				●							
Select 2 EC		●									
Snapshot TG	●										
Solution IVM				●			●				
Spike 20P			●	●				●			
Spike 80W			●	●				●			
SpraKil S-13			●	●							
SpraKil S-26			●	●							
SpraKil S-5			●	●							
Staa-Free 2+2			●	●							
Stalker					●	●	●		●		
Stronghold										●	
Surflan	●										
Telar		●								●	
TopSite			●	●							
Tordon 101M		●							●		
Tordon K		●				●			●		
Transline		●									
Treflan 5G	●										

TABLE 7: Non-crop herbicides and labeled uses (*continued*). **Selective Pre** - preemergence applications intended to control weeds from seed in established plantings. **Selective Post** - herbicides that would act selectively on broadleaf weeds, or grasses, but not both. **Non-selective Pre** - Materials used to maintain bareground. **Non-selective Post** - Products that will injure all existing vegetation. **Weed Control under Pavement** - Materials applied to the road base immediately prior to paving. **Low Volume Basal Bark** - A brush control treatment where the herbicide is diluted in an oil carrier and applied to the lower bark of woody plants. **Cut Surface** - Brush control treatments that include treating a cut stump, exposed cambium, or injection treatments. **Spot Concentrate** - The 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** - A 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 Weed Control** - Control of weeds in water.

Product	Selective Pre	Selective Post	Non-selective Pre	Non-selective Post	Weed Control under Pavement	Basal Bark	Cut Surface	Spot Concentrate	Cut Stubble	Growth Regulation	Aquatic Weed Control
Vanquish		●					●				
Vantage		●									
Vegemec			●	●							
Velpar		●	●	●							
Velpar DF		●		●							
Velpar L		●		●							
Veteran 10G		●									
Veteran 720		●									
Veteran CST							●				
Weed Blast 4G			●	●							
XL 2G	●										

2,4-D 4 Amine IVM

(*2,4-D*) **Producers: Riverdale, PBI/Gordon**

Application Rate: 0.24 to 7.6 lbs ae/acre.

Formulation	per/acre
2,4-D 4 Amine IVM (3.8 S)	8 oz to 2 gallons
Hi-Dep IVM (3.8 S)	1 qt to 2 gallons
Solution IVM (80.5 SP)	40 to 90 oz

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: 2,4-D 4 Amine and Solution IVM are labeled for terrestrial and aquatic use. Hi-Dep IVM is labeled for terrestrial applications, and non-irrigation ditchbanks.

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] (21.5% 2,4-D; 21.5% dichlorprop; 5.4% dicamba) - Apply 2 to 3 pts/acre for control of broadleaf weeds in turf, and 1 to 3 gallons/acre for 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] (21.8 % dichlorprop, 21.3% 2,4-D) - Apply at 2.2 to 3.3 qts/acre for control of broadleaf weeds in turf. Apply at 2 to 9 gallons/acre for control of brush, using foliar, cut surface, or basal bark treatment.

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.

Vegemec [0.38 EC] (3.6% prometon, 1.0% 2,4-D) - Apply at 41 to 54 gallons/acre for 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] (20.4% 2,4-D; 10.6% dicamba) - Apply at 1 to 4 qts/acre for broadleaf weed control in turf, and up to 2 gallons/acre for brush control.

Accord (*see* Roundup Pro)

Arsenal

(*imazapyr*) **Producer: American Cyanamid**

Application Rate: 0.002 to 1.5 lbs ai/acre.

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

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 is an enzyme 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: uplands, non-tidal wetlands where surface water is not present, non-irrigation ditchbanks, and ditchbottoms where only isolated puddles of surface water occur.

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.

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. Though not widespread (yet), kochia does occur on industrial and roadside sites in PA. Be certain to practice resistance-management (see *Herbicide Resistance*, p. XX).

