MISC0547E

Weed Control Training Supplement for Limited Private Applicators and Rancher Private Applicators

Chris M. Boerboom, Carol A. Ramsay, and Bob Parker

Washington State University Extension

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Extracted from Agricultural Weed Management (MISC0167)

This is a supplement to the training materials for the Limited Private Applicator and Rancher Private Applicator pesticide licenses. Both the limited and rancher licenses target weed control as the major focus of pest control. The WSDA pesticide exams for each of these categories include questions that are not currently found in the Private Applicator Pesticide Education Manual (MISC0126). This supplement contains extracted text from the Agricultural Weed Management Manual (MISC0167) and covers in more detail basic weed biology and management concerns. Between this supplement and the Private Applicator Pesticide Education Manual, all of the material contained in the exams is covered.

Chris M. Boerboom, Ph.D., former Washington State University Extension weed specialist
Carol A. Ramsay, M.S., WSU Extension project associate, WSU Pullman.
Bob Parker, Ph.D., WSU Extension weed scientist, WSU Prosser Irrigated Agriculture Research and Extension Center.

Contents

Introduction

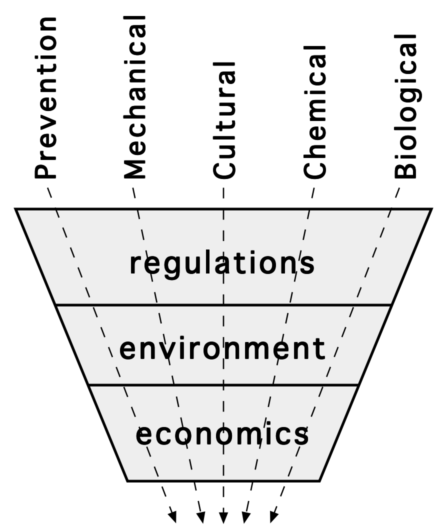
A "weed" is an undesirable plant. Any kind of plant may be considered a weed if it becomes a hazard, nuisance, or causes injury to us, our animals, or our cultivated crops. In agriculture, weeds are a major problem. They compete with crops for light, water, and nutrients. Some release chemicals harmful to other plants. Competition often decreases crop yield. Harvesting weedy fields also is more difficult and costly. Buyers may dock the price of the harvested crop that is contaminated with weed seeds or weed parts because of lower quality. In forage crops, weeds may alter crop palatability or taint the taste of milk. Some weeds are poisonous to humans or livestock; others cause skin irritations and infections.

A plant may be considered a weed in one instance and beneficial in another. For example, quackgrass may compete with crops, yet it stabilizes steep slopes to prevent erosion. Barley becomes a weed when it "volunteers" in wheat. Some weeds provide food and shelter to animals and beneficial insects.

The benefits from weed management are noticeable both in the field and at the bank. Crops grown with an eye toward good weed management are more tolerant of other pests, produce higher yields, and lend themselves to more efficient harvests. We benefit economically from higher yields and net profit when using a cost-effective control program.

Historically, people spent a great deal of time and effort pulling, hoeing, mowing, chopping, and otherwise destroying weeds. The introduction of chemical herbicides greatly increased our ability to manage weeds economically and efficiently. However, the use of herbicides requires the knowledge and skills to handle and apply these materials properly and safely.

An integrated management approach to weed control obtains the greatest economic benefit while protecting the environment and observing regulations. To design a management plan against a particular weed, first identify the weed and learn something about its biology. Understanding the weed's biology and its habits will help you decide whether the weed needs to be controlled. If control is necessary, evaluate the suitability of various control tactics and determine the costs of these measures. Next, evaluate the impact of the desired control measures on the environment. Using certain herbicides may not be wise on a particular site because of environmental concerns. Similarly, some mechanical practices may cause unacceptable damage to certain sites. After considering all of these factors, design and implement the management plan.



Integrated Weed Management (IWM)

The best management plans use an integrated approach, drawing on more than one method for weed control. Integrated weed management (IWM) uses several control methods together to control weeds economically and efficiently.

If you select chemical control as a portion of your management strategy, follow the herbicide label instructions to ensure safe and effective application.

Basic Weed Science

Origin of Weeds

Weeds are classified as native or introduced according to their origin. Plant origin may help determine weed management strategies and the difficulty of control.

Native weeds have historic origins in the area and were not brought here by human activity. Natural enemies, competition from other plants, and environmental conditions hold many native weed populations in check. Sometimes these plants may be troublesome, but native plants rarely become problem weeds.

