Section V

New Mexico Pesticide Applicator Training
Agricultural Pests and Agricultural Weeds

Control of Weeds

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INTRODUCTION

The discussion on the management of weeds begins with a definition of a "weed." How do you define these types of plants? Are they just "plants out of place" or "plants whose virtues have not yet been discovered"? Are they poisonous, injurious, harmful, hard to manage, or pernicious?

Consider this definition. Does it fit most situations?

> **"A weed is any plant which interferes with the management objectives for a given area of land (or body of water) at a given point in time."**

Who sets management objectives in the agricultural setting? Is it the farmer, grower, producer, or rancher? An individual may view a single spurred anodal in the chile field as one too many. His neighbor may think it's just fine to let that pretty plant grow along with the chile. The level of weed management is going to depend, in part, upon the management objectives established for a given property.

Given the definition of a weed, let's consider the characteristics that transform ordinary plants into "weedy" plants. Relatively few plants have the characteristics that make them true weeds. Of the total number of plants in the world (about 250,000 species), only 3% or 8,000 species are thought to behave as weeds in agriculture. Of these, about 250 or 0.1% of the total are recognized as major problems in world agriculture, and only about 0.01% or 25 species are major weed problems in any one crop. In their book, *The World's Worst Weeds*, the authors have identified the top 76 weeds in the world. Listed are the top 13 weedy plants species from their list and a few species that should be familiar to you.

1. *Cyperus rotundus*	Purple Nutsedge
2. *Cynodon dactylon*	Bermudagrass
3. *Echinochloa crusgalli*	Barnyardgrass
4. *Echinochloa colonum*	Junglerice
5. *Eleusine indica*	Goosegrass
6. *Sorghum halepense*	Johnsongrass
7. *Imperata cylindrica*	Cogongrass
8. *Eichhornia crassipes*	Water Hyacinth
9. *Portulaca oleracea*	Common Purslane
10. *Chenopodium album*	Common Lambsquarters
11. *Digitaria sanguinalis*	Large Crabgrass
12. *Convolvulus arvensis*	Field Bindweed
13. *Cyperus esculentus*	Yellow Nutsedge

Characteristics that make weedy plants so competitive, persistent, and pernicious are as:

1. Number of seeds per plant

   o Weeds are producers of large numbers of seeds. For example,

   * Barnyardgrass . . . . 7,000 seeds,
   * Common Purslane . . . . 52,000 seeds,
   * Common Lambsquarters . . . . 72,000 seeds,
   * Redroot Pigweed . . . . 117,000 seeds, and
   * Russian Thistle . . . . 200,000 seeds.

2. Dormancy

   o Dormancy is the ability of seeds to remain viable in the soil for extended periods of time. For example,

   * Johnsongrass . . . . 20 years,
   * Field Bindweed . . . . 20+ years,
   * Common Lambsquarters. . . 40 years, and
   * Redroot Pigweed . . . . 40 years.

3. Special adaptation or appendages

   o Plants have developed means to assist in their spread and distribution. Some examples include,

   a. Hooks and spines . . . . . . Sandbur
   . . . . . . Puncturevine

   b. Pappus (parachutes) . . . . . Musk thistle
   . . . . . Milkweeds

4. Vegetative reproductive capabilities

   o Vegetative reproductive structures are those asexual portions of the plant that allow for new plants to arise without the fertilization of the flower. Examples include the following:

   a. Roots with adventitious buds
   Ex. . . . Leafy Spurge and Canada Thistle

   b. Rhizome
   Ex. . . . Johnsongrass and Bermudagrass

c. Tubers
Ex. . . . Yellow and Purple Nutsedge

d. Crowns
Ex. . . . Dandelions

e. Stolons
Ex. . . . Bermudagrass

As we observe our fields, several plants seem to fit into the classification of being weedy, either through their different reproductive characteristics or their seed characteristics. In any case, certain plants are just plain and simple, weedy.

PLANT CHARACTERISTICS

In developing an effective weed management plan it is important to understand some general facts regarding plant species. Knowledge of such things as correct name, life cycle, method of reproduction, and means of spread will allow for the development of a management plan that will optimize timing of a management operation, as well as assist in the decision regarding which weed management method to use.

Plant Biology

A plant is a complex life form, in both structure and biology. There are two basic parts of a plant: the underground portion, or root, and the above-ground or aerial structure, the shoot. The stems, branches, leaves, flowers, and fruiting structures make up the shoot. The roots anchor the plant and supply water and dissolved minerals to the shoot tissue. The leaves, with energy derived from light, convert water and carbon dioxide into sugars, which are essential for the growth of both roots and shoots. Water moves upward; sugars move downward to the root, or to points of active growth where the energy is needed. This movement (translocation) takes place in conducting vessels that are interconnected throughout the plant. The water-conducting vessels are referred to as *xylem* and the vessels that carry sugars are the *phloem*. Any type of stress, mechanical injury, water deprivation, excessive heat, etc., results in reduced translocation within the plant.

Stress placed upon the plant due to heat or lack of water also results in an increase in the cuticular waxes on the leaf surface. Leaves of plants are covered with a layer of nonpolar waxes. These waxes maintain the proper water balance in the leaf tissue. Water in the cells allows plant cells, and hence the plant, to remain rigid. Any reduction in the pressure results in a wilting of the plant. In order to reduce water loss, plants will increase the layer of waxes on the surface of the leaves, thus creating a thicker nonpolar barrier for water to escape through, and effectively preventing applied aqueous sprays from penetrating the plant.