Combination Products

Sahara DG (62% diuron, 8% imazapyr) -Apply at 5 to 19 lbs/acre, 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) - Apply at 6 to 38 oz/acre for 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) - Apply at 200 to 300 lbs/acre for 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	5 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 an enzyme 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 grass weed control in wildflower-only plantings in non-crop areas. Not to be used in landscape beds.

Notes: Control of grasses 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 control of grasses provided by Assure II.

BareSpot Monobor-Chlorate

(sodium metaborate + sodium chlorate) **Producer: Pro-Serve**

Application Rates: (ai/acre)

combined	430 to 1700 lbs
sodium metaborate (68%)	298 to 1180 lbs
sodium chlorate (30%)	132 to 520 lbs.

Formulation	per/acre
Monobor-Chlorate (98 P)	435 to 1740 lbs/acre

Mode of Action: Not well understood. Both materials are readily absorbed by leaves or roots, but the extent of translocation is not known. Can be applied pre- or postemergence.

Sodium metaborate may bind to, and inactivate calcium in the plant. Sodium chlorate is a strong oxidizer, and may inhibit protein sulfation.

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

Uses: Total vegetation control in non-crop and industrial sites.

Notes: Persistent in soil. Do not apply near roots of desirable plants. Cannot be stored in opened bag - all material must be used upon opening. These are relatively ancient materials that have been replaced by synthetic, organic molecules. Due to relatively high toxicity ('Danger 'signal wording), and extreme use rates, applicator risk is relatively high. Manufacturer claims these chemicals are toxic to soil

microorganisms - reducing the rate of herbicide degradation. This is not necessarily a desirable quality for an herbicide.

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

BareSpot Bareground BD [94 P] (50% sodium metaborate, 40% sodium chlorate, 2% bromacil, 2% diuron) - Apply 218 to 872 lbs/acre.

BareSpot Ureabor [98 P] (66.5% sodium metaborate, 30% sodium chlorate, 1.5% bromacil) - Apply 436 to 1308 lbs/acre.

BareSpot Weed&Grass [98 P] (66.5% sodium metaborate, 30% sodium chlorate, 1.25% diuron) - Apply 436 to 1308 lbs/acre.

Pramitol 5 PS [96 P] (50% sodium metaborate, 40% sodium chlorate, 5% prometon, 0.75% simazine) - Apply 152 to 400 lbs/acre.

Barrier (*see* Casoron)

Basagran
(bentazon) **Producer: BASF**

Application Rates: 0.75 to 2.0 lbs ai/acre.

Formulation	per/acre
Basagran SG (87 SP)	14 to 36 oz/acre
Basagran T/O (4 S)	1.5 to 4 pts/acre
Lescogran (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
(dichlobenil) **Producer: Uniroyal, PBI/Gordon**

Application Rate: 2.0 to 20 lbs ai/acre.

Formulation	per/acre
Barrier 4 G	100 to 300 lbs
Casoron 4 G	50 to 500 lbs

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, or incorporated. 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.

Cutless
(flurprimidol) **Producer: Dow AgroSciences**

Application Rate: 0.5 to 1.5 g ai/inch of stem diameter

Formulation	per inch stem diameter
Cutless Tree Implants	0.5 to 1.5 implants

Mode of Action: Systemic. Moves with water from implant site to growing points in canopy.

Flurprimidol inhibits the synthesis of the plant hormone gibberellic acid. This causes reduced cell elongation, resulting in shorter stems and smaller leaves.

Sites: Implanted in target trees.

Uses: Reduction of terminal growth and biomass production of trees growing near utility lines, to reduce pruning requirements.

Notes: Dosage is based on tree species and desired growth suppression. The tree is measured four feet above ground level, number of implants determined, and 3/8 inch diameter holes are drilled that are the thickness of the bark plus one inch deep. Growth regulation may not be apparent until the year after implanting. Trees can be retreated when growth suppression is no longer apparent.