Introduced plants came from other parts of the country or world by accident or unintentionally. The Pacific Northwest often lacks the weed's natural predators or limiting factors such as climate to hold them in check. Lack of natural control allows the weeds to flourish and spread. Most problem weeds are introduced plants.

Escaped plants were intentionally introduced by humans as crops, forage, or ornamentals. They subsequently have spread beyond their intended areas. Again, the natural mechanisms that suppress these weeds were not imported with them or are not present in the new environment. Dalmatian toadflax, Scotch broom, and kochia are examples of escaped ornamental plants.

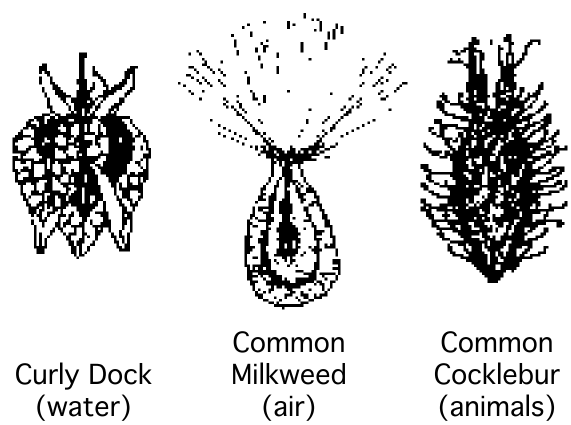
How Weeds Spread

Weeds spread when outside agents move or carry seeds or growing plant parts (roots, rhizomes) into new territory. Some invading weed species have evolved special seed shapes or structures to aid their movement by wind, water, or animals. Also, many plants have vegetative parts that resprout new roots or shoots. When carried into new areas, these plant fragments may grow and start new infestations.

Wind carries many seeds to new areas. Weeds such as dandelions have a parachutelike attachment that carries the seed in the wind. For other weeds, the entire plant moves or tumbles with the wind, dropping seeds as it rolls; tumble mustard and Russian thistle are common examples.

Water from rain or irrigation and the subsequent surface runoff transports many seeds. Some seeds have an oily coating or an air bladder to aid flotation. Rivers, streams, and irrigation canals move large numbers of seeds.

Mammals, birds, and humans carry seeds on their bodies, dropping them into new areas. Plants have seed shapes (burs, hooks, barbs) that cling to feathers, hair, and clothing. Some seeds are ingested and excreted by wild or domestic animals. The seeds often survive and subsequently germinate after they have passed through an animal's digestive tract.



Weed Seed Dissemination

People unintentionally move and introduce weeds over long distances. Equipment (combines, trucks, cultivators, recreational equipment, automobiles) and livestock feed carry seeds to new sites. Planting crop seed contaminated with weed seeds is a major agricultural problem.

Weed Establishment and Persistence

Weeds rapidly become problems when introduced into most agricultural settings if the environment is suitable. Standard tillage and grazing practices disturb the soil or ground cover and leave an opening for weeds to germinate and compete with crop or range plants. Once established, weeds are prolific seed producers, ensuring their survival.

Number of seeds produced per plant

Weed	*Seeds per Plant*
Common mullein	223,200
Redroot pigweed	117,400
Shepherdspurse	38,500
Kochia	14,600
Wild sunflower	7,200
Canada thistle	680
Wild oat	250

Source: Stevens, O.A. Amer. J. Bot. 19:784-794.

Weed seeds, depending on the species, can lie dormant in the soil from a period of a few months to many decades. This long seed viability helps guarantee weed survival. Because weeds can produce high numbers of seed and many weed seeds can survive in the soil for years, weed management is usually a long-term process.

Weed Classification and Life Cycles

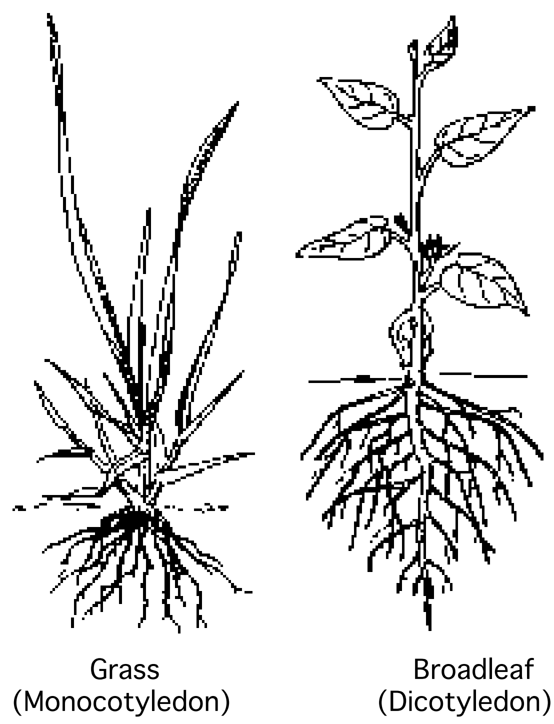
Accurately identifying weeds is the first important step in an effective weed management program. You may easily recognize some of the more common weeds; however, identifying some new weed species is a difficult task requiring a working knowledge of plant anatomy and classification.