The root system of plants will vary depending upon plant species. Certain plant species have fibrous roots, while other have a taproot, and yet others will have a form of vegetative, asexual, reproductive root system. Examples of asexual reproductive structures include rhizomes (roots with adventitious buds), crowns, and tubers.

In considering these different characteristics, plants have been classified into different groups based upon life cycle and reproductive structures.

CLASSIFICATION OF WEEDS

Weeds are usually characterized by their general growth types:

1. Grasses have a single embryonic leaf (magnitude), fibrous root systems, and parallel veins on the leaves.

2. Broadleaves have two embryonic leaves (dicot), taproot systems, and a netted leaf venation.

Each of these two general groupings have been further subdivided by life cycle, which begins with the germination of the seed followed by vegetative growth, and is completed with flowering and the maturation of seed. Time of germination and means of spread and reproduction help to create a clear picture of the different classes. General management statements can be made as a result of this type of classification, as well.

The classification scheme is as follows:

1. *Annual weeds* complete their life cycle in one year.

This group of weeds has been further subdivided according to its time of germination into the following groups:

a. *Winter annuals* germinate in the fall of the year, mature and set seed in the spring of the second year.

Selected examples of winter annual weeds include:

o Rescuegrass
o Downy Brome
o Jointed Goatgrass
o The Mustards:
  * Flixweed
  * Tansymustard
  * Shepherdspurse

* London Rocket
* Blue Mustard

b. *Summer annuals* germinate in the spring of the year, mature and set seed in the same year.

Selected examples of summer annual weeds include:

o Annual Morningglory Species
o Barnyardgrass
o Common Purslane
o Common Lambsquarters
o Crabgrass
o Dodder
o Field Sandbur
o Foxtail, Green and Yellow
o Kochia
o Pigweed Species
o Puncturevine
o Prostrate Spurge
o Russian Thistle
o Spurred Anodal

There are a couple of points that need to be made regarding annual weeds.

1. Their only means of spread and reproduction is through the formation and dispersion of seed. This means that the principle of management is simple: **don't let them set seed.**

2. Any management plan is going to have to deal with multiple germination, since these weeds will germinate in the soil whenever the conditions favor the process to get started. This means that once you have managed the first flush of annual weeds, through cultivation, etc., there will be another group of seeds waiting in the wings for their chance to germinate and come up.

2. *Biennial weeds* take two years to complete their life cycle, or they live two years, and, are often, referred to as short-lived perennials.

Selected examples of biennial weeds include:

Musk thistle is a good example of a true biennial with its rosette of leaves the first year, followed by the bolting of the seed stalk, flowering, and seed set during the second year.

Common mallow is another biennial, but in this case the plant does not produce a rosette of leaves followed by bolting, rather it has a life span of two years.

With biennial weeds the management principle is the same as with the annual weeds since their only means of spread and reproduction is through the formation of seed. Not letting the plant set seed is what is required if these types of plants are to be effectively managed.

3. *Perennial weeds* have the vegetative reproductive structures already mentioned.

The management of these weeds requires not only stopping their seed production, but also the management of the vegetative structure under the soil, or above the soil in the case of the stolon.

Like the annuals, the perennial weeds have been subdivided into two groups, but not according to their time of germination, rather according to their type of root system.

a. *Simple perennials* are capable of coming back year after year from the same root, but there is no underground lateral branching.

Selected examples of simple perennial weeds include:

Dandelion
Plantain

b. *Creeping perennials* are capable of coming back year after year from the same root system and also have the creeping vegetative reproductive structures.

Selected examples of creeping perennial weeds include:

Bermudagrass
Johnsongrass
Nutsedge - Yellow and Purple
Field Bindweed
Silverleaf Nightshade
Texas Blueweed

Management plans have a greater chance of success if weeds are correctly identified.

WEED MANAGEMENT OPTIONS

After a weed is correctly identified, it is time to turn our attention toward developing the management plan. There are several different groups of management options available when developing a plan. These have been broken down into **biological**, **chemical**, **cultural**, **educational**, **physical**, and **preventive** weed management.

Biological Weed Management

A plant's environment consists of many organisms, including other plants, disease organisms, insects, and animals that feed upon the plant. Biological weed management uses a disease organism, insect, or higher animal to bring sufficient pressure on the target plant and keep it at a low population level. Most advances in biological weed management have been made through carefully researched introductions of host-specific insects. The goal in biological weed management is to maintain a balanced population of both biocontrol agent and the weed in question, with the density of the weed population reduced to an insignificant level.

To reduce the likelihood of an introduced biological control agent attacking nontarget plants, considerable time and energy, along with money, is spent to identify, locate and test agents that are host-specific. It is important to remember that a single introduced biological control agent cannot be expected to manage a complex of several weeds; but there is always promise for biological control for a single aggressive weed species that is too widespread or inaccessible to be controlled through other management options. Examples of biological weed management projects include the release of biocontrol agents for the management of puncturevine, which was done several years ago. More recently, projects have been established and research is being done on the biocontrol of weeds such as leafy spurge and broom snakeweed.

Chemical Weed Management

The use of herbicides, or tools of chemical weed management, will be discussed later in the manual.

Cultural Weed Management

The principle behind cultural weed management is to give the crop the competitive edge. Just as crop yields are affected by weed competition from the day of crop emergence until harvest, the vigor and seed production of weeds are influenced by agronomic practices. Cultural practices that shift the competition balance in favor of the crop increase productivity. Examples of practices that will improve the competitive ability of crop can be placed into two general groups: *sound agronomic practices* and *crop rotations*.