Direx 4L (*see* Diuron)

Diuron
(*diuron*)
Producer: Dow AgroSciences, Griffin, Terra, UAP

Application Rate: 4 to 48 lb ai/acre

Formulation	per/acre
Diuron 4L	1 to 11.25 gal/acre
Diuron 80 (DF, WDG)	5 to 60 lb/acre
Direx 4L	1 to 3 gal/acre
Karmex DF (80 DF)	5 to 15 lb/acre

Mode of Action: Systemic. Diuron moves upwards in the plant, 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.

BareSpot Bareground BD [94 P] (50% sodium metaborate, 40% sodium chlorate, 2% bromacil, 2% diuron) - Apply 218 to 872 lbs/acre.

BareSpot Weed&Grass [98 P] (66.5% sodium metaborate, 30% sodium chlorate, 1.25% diuron) - Apply 436 to 1308 lbs/acre.

DiBro 2+2 [4 G] (2% bromacil, 2% diuron) - Apply at 200 to 400 lb/acre.

Krovar I DF [80 DF] (40% bromacil, 40% diuron) - Apply at 4 to 30 lbs/acre.

Sahara DG (62% diuron, 8% imazapyr) - Apply at 5 to 19 lbs/acre, pre- or postemergence to maintain bare ground on industrial sites, or weed control under paved surfaces.

SpraKil S-13 [4 G] (3% diuron, 1% tebuthiuron) - Apply at 150 to 400 lb/acre.

SpraKil S-26 [8 G] (6% diuron, 2% tebuthiuron) - Apply at 150 to 300 lb/acre.

Staa-Free 2+2 [4 G] (2% bromacil, 2% diuron) - Apply at 200 to 400 lb/acre.

TopSite 2.5 G (2% diuron, 0.5% imazapyr) - Apply at 200 to 300 lbs/acre for control of herbaceous weeds on sites where bare ground is desired. Most effective when applied preemergence.

Weed Blast 4 G (2% bromacil, 2% diuron) - Apply at 200 to 400 lb/acre.

Embark
(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 bermudagrass on roadsides, airfields, plant sites, military posts, or right-of-ways.

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) - Apply at 6 to 38 oz/acre for 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: Novartis**

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. 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 bare ground areas of industrial sites and rights-of-way. 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
(*clethodim*) **Producer: Valent**

Application Rate: 0.0625 to 0.25 lb ai/acre

Formulation	per/acre
Envoy 0.94 EC	13 to 34 oz/acre
Select 2 EC	4 to 16 oz/acre

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

Clethodim is an enzyme 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: Both products can be used for 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 applying Select, always use a crop oil concentrate. When treating in ornamentals with Envoy, use a non-ionic surfactant to reduce the potential for injury. Where no ornamentals are present, use a crop oil concentrate with Envoy. Like most other selective grass herbicides, clethodim is not effective on fine fescues. Grass control may be reduced if clethodim is tank-mixed with other herbicides.

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

Application Rate: 0.012 to 0.15 lb ai/acre

Formulation	per/acre
Escort 60 DF	0.33 to 4.0 oz/acre

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

Metsulfuron is an enzyme 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 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 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 has been applied, there is a one to four month replant interval after treatment, depending on grasse species.

Finale
(*glufosinate ammonium*) **Producer: Aventis**

Application Rate: 0.5 to 1.5 lb ai/acre

Formulation	per/acre
Finale 1S	2 to 6 qt/acre

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

Glufosinate is an enzyme inhibitor. Its activity disrupts 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.

Fusilade II
(*fluazifop P-butyl*) **Producer: Zeneca, PBI/Gordon**

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 enzyme 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 oramental 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 fine 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 [2.6 E] (24.2% fluazifop P-butyl, 6.8% fenoxaprop P-butyl) - apply at 7 to 9 oz/acre for selective control of annual grasses and Johnsongrass in Bermudagrass, fine fescue, perennial ryegrass, smooth bromegrass, or tall fescue.