People and resources available to help you identify plants or weeds exist through the university and county extension systems, county noxious weed programs, and field personnel. Resources include taxonomic keys, picture guides, pamphlets, and weed identification computer software.

It may not always be necessary to identify the exact weed species you are trying to control. But knowing whether a weed is a grass or a broadleaf and understanding its life cycle will help you select a successful control method.

Major plant groups are designated according to the ***structural characteristics*** common to all the plants in each group. For instance, we generally divide weeds into two major groups: monocotyledons and dicotyledons.

Monocotyledons (grasses and sedges). Seedlings have only one seed leaf (*mono*=one; *cotyledon*=seed leaf). Leaves are narrow and upright. Leaf veins run parallel to leaf margins. The roots are fine and branching (fibrous). Sedges differ from grasses in having triangular-shaped stems rather than round or oval ones.



Two major plant groups

Dicotyledons (broadleaf plants, shrubs, and trees). Seedlings have two seed leaves (*di*=two; *cotyledon*=seed leaf). Leaves are generally broad with netlike veins. The root system is coarse, often having a strong taproot. Plants may be herbaceous (a plant that does not regrow from woody tissue above the ground) or they may be woody (brush, shrubs, and trees). Brush and shrubs have several stems and rarely grow taller than 10 feet. Trees usually have a single stem (trunk) and generally grow taller than 10 feet.

Another type of weed classification is based on the ***plant life cycle.*** The effectiveness of a weed management plan often depends on knowing the weed's life cycle. Some control methods are more effective during certain stages. Successful management depends on timing control measures to coincide with the weed's specific, vulnerable stages. Plants are classified by their life cycle as annuals, biennials, or perennials.

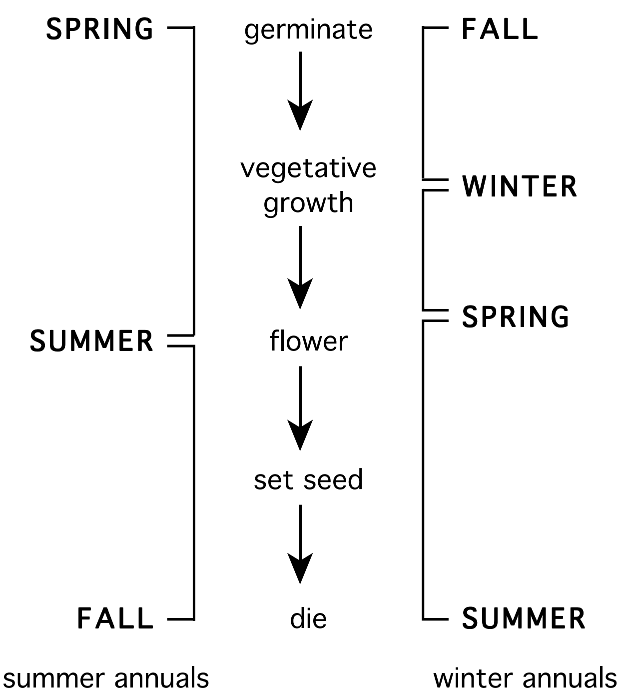
Annual plants complete their life cycle in less than one calendar year. Normally annuals are the easiest weed type to control, although they are the most common weed type in cultivated fields. Annuals are a continual problem because of an abundance of dormant seed, fast growth, and high seed production. They may actually cost more to control than perennial weeds due to high numbers of different species. There are two types of annual plants: summer annuals and winter annuals.