Sound agronomic practices use the common sense approach to crop production and include such practices as:

- Selecting crop varieties adapted to the area where it will be grown.
- Knowing the right time to plant and then planting accordingly.
- Maintaining sufficient soil fertility to ensure crop vigor.
- Providing adequate soil moisture for the crop planted.
- Managing other pests, such as diseases and insects, which reduce the vigor of the crop.
- Anticipating the weeds that may be present based upon the past history of the field.
- Depending upon the crop, that is planted, certain weeds are more easily managed under one type of cropping system than another.

The second grouping, crop rotation, also requires the grower to have a good feel for the field that will be planted. Many weeds are associated with particular crops such as annual morningglory in cotton; field bindweed and jointed goatgrass in winter wheat; mustards and dodder in alfalfa; and spurred anodal in chile. A crop rotation sequence that uses different cultural requirements will help manage weeds by exploiting the different growth habits. Crop rotations also permit the use of different herbicides, since herbicides that provide good control of a particular weed are labelled for one crop and not for another.

Rotating from solid-seeded crops (alfalfa or cereals) to a row crop (lettuce or cotton) provides a opportunity for weed management. A rotation from active crop production to fallow also allows for the use of different management tools.

Rarely will any of these management methods or ideas provide satisfactory management of the weeds by themselves, but they are useful when used in an integrated approach with the other methods.

Educational Weed Management

It has been said, "To error is human; to really mess up takes effort." The field of weed management is an evolving discipline. Research is constantly being done to develop more competitive plants, drought tolerant plants, and those which are better adapted for our area. Becoming aware of trends in agricultural production will improve the chances for the development of effective crop rotations, identification of optimum cultivation timings, efficacy and adaption of new herbicides labelled for crops grown in our state, and any other new piece of information available to assist in the production of agricultural commodities in New Mexico.

Physical Weed Management

Physical weed management includes any technique that uproots, buries, cuts, smothers, or burns weedy growth. Such operations have been broken down into several groupings:

1. *Hand Methods* - The hand hoe is still used, though it does pose some disadvantages since you have to have someone operate it. Increased labor cost and the lack of available labor have reduced the use of this operation in many situations. Hoeing and hand-pulling are still done in high-value crops, such as lettuce and chile, or where selective herbicides have not been developed and registered for the particular crop. For most producers, hand hoeing or pulling is utilized where few weed escapes are found and weed management needs to be implemented before weeds set seeds.

2. *Cultivation Methods* - When cultivation is employed the desiccation of weeds is going to be more complete under hot, dry conditions since tilled weeds may root again in cool, moist surroundings. Preplant cultivations with a disk or harrow after annual weeds have emerged reduce the population of weed seed. This is enhanced by pre-irrigation, if possible, should the soil moisture be below optimum levels for germination. The use of sweeps or subsurface knives to cut shoots of deep-rooted perennial before planting the crop will allow the crop to germinate and, hopefully, become established before the perennial weed reappears.

Repeated between-row cultivations, using sweeps, knives, or rolling cultivators further reduce weed competition until the crop is able to shade the soil. Throwing soil into the row at the base of the crop plants will smother smaller annual weeds. The major disadvantage of cultivation equipment is that it offers little control of the weeds in the seed row.

In many situations, cultivation is utilized along with a banded application of an herbicide. The cultivation is employed to manage the weeds between the crop rows, whereas the herbicide is used to manage the weeds in the crop row.

In crops such as pecans and grapes, the use of physical weed management options poses an additional threat, that of mechanical injury to the cane or tree as a result of trying to get as close to the cane or tree as possible. In many situation, growers have found it to be quite advantageous to physically manage the weeds between the rows and use herbicides to deal with the cane or tree row. In some situations, the growers used the herbicide to treat only the area around the tree and then physically managed the weeds all around the tree. Either way, the "mechanical blight," or injury to the desired plants, is reduced.

The seed of most plants germinate in the top 2 inches of soil. The seed supply can be reduced from this zone most rapidly if there is no disturbance to the soil. Management options such as smothering, flaming, or the use of postemergence herbicides offer no disturbance to the soil surface. Cultivation, on the other hand, brings additional seed to the zone where proper conditions exist for germination. Since viable seeds may remain dormant in the soil for many years, every possible measure should be taken to prevent the flowering and seed development. In grain fields, discing or harrowing is done during the fallow period to reduce the soil moisture depletion due to annual weeds. Reduction of established stands of perennial weeds such as field bindweed, Texas blueweed, or Johnsongrass require a rigorous program of repeating the cultivation operations. The goal is to gradually deplete the stored reserves in the roots or rhizomes, thus causing the plant to starve to death. Such operations need to be made every 10 to 14 days following emergence of new growth at least through two years.

3. *Mowing or Shredding* - Either of these options provides weed management through the prevention of seed production if the operation is done prior to flowering, and also results in depletion of stored food reserves of perennial weeds. Alfalfa producers have learned that unless the mower is set quite low the mowed mustard species will just produce a multi-stemed plant and produce even more seed. It has been observed that the mowing operation for weed management is more a convenient operation than a timely operation.

4. *Smothering/Mulches* - Whether wood or bark chips, straw, compost, or some type of sheeting is used, smothering weeds can be used to manage weeds around the base of perennial crops. The use of mulches in vegetable production is well documented though not widely used in New Mexico. Concerns expressed center around two issues 1) removal and disposal of mulch material once harvest is completed and 2) the lack of control of perennial weeds.

5. *Flame/Burning* - The use of nonselective heat from a flamer has been used for many years, particularly when it comes to managing weeds in ditches. It has also been used to control dodder in alfalfa fields. It offers nonselective control of annual weeds, but will only burn off the tops of perennial weeds and, in some situations, may create a more favorable situation for growth of this type of plant.