Gallery
(*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
Gallery T&V 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, either Gallery formulation can be used to maintain bare ground near desirable plantings. Gallery 75 DF has wider labeling than the T&V product, and can also be used 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) Apply at 200 to 300 lb/acre for preemergence control of annual broadleaf and grass weeds. Best results occur if 0.5 inch of rainfall occurs within 3 days.

Garlon
(*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 (4 EC)	1 qt to 2 gal/acre
Pathfinder II	ready-to-use

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; 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. Triclopyr is only active on broadleaf species.

Sites: Upland sites, non-irrigation ditchbanks, and seasonally dry wetlands, floodplains, deltas, and transition areas between uplands and wetlands. Do not apply directly to water.

Uses: Selective broadleaf weed control, control of brush with foliar, basal bark, and cut surface and injection treatments. Can be used in certain areas used for livestock grazing.

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.

Glyfos (*see* Roundup Pro)

Glypro, Glypro Plus (*see* Roundup Pro)

Gramoxone Extra
(*paraquat*) **Producer: Zeneca**

Application Rate: 0.62 to 0.94 lb ai/acre

Formulation	per/acre
Gramoxone Extra 2.5S	2 to 3 pints/acre

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

Paraquat causes 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 Extra 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.

Hi-Dep IVM (*see* 2,4-D 4 Amine IVM)

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

Application Rate: 1.5 to 24 lb ai/acre

Formulation	per/acre
Hyvar X	2 to 15 lbs/acre
Hyvar XL	0.75 to 12 gal/acre

Mode of Action: Systemic. Bromacil moves upwards in the plant, following the water stream from root 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.

BareSpot Bareground BD [94 P] (50% sodium metaborate, 40% sodium chlorate, 2% bromacil, 2% diuron) - Apply 218 to 872 lbs/acre.

BareSpot Ureabor [98 P] (66.5% sodium metaborate, 30% sodium chlorate, 1.5% bromacil) - Apply 436 to 1308 lbs/acre.

DiBro 2+2 [4 G] (2% bromacil, 2% diuron) - Apply at 200 to 400 lb/acre.

Krovar I DF [80 DF] (40% bromacil, 40% diuron) - Apply at 4 to 30 lbs/acre.

Staa-Free 2+2 [4 G] (2% bromacil, 2% diuron) - Apply at 200 to 400 lb/acre.

Weed Blast 4 G (2% bromacil, 2% diuron) - Apply at 200 to 400 lb/acre.

Karmex (*see* Diuron)

Krenite
(*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
Krenite UT (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, 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 right-of-ways. 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.

Lescogran (*see* Basagran)

Ornamec (*see* Fusilade II)

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

Application Rate: 0.047 to 0.38 lb ai/acre

Formulation	per/acre
Oust 75 DF	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 enzyme 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, control, 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*, p. XX).

Pathfinder II (*see* Garlon)

Patron DP-4
(*dichlorprop*) **Producer: Riverale**

Application Rate: 0.5 to 12 lb ai/acre

Formulation	per/acre
Patron DP-4 (EC)	1 pint to 3 gal/acre

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

Dichlorprop (2,4-DP) 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. Dichlorprop is only active on broadleaf species.

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

Uses: Foliar application to brush.

Notes: Like 2,4-D, dichlorprop is active on all broadleaf species, but truly lethal to only a limited spectrum of species. Dichlorprop is effective as a stand-alone product on selected oak species such as post and blackjack. In mixed-species applications, dichlorprop should be part of a tank-mix.

Combination Products

BK 800 [4.5 EC] (21.5% 2,4-D; 21.5% dichlorprop; 5.4% dicamba) - Apply 2 to 3 pts/acre for control of broadleaf weeds in turf, and 1 to 3 gallons/acre for non-crop weed and brush control. Brush applications can be to foliage, cut surface, or basal bark.

Patron 170 [3.7 EC] (21.8 % dichlorprop, 21.3% 2,4-D) - Apply at 2.2 to 3.3 qts/acre for control of broadleaf weeds in turf. Apply at 2 to 9 gallons/acre for control of brush, using foliar, cut surface, or basal bark treatment.