List of common summer and winter annuals

Summer annuals	*Winter annuals*
Barnyardgrass	Annual bluegrass
Green & yellow foxtails	Common chickweed
Common lambsquarters	Tumble mustard
Common ragweed	Corn cockle
Knotweeds	Cornflower
Pigweeds	Downy brome
Puncturevine	Field pennycress
Common purslane	Jointed goatgrass
Russian thistle	Shepherdspurse
Wild oat	

Summer annual plants germinate (sprout from seed) in the spring or summer. They grow, flower, set seed, and die before winter. The seeds lie dormant in the soil until the next spring or several springs later, when the cycle repeats itself.

Winter annual plants germinate from late summer to early winter. They overwinter in a vegetative stage. In the spring or early summer, they flower, set seed, mature, and die, but live for less than one full year. The seeds lie dormant in the soil during the summer months. Winter annuals are most troublesome in fall-seeded crops, such as winter wheat, and inperennial crops, such as alfalfa and mint, which go through winter dormancy.



Life cycles of annuals

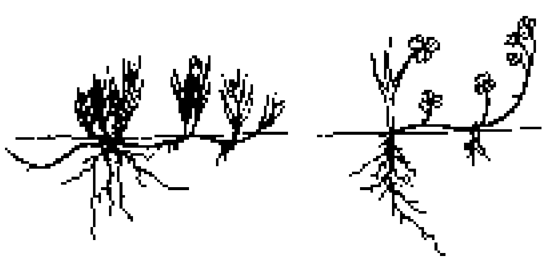
Biennial plants complete their life cycle within 2 years. In the first year, the plant forms basal leaves (rosette) and a tap root. The second year the plant flowers, matures, and dies. There are no biennial grasses or sedges.

Sometimes people confuse biennials with winter annuals. Winter annuals normally live during two calendar years and during two seasons, but they complete their life cycle in less than 12 months.

List of common biennials

Tansy ragwort
Common mullein
Common burdock
Bull thistle
Poison hemlock

Perennials live more than 2 years, and some may live almost indefinitely, resprouting from vegetative plant parts. Because of these persistent, resprouting roots, rhizomes, stolons, tubers, plant fragments, etc., perennials are difficult to control. To avoid these problem weeds, do not let perennial seedlings become established. Most reproduce by seed and many spread vegetatively as well. Perennials are classified according to how they spread: simple or creeping.



spread by rhizomes — spread by stolons

Vegetative propagation by creeping perennials

Simple perennial plants resprout from crown buds on the tap root and spread by seed. The roots are usually fleshy and may grow very large. Dandelion is a common example; if you cut it off below ground level, the plant can resprout from the taproot.

Creeping perennials reproduce by creeping roots, creeping aboveground stems (stolons), or creeping belowground stems (rhizomes). In addition, they can reproduce by seed. Canada thistle and field bindweed sprout new shoots from creeping roots. Bentgrass and bermudagrass sprout new plants from aboveground runners or stolons. Quackgrass and Johnsongrass sprout new growth from rhizomes, the underground stems. Yellow nutsedge also produces rhizomes, but the rhizomes end with underground tubers that sprout new plants.

List of common perennials

Simple	*Creeping*
Common dandelion	Leafy spurge
Curly dock	Field bindweed
Buckhorn plantain	Canada thistle
Broadleaf plantain	Mouseear chickweed
Pokeweed	Ground ivy
	Bermudagrass
	Johnsongrass
	Quackgrass
	Yellow nutsedge

Once a field is infested, creeping perennials are probably the most difficult group to control. Control might require repeated cultivation or mowing, herbicide application(s) (possibly a residual herbicide), or combinations of the above.

Weed Management Strategies

Weed management demands careful attention to the cropping system and the surrounding environment. The first step in a management plan is to be vigilant and aware of potential problem weeds. Weeds will infest any ground disturbed by cultivation, grazing, or erosion. Establish a list of potential invaders and watch for the introduction of noxious weeds (state-regulated weeds, see section *Laws Affecting Weed Management*). Review the biology of the weeds already present and identified. Once you establish a working knowledge of weeds, you can evaluate potential management strategies.

Understanding the environment where weeds compete or grow is important. Certain weeds invade or grow in rangeland, while others appear on cropland. Particular cropping systems provide favorable environments for specific types of weeds. For example, more intensively tilled row crops discourage the growth of perennial weeds while encouraging the growth of annuals. Established perennial crops, such as alfalfa, strongly outcompete summer annual weeds, but perennial weeds may increase due to a lack of tillage. Where similar crops are grown repeatedly, weeds favored by the cropping system (tillage, herbicide, harvest) will increase.

A total weed management approach is necessary to control weed populations in agricultural land or rangeland. First, prevent weeds from invading. If weeds become established, use mechanical, cultural, biological, or chemical