Preventive Weed Management

It has been said that preventive weed management is the most difficult option since it requires the producer or grower to be aware of what may happen. If he sees something that looks like it doesn't belong, chances are it doesn't. The list of plants that are not native to the state, or even the country, is long and includes examples such as Russian thistle, field bindweed, yellow and purple nutsedge, Johnsongrass, kochia, and many others. There was a time when these plants were not part of the natural plant community in fields. It is easily recognized that an ounce of prevention is worth a pound of cure. In production agriculture there are several common sense practices that comprise preventive weed management:

- Purchasing certified weed free seed.
- Using feed grain and hay that is free of weed seed. Several states in the West have adopted "Certified Noxious Weed Free Forage" programs in which producers certify that their forage is free from noxious weeds.
- Avoiding the movement of livestock from a weed infested area into an area that is not infested with weeds. Allowing some time for the weed seeds to move through the livestock prior to moving them into a clean area.
- Cleaning harvesters, hay balers, cultivators, discs and other cultivation equipment,

mowers, and any other type of farm equipment before moving from a weed infested area.

- Avoid bringing in sand, gravel, or soil from weed infested areas.
- Inspecting nursery plants for the presence of weeds.
- Keeping ditches and fence rows free of weeds.

Anything that will prevent the movement of weeds from an infested area to a noninfested area is to the grower's advantage. Any plant that is unknown to the producer can be identified through the local county extension agent.

HERBICIDE USE PRINCIPLES

In dealing with the use of herbicides, discussions will be centered on herbicide labels; classification of herbicides; and herbicides and the environment, which includes plant and soils interactions.

Herbicide Labels

When considering the use of an herbicide, the most critical component is the ability to read, understand, and follow the label. When looking at an herbicide label, the grower/producer should be able to identify the following pieces of information:

Trade name - name the manufacturer gives the product.

Ingredients Statement

Active ingredient - the name of the compound that is managing the weeds also referred to as the "common name" of the herbicide.

Inert ingredient - non-herbicidal compounds in the formulation that are added to improve the performance of the active ingredient. Such compounds include, solvents, water, surfactants, etc.

How much active ingredient is in a particular container in terms of pounds per gallon (lbs/gal) if the herbicide is a liquid formulation, or the percentage of the product's overall weight if the herbicide be formulated as a dry formulation.

EPA registration number - it is important to identify this due to the need to keep records of what is applied, especially for restricted-use herbicides.

Company who manufactured the product.

Signal toxicity word - which will be one of the following:

Toxicity Word	EPA Cat.	Meaning
"Danger"	I	Highly toxic
"Warning"	II	Moderate toxicity
"Caution"	III	Slightly toxic
"Caution"	IV	Very low toxicity

Precautionary Statements which include:

Statement of practical treatment - what to do if the herbicide gets in your eyes, is swallowed, or inhaled, or gets on your skin.

Note to the physician - telling him what to do.

List of weeds that will be controlled with the particular herbicide.

Timing and rates of application. This is critical, because some herbicides have to be applied before the weeds emerge, while others can be applied following emergence. It is also against the law to apply an herbicide in any fashion that is not in harmony with the directions on the label.

Herbicide Application Classification

When dealing with the classification of how herbicides are applied, the following terms are used to explain when and how the herbicide is to be used:

1. *Application Type* - Refers to the type of herbicide application made. When an herbicide is applied over the entire field, this type of application is referred to as a **broadcast** application. **Banded** applications are those in which the herbicide is applied as a band over the crop or seed bed.

2. *Application Timing* - Herbicides can be applied at different times in relation to crop and/or weed stage of growth. Specific terms are used to describe these different application timings.

a. **Preplant** treatments are made to the soil prior to the planting of the crop. The herbicide(s) can be applied to flat ground, either before or after pre-irrigation, and incorporated by discing the fields or listing up the beds. Such preplant herbicides, which require incorporation, are referred to as **preplant incorporated** herbicides. Preplant treatments are made after seedbed preparation and directly before planting the seed, either as a broadcast or banded application. Trifluralin (Treflan®) is a common example of a preplant incorporated herbicide.

b. **Preemergence** treatments are made prior to emergence of the weeds, or in some postemergence labels, it stipulates that it needs to be made prior to emergence of the weed, but postemergence to the crop. Pendimethalin (Prowl®) is a good example of a preemergence herbicide used in cotton. In field corn, the label for pendimethalin states that the application is to be made once the corn reaches a certain height and also requires that there be no weeds present at the time of application of they will not be controlled. Such applications require that some form of cultivation occur prior to the application of the pendimethalin in this situation. Metolachlor (Dual®) also has this type of label for chile--application made preemergence to the weeds and postemergence to the chile. Other examples of preemergence herbicides include, alachlor (Lasso®), acetochlor (Surpass® and Harness®), dimethenamid (Frontier®), and atrazine.

With preemergence herbicides there has to be some form of incorporation for them to be activated since their mode of action is associated with the germination of the weed seed. Incorporation can be accomplished either through irrigation or mechanical incorporation, depending upon what is directed by the label.

c. **Postemergence** applications are made to emerged and actively growing weeds. At the time of application the crop can either be emerged or nonemerged, depending upon the herbicide. Examples of postemergence herbicides are chlorsulfuron, dicamba, fluazifop-P, glufosinate, glyphosate, imazapyr, imazethapyr, paraquat, sethoxydim, and 2,4-D.