Pendulum
(*pendimethalin*) **Producer: American Cyanamid**

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 WDG (60 WDG)	3.3 to 6.6 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.

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 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.

Pennant Liquid

(*metolachlor*) **Producer: Novartis**

Application Rate: 2 to 4 lb ai/acre

Formulation	per/acre
Pennant Liquid (8 EC)	2 to 4 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: American Cyanamid**

Application Rate: 0.031 to 0.19 lb ai/acre

Formulation	per/acre
Plateau (2 S)	2 to 12 oz/acre
Plateau DG (70 DG)	1.43 to 4.29 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.

Imazapic is an enzyme 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 prairiegrasses 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. Although there are no reports of weed resistance to Plateau yet, there is no reason to believe there won't be. Practice resistance management when using Plateau or similar herbicides (see *Herbicide Resistance*, p. XX).

Pramitol

(*prometon*) **Producer: UAP**

Application Rate: 8 to 20 lb ai/acre

Formulation	per/acre
Pramitol 25 E	4 to 10 gal/acre

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) - Apply 152 to 400 lbs/acre.

Vegemec [0.38 EC] (3.6% prometon, 1.0% 2,4-D) - Apply at 41 to 54 gallons/acre for non-selective, residual control of vegetation. 2,4-D provides quick knockdown, prometon provides soil activity.

Predict
(*norflurazon*) **Producer: Novartis**

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.

Profile 2 SC
(*paclobutrazol*) **Producer: Dow AgroSciences**

Application Rate: 1 to 4 g ai/inch of stem diameter, breast height (DBH)

Formulation	per inch stem diameter
Profile 2 SC	0.14 to 0.56 oz

Mode of Action: Systemic. Moves with water after root absorption to growing points in canopy.

Paclobutrazol inhibits the synthesis of the plant hormone gibberellic acid. This causes reduced cell elongation, resulting in shorter stems and smaller leaves.

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

Uses: Non-food trees under utility lines, in urban and residential areas, and on non-cropland.

Notes: Profile 2 SC is applied as a dilute solution of 10.7 oz product/gallon. The dilute solution can be applied either as a basal drench or by soil injection. Where the water table is very high, an implanted material is a better choice.

Pronone (*see* Velpar)

Reward
(*diquat*) **Producer: Zeneca**

Application Rate: 0.25 to 0.5 lb ai/acre

Formulation	per/acre
Reward	1 to 2 pts/acre
Reward LS	1 to 2 pts/acre

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

Diquat causes 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, while Reward LS is solely for terrestrial use.

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.

Rodeo (*see* Roundup Pro)

Roundup Pro

(*glyphosate*) **Producer: Monsanto, Cheminova, Dow AgroSciences**

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 Dry (65 SP)	2.4 oz to 12 lb/acre
Accord (3 S)	2 to 10 qt/acre
Glyfos (3 S)	4 oz to 5 qts/acre
Glypro (4 S)	6 oz to 7.5 qts/acre
Glypro Plus (3 S)	4 oz to 10 qts/acre
Rodeo (4 S)	3 oz to 7.5 pts/acre

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 enzyme 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: Accord, Glypro, and Rodeo are labeled for certain aquatic weed control applications. The other products are for terrestrial applications, including ditch banks, and dry ditch or canal bottoms.

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 control of top growth, but none have the same effectiveness on a broad spectrum of perennial species. Roundup Pro, Roundup Pro Dry, and Glypro Plus do not require additional surfactant when used alone. Accord, Glypro, and Rodeo contain no surfactant, so additional surfactant is necessary. Do not mix glyphosate solutions in galvanized or unlined steel tanks, as a hydrogen gas, which is extremely explosive, is released. Use stainless steel, or non-metallic tanks only.

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 through its membrane 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 tall fescue.

Select (*see* Envoy)

Solution IVM (*see* 2,4-D 4 Amine)

Spike
(*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
Spike 80 W	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, 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) - Apply at 150 to 400 lb/acre.