Herbicide Use Classification

Herbicides have been classified in many different ways. Some classifications result in several different groups such as the classification based upon mode of action of the individual herbicide. Others have very few classes and several herbicides within each class such as classification based upon timing of application. The field use classification will be used here because it presents a useful and more practical means by which the herbicides can be grouped. It is more producer friendly, in that the producer can visualize the different classes as they are presented. In this classification there are several terms that need to be defined in order to understand the different groupings.

Foliar applied herbicides are applied to the above-ground portion of the plant. Herbicides that are foliar applied have activity associated with the leaves and stems of the weed.

Selective refers to the fact that the herbicide used is more toxic to some group of plants than to others, such as grasses vs. broadleaves. The selectivity can be based upon placement; chemical reactions taking place in one plant which renders the herbicide in the plant nontoxic before it can reach its site of activity; and the crop which the herbicide was applied to. As one would expect, *nonselective* means that the herbicide is toxic to what ever plant it comes in contact with.

Soil applied herbicides are applied to the soil and have activity in the soil environment, either through controlling newly germinating weed seeds, or by their being taken up by the roots and moved within the plant through the xylem.

Systemic refers to movement within the plant. Once the herbicide gets into the plant it will move from the site of application to the site of herbicidal activity. Some herbicides move only in the xylem (water-conducting system in the plant), others only in the phloem (carbohydrate-conducting system in the plant), and others will move in both the xylem and phloem.

Nonsystemic means there is no movement within the plant. Such nonsystemic activity may be associated with the mode of action of the particular herbicide. For example, Paraquat has a mode of action that is so rapid that the plant is not capable of translocating (moving within the plant) the herbicide. Trifluralin, on the other hand, has as its site of herbicidal activity the cells in the roots, and when cell division in the roots stops, movement stops.

Using this information, the following classification of herbicides is presented:

HERBICIDE

Selective

Foliar Applied		Soil Applied	
Systemic	Nonsystemic	Systemic	Nonsystemic
* 2,4-D	* bromoxynil	* atrazine	* pendimethalin
* sethoxydim	* flumiclorac	* prometryn	* trifluralin
* dicamba		* diuron	* oryzalin
* fluazifop-P		* norflurazon	* metolachlor

* imazethapyr

Common Name	Trade Name(®)
2,4-D	several
sethoxydim	Poast, Poast Plus
dicamba	Banvel
fluazifop-P	Fusilade DX
imazethapyr	Pursuit
bromoxynil	Buctril
flumiclorac	Resource

* alachlor
* acetochlor

Common Name	Trade Name(®)
atrazine	Aatrex, others
prometryn	Caparol
diuron	Karmex, others
norflurazon	Zorial, Solicam
pendimethalin	Prowl
trifluralin	Treflan, others
oryzalin	Surflan
metolachlor	Dual
alachlor	Lasso
acetochlor	Surpass, Harness

Nonselective

Foliar Applied

Systemic
* glyphosate
* imazapyr

Nonsystemic
* paraquat
* glufosinate

Soil Applied

Systemic
* bromacil
* prometon

Nonsystemic

Common Name	Trade Name(®)
glyphosate	Roundup, Rodeo, Roundup Pro
imazapyr	Arsenal
paraquat	Gramoxone Extra
glufosinate	Finale, Rely

Common Name	Trade Name(®)
bromacil	Hyvar
prometon	Pramitol

In looking at how the different herbicides are classified it helps to see where a particular herbicide might fit into the management plan. In orchards, the management of weeds around trees is quite important, therefore a nonselective herbicide is desirable. In this case, the applicator is interested in making a foliar postemergence application. There are a couple of options to consider: glyphosate (a systemic herbicide) and glufosinate (a nonsystemic herbicide). If perennial weeds are present, the glyphosate would be the better choice. If annual weeds are present and the tree limbs have the potential for contact with the herbicide spray, then glufosinate is the material of choice since there is no need for systemic activity and should the herbicide spray come in contact with the leaves, there would be only leaf burn.

There are problems inherent in every classification scheme. This classification scheme lacks information regarding residual activity or persistence. This will be discussed later on in the manual.

HERBICIDE FORMULATION

In the process of developing an herbicide several things have to take place. First, the active ingredient has to be discovered, screened and tested. During the labeling process, the formulation for the active ingredient must be developed. The herbicide formulation is made up of the active ingredient and the inert ingredients. Inert ingredients are added for several reasons:

- To educe the potential decomposition and "settling-out" of the active ingredient while in storage.
- To improve the overall half-life of the active ingredient.
- To minimize effects on water quality.
- To improve penetration through the leaf surface.
- To allow for the active ingredient to mix with the water in the spray tank.
- To make the formulation easier to handle.

The bottom line is that inert ingredients are added to enhance the herbicidal activity of the active ingredient.

There are two types of formulations: **dry** and **liquid.** Each is subdivided into various subgroups. Within each subgroup are strengths and weaknesses associated with individual formulations.

Dry Formulations

1. *Soluble powder (S or SP)* can be equated to powdered sugar. The active ingredient is a dry, polar (water-loving) molecule, which means that when it comes in contact with water in the spray tank it will readily dissolve and form a **true solution**, just like the sugar that

is put in coffee--once it is stirred it stays in solution. These formulations require very little agitation and usually have a surfactant as part of the formulation to improve the wetting ability of the final spray solution. The active ingredient is presented as a percentage of the formulation, usually in the 80 to 90 percent range. One drawback associated with this formulation is the tendency of the powder to blow when adding it to the spray tank should there be a breeze. An example of this type of formulation is Velpar 90S® (hexazinone).

2. *Wettable powder (WP)* can be equated to adding Nestle's Quik® in a glass of milk. The chocolate powder is added to the milk and then stirred. By the time the toast is made the chocolate powder has settled to the bottom of the glass. So it is with the wettable powders, their active ingredient is not soluble in water, and is then finely ground into a powder that is added to the spray tank where it is mixed with the water to form a **suspension** in the tank. Such formulations are, thus, going to require constant agitation in order to keep them in suspension. Also associated with the wettable powders is the abrasive nature the spray solution has on the sprayer parts, particularly the spray tips. Since the active ingredient is a finely ground powder, it is obvious to see that there will be some form of abrasive wear associated with this type of formulation. Also associated with the wettable powders is the problem of dust. The wettable powder formulations are often referred to as the "first generation" formulation because many of the first herbicides were formulated as wettable powders. Examples include Sinbar 80W® (terbacil) and Dacthal 75W® (DCPA).

3. *Water dispersible granules (WDG)* or *dry flowables (DF)* are best equated with Ovaltine® when it is mixed with milk. The initial product is a granular product which, when added to milk, settles to the bottom of the glass unless it is stirred. As with the wettable powders, the water dispersible granules or dry flowables have active ingredients that are not soluble in water and form suspensions when added to the spray tank. Part of the formulating process adds dispersing agents which will aid in the dispersion of the active ingredient, but it still will not dissolve in water. Therefore, agitation in the spray tank is going to be critical. On the positive side, by creating dispersible granules, the problems associated with dust have been eliminated. This type of formulation is referred to as the "third-generation" formulation. In looking at some old herbicide literature it can be found that products which were once formulated as wettable powders are now being formulated as water dispersible granules or dry flowables. Examples of this type of formulation are many, including Karmex 80DF® (diuron), Solicam 80DF® (norflurazon), Glean DF® (chlorsulfuron), and Escort 60DF® (metsulfuron methyl).

4. *Granules (G)* look like fertilizer particles and are not to be mixed with water in the spray tank. The active ingredient that is formulated as a granule is impregnated on some form of a particle, either clay or a similar type of material. The percent active ingredient per pound of material is quite low, usually between 2 and 10 percent. Granules do not require a sprayer to make the application, just some type of dry pesticide applicator is usually needed, but this is not always the case. The granular formulation of trifluralin,

Treflan TR-10®, has a small granule that must be applied using special application equipment. Other examples of granules are Pramitol 5P® (prometon) and Dual 25G® (metolachlor).

Liquid Formulations

1. *Solutions (S)* are best visualized when food coloring is added to water. What is seen is the formation of a true solution using two liquids. Herbicides formulated as solutions require little or no agitation once the formulation is initially mixed. Since these are polar solutions, there is usually some type of surfactant added to the formulation to aid in getting the polar solution through the nonpolar (water-hating) surface of the leaf. With this, and any other liquid formulation, the active ingredient is listed as "pounds per gallon." The most common example of this type of formulation is Roundup® (glyphosate); others include, 2,4-D Amine, Banvel ® (dicamba), and Curtail 2.4S® (clopyralid + 2,4-D).

2. *Flowables (F and L)* are going to react in water like Hershey® syrup in milk, they will go to the bottom. The active ingredient of flowable herbicides is a finely ground particle suspended in a liquid carrier. They do require good agitation if they are going to be kept in suspension in the spray tank. They are referred to as the "second-generation" formulation. This formulation was developed to replace the wettable powder formulation because of the dust problem associated with the wettable powders. Though there is not dust problem associated with the flowable formulations, they do have a problem associated with cleaning out all the residue from the container. With this in mind, the dry flowables were developed to eliminate the residue problems associated with the flowables and the dust problem associated with the wettable powders, hence the "third-generation" of formulations. Examples of flowables include Atrazine 4F® (atrazine) and Marksman 3.2F® (dicamba + atrazine).

3. *Emulsifiable concentrates (EC)* have a water-insoluble liquid active ingredient which, when mixed with water, separates into two layers. In order to overcome this problem, an emulsifier has been added to the formulation. This emulsifier, which is a molecule which has a polar head and a nonpolar tail, is added to the formulation.

O--

Polar Head Nonpolar Tail

The nonpolar tail is attracted to the nonpolar active ingredient and surrounds the molecule. This leaves the polar head exposed, and when it comes in contact with the water molecules all they see is a polar head and they form a nice solution as a result of the addition of the emulsifying agent. It can be compared with a Hostess Chocolate Cupcake®, the creamy nonpolar filling is not seen because the emulsifying agent, the polar chocolate cake is surrounding it. There may be more than one emulsifier added to the formulation along with solvents, which also aid in the formulation. These formulations form a milky-looking emulsion when added to water and require little agitation once they are initially mixed. Examples of emulsifiable concentrates include Prowl 3.3E® (pendimethalin, Treflan 4EC® (trifluralin), Dual 8E® (metolachlor), Harness® and Surpass® (acetochlor), and Fusilade DX® (fluazifop-P).

4. *Microencapsulated (MC)* have the active ingredient encased in a plastic coating. These plastic-coated molecules are then suspended in a water base. The encapsulation protects the herbicide from adverse conditions and prevents loss from evaporation and leaching. The resulting product is an herbicide which is time-released. Since the plastic coating polymers are not water soluble, this type of formulation requires constant agitation in order to keep the active ingredient in suspension. Lasso Micro-Tech® (alachlor) is an example of this type of formulation.

ADJUVANTS

Spray adjuvants are used to modify or maximize the performance of an herbicide. For best results, it is important to understand the target weed, the herbicide to be used (since different herbicides require different types of adjuvants), and the environmental conditions present at the time the application is to be made. The first thing to point out is that if the label of the herbicide identifies a certain type of adjuvant, then it is to your benefit to follow the label directions. One common problem associated with the use of adjuvants is that at times they are added when the label makes no reference to the need for adding one. It should be noted that if injury occurs as a result of the addition of a nonrecommended adjuvant, the grower or producer assumes all responsibility.

There are several types of adjuvants, and often we use the terms activator, additive, detergent, soap, spreader, surface-active agent, and wetting agent interchangeably. However, these are all not the same and will result in different physiological responses. The following is a listing of some of the different classes of adjuvants:

1. *Surfactants* are responsible for the reduction in surface tension of the spray droplet, which results in increased spray coverage and penetration. Surfactants are usually classified as either anionic, cationic, or nonionic. In agricultural situations, the most commonly used surfactant is the nonionic surfactant because it is relatively unaffected by water hardness and is compatible with all types of herbicides. Nonionic surfactants may also contain fatty acids. The "active ingredient" percentage should be at least 80 percent for most nonionic surfactants. Other names for this group of adjuvants are spreader, wetting agent, and surface-active agent.

2. *Crop oils* contain phytobland paraffinic oils. They are also referred to as "dormant oils." Crop oils are 95-98 percent oil and the rest is nonionic surfactant. Crop oils are usually used at the rate of 1-2 gallons per acre.

3. *Crop oil concentrates (COC)* are phytobland oils (petroleum based), or vegetable oils with a surfactant added to make them miscible with water. The oil increases the penetration of the spray through the cuticle of the leaf. They contain 83-85 percent oil and the rest nonionic surfactant. They are used at the rate of 1-3 pints per acre.

4. *Buffers* are added to the spray solution to maintain or reduce the pH.

5. *Compatibility agents* help maintain emulsion stability when herbicides are mixed and applied with liquid fertilizer solutions.

6. *Defoamers* are used to eliminate air trapped in the foam of the spray solution. They are usually silicones or siloxanes.

7. *Drift control agents* - modify the spray characteristics to reduce the potential for drift by minimizing small droplet formation, that are more susceptible to off-target movement.

8. *Stickers* are adhesives which are added to increase the amount of spray deposits that remain on the leaf surface. They are also used to maintain protective sprays of fungicides and insecticides.

The proper selection of the adjuvant, when the label directs, is critical since different herbicides may require different adjuvants. An herbicide which is formulated with the addition of a surfactant in the formulation is not going to respond favorably to the addition of a crop oil concentrate; in fact there may be a reduction in herbicidal activity. The label will direct which adjuvant to use under different situations. Certain plants may be injured when a crop oil concentrate is added to the solution, but not when a nonionic surfactant is selected.

HERBICIDES AND THE ENVIRONMENT

Plant Interactions

In order for an herbicide to affect the plant, there are a couple of requirements which have to be met:

a. The herbicide has to come in contact with the plant. This is not as critical with postemergence herbicides as with the preemergence herbicides. Preemergence herbicides are applied with the understanding that they will be moved into the soil prior to the germination of the weed species. Often times the material is applied and left alone on the top of the soil. Though the label may indicate that it will remain in its herbicidally active form for a couple of weeks, the weeds may not wait and may germinate before the active ingredient is moved into the zone of herbicidal activity.

b. Once inside the plant, the herbicide has to make it to its site of herbicidal activity within the plant. It is this principle that is involved with some of the selectivity that is observed.

There are several factors that are going to influence whether the herbicide comes in contact with the plant or gets to its site of herbicidal activity within the plant. Some of the more common ones include:

a. *Age of the plant* - It is well understood that younger more actively growing weeds are more susceptible to control than are the established more mature plants. Associated with this growth factor is the fact that older leaves exhibit a reduced translocation rate which will decrease the movement from the site of herbicidal uptake to the site of herbicidal activity.

b. *Shape of the leaf* - Broader leaves will affectively retain more herbicide than narrow leaves.

c. *Surface makeup of the leaf* - Here we are concerned with the amount of cuticular waxes deposited on the leaf surface. It is this layer of wax that keeps water in the plant and keeps the herbicide in its water carrier on the outside of the leaf. Varying level of these waxes will then influence the movement of the herbicide molecule through the leaf, with the thicker layer posing a greater barrier than the thinner layer.

Also associated with the surface of the leaf is the presence, or absence, of hairs or trichomes. These structures often keep the herbicide spray droplet from coming into direct contact with the leaf surface. As a result the amount of active ingredient that makes it into the plant is reduced.

d. *Environmental condition* - The influence of the environment is obvious and considerable. It is the principle of stress placed on the plant, as a result of its environment, that is of interest here. Stress due to lack of moisture, or heat, or even physical stress results in a reduction in translocation or movement in the plant. The formation of a thicker cuticle, which makes it more difficult for the herbicide to get from the outside in, is also the result of stress placed on the plant.

By understanding some of the factors involved in the interactions of herbicides and plants helps one to appreciate what happens when an herbicide is applied to the plant surface and the desired result is not achieved. Knowing how a plant responds to stress also allows for an understanding of why the label points out, "do not apply to stressed plants."

Soil Interaction

In addressing the interaction between the herbicide and the soil, the two major players need to be discussed: the **herbicide** and the **soil**.

With the herbicide there are four major factors involved with its behavior in the soil: solubility, adsorption, degradation or breakdown, and residual. It is the first two which are the most critical in relationship to the movement of herbicides through the soil profile.

a. *Solubility* - The solubility of an herbicide is based on the amount of that particular material that will dissolve in water or the liquid phase of the soil. These will range from being practically insoluble, such as trifluralin, pendimethalin, and oryzalin, to those which readily dissolve in water including glyphosate, dicamba, and 2,4-D amine salts.

As water moves down through soil, it carries with it water-soluble compounds. This movement is referred to as **"leaching."**

It is understood that the greater the water solubility, the greater the potential for its movement through the soil with the liquid phase.

In looking at the solubility values of these two examples, it is easy to predict which of the compounds will dissolve in water more readily.

· Glyphosate	1,000,000 mg/l sol.
· Oryzalin	2.5 mg/l sol.

b. *Adsorption* - Also referred to as "magnetic charge" is the next factor to consider in relationship to the herbicide and its relationship to soil movement. Along with its characteristic solubility, each herbicide has a characteristic charge associated with it. This charge can range from little or no charge to strongly magnetic.

Herbicides or compounds with an overall positive charge will be tightly bound to the soil fraction, while those with an overall negative charge will be repelled from the soil fraction to varying degrees.

Many soil factors influence pesticide adsorption. Soil texture is one of the major factors. Soils high in organic matter or clay are going to be more adsorptive than coarse, sandy soils. Other factors include pH, temperature, and water content of the soil.

In reporting this characteristic, the term "Koc" is used to measure the degree to which a particular herbicide is bound either through chemical or physical bonds.

When looking at the following examples, note that "Koc" values above 1,000 indicate that the herbicide is held quite tightly to the soil fraction.

In looking at one example we now have two pieces of information to report:

· Glyphosate:

* Solubility . . . . 1,000,000 mg/liter
* Koc Value 10,000

Using these two pieces of information, what can be concluded regarding this particular herbicide's ability to leach? From the solubility value, one would conclude it should leach, yet on the other hand, the Koc value is in the range that indicates a strong binding to the soil phase. What we see here is opposing factors, and one has to over ride the other. In this case it is the adsorption or binding that overrides the solubility. This results in the fact that glyphosate will not leach through the soil because it is held to the soil very tightly, so tightly that it cannot be moved through the soil with the soil water. This is understood, because when this herbicide is used, we find there is no soil activity. This is a postemergence systemic herbicide that offers no residual activity.

Take home message: As important as solubility potential of a particular herbicide may be, it is found that the magnetic charge, as it relates to the soil binding of the herbicide, is a more important factor to consider when discussing the movement of herbicides in the soil.

c. *Degradation or breakdown* is the process whereby reactions take place to render the active ingredient inactive. The following are some of the different ways herbicides can be degraded:

1. Microbial degradation of herbicides is the breakdown by fungi, bacteria, and other microorganisms that use the herbicide as a food source.

Soil conditions such as moisture, pH, aeration, temperature, and the amount of organic matter affect the rate of breakdown under the microbial method.

2. Chemical decomposition is the breakdown of the herbicide by non-living soil processes, including hydrolysis, dealkylation,substitution, and others.

Temperature, moisture, pH, chemical and physical properties of the herbicide, and adsorption are all involved in the chemical degradation process.

With these two breakdown systems there is a tight relation to the soil conditions. Those conditions which favor microbial decomposition, also favor chemical degradation. These include high organic matter, warm soil temperatures, and adequate moisture.

Under conditions of low organic matter, hot and dry soils (which is the situation for a lot of our state) what does this tell us about the breakdown of herbicides under those conditions--it is slower.

3. *Photodecomposition* - Certain herbicides can be broken down by sunlight. This is done in a way in which the bonds between certain elements are excited to the point of breaking or shifting. When this occurs the molecule changes shape and is rendered inactive as an herbicide.

d. *Persistence* is the ability of an herbicide to resist breakdown. The rate of breakdown, which is persistence, is measured in terms of half-life of the active ingredient. The chemical half-life is the time required for half of the original herbicide application to be broken down into its metabolites.

Some of the factors influencing persistence include:

- Herbicide solubility
- Herbicide adsorptivity
- Mechanism of breakdown
- Environmental conditions
- Soil type
- Organic matter content

In dealing with the soil aspects of this interaction between herbicides and the soil, we readily identify a couple of critical factors.

a. *Soil Texture* - With this we are concerned with the different soil particles, sand, silt, and clay. The soil texture affects the movement of herbicides in several ways:

Movement of water through the soil, with coarser soils having a more rapid downward movement.

Binding or adsorption. Coarser soils have fewer binding sites and can be saturated with the herbicide at a lower application rate than can the heavier soils.

Degradation. Heavier soils have more organic matter, moisture, and ideal temperature range for the degradation to occur microbially and chemically.

b. *Organic matter content* is the amount of organic matter in the soil. This value will greatly influence how well the soil can retain the herbicide. Increasing the soil's organic matter content, through practices such as application of manure or plowing under cover crops, increases the soil's ability to hold both water and dissolved herbicides in the zone of herbicidal update and degradation.

We have covered the two major players involved in the process of pesticide movement. We have identified the different factors associated with the different processes. The status of herbicides in the soil is a complex situation. There are three major fates associated with the reaction of an herbicide and the soil: adsorption, movement, and degradation. These are all interrelated and difficult to separate on their own, but it is necessary to have a general understanding of them in order to have a better feeling for what is going on in the soil once an herbicide comes in contact with the soil.

By taking the time to discuss these different principles and factors influencing the activity of herbicides in the soil, it becomes apparent there are no simple statements that can be made regarding the status of herbicides in the soil without a good foundational background.

NOTES