SpraKil S-26 [8 G] (6% diuron, 2% tebuthiuron) - Apply at 150 to 300 lb/acre.

Stalker (*see* Arsenal)

Surflan A.S.
(*oryzalin*) **Producer: Dow AgroSciences**

Application Rate: 2 to 6 lb ai/acre

Formulation	per/acre
Surflan A.S. (4 L)	2 to 6 qts/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 rights-of-way. 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) - Apply at 200 to 300 lbs/acre for preemergence control of most grasses and many broadleaf weeds from seed.

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

Application Rate: 0.012 to 0.14 lb ai/acre

Formulation	per/acre
Telar DF (75 DF)	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 enzyme 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.

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 can reduce resprouting of suckering tree species such as sumac, tree-of-heaven, black locust, or sassafras.

Combinaton 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.

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.

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

Application Rate: 0.0.09 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, 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. 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 Composite family, such as thistles; as well as legumes and many plants in the buckwheat family.

Treflan
(*trifluralin*) **Producer: UHS**

Application Rate: 4 to 16 lb ai/acre

Formulation	per/acre
Treflan 5 G	80 to 320 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 rights-of-way. 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. Treflan 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) Apply at 200 to 300 lb/acre for preemergence control of annual broadleaf and grass weeds. Best results occur if 0.5 inch of rainfall occurs within 3 days.

Vanquish
(*dicamba*) **Producer: Novartis**

Application Rate: 0.25 to 2.0 lb ae/acre

Formulation	per/acre
Vanquish (4 S)	0.5 to 4 pts/acre
Veteran 10 G	2.5 to 20 lb/acre
Veteran CST (1 S)	Ready-to-Use

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, 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. Clopyralid 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 fomerly used in non-crop areas. Spot-treatment application rates for Veteran 10 G can be as high as 2 lb/1000 sq. ft (equivalent to 88 lbs/acre), but are still limited to 20 lbs per treated acre. Veteran CST is labeled only for cut surface and injection applications to woody plants.

Combination Products

BK 800 [4.5 EC] (21.5% 2,4-D; 21.5% dichlorprop; 5.4% dicamba) - Apply 2 to 3 pts/acre for control of broadleaf weeds in turf, and 1 to 3 gallons/acre for non-crop weed and brush control. Brush applications can be to foliage, cut surface, or basal bark.

Veteran 720 [2.9 S] (20.4% 2,4-D; 10.6% dicamba) - Apply at 1 to 4 qts/acre for broadleaf weed control in turf, and up to 2 gallons/acre for brush control.

Vantage
(*sethoxydim*) **Producer: BASF**

Application Rate: 0.19 to 0.47 lb ai/acre

Formulation	per/acre
Vantage (1 EC)	1.5 to 3.75 pts/acre

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

Sethoxydim is an enzyme 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 oramental plantings including wildflowers, and seedhead and growth suppression of tall fescue.

Notes: No additional surfactant should be added to Vantage mixtures. Control of annual grasses is more effective when they are only a few inches tall. Like most other selective grass herbicides, sethoxydim is not effective on fine fescues. Tank-mixing Vantage with most broadleaf herbicides may reduce grass control. Vantage is labeled for tank-mixing with Stinger, which is the same material as Transline, but labeled for different sites.

Velpar
(*hexazinone*) **Producer: DuPont, Pro-Serve**

Application Rate: 0.68 to 12 lb ai/acre

Formulation	per/acre
Velpar (90 SP)	0.75 to 8 lb/acre
Velpar DF (75 DF)	1 to 10.7 lb/acre
Velpar L	3 pt to 4 gal/acre
Pronone 10 G	60 to 120 lb/acre
Pronone 25 G	24 to 48 lb/acre
Pronone Power Pellet (75 P)	spot treatment

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.

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

Application Rate: 0.12 to .025 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, 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. 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. This product is a recent introduction to the non-crop market, so its strengths and weakness are not widely known at this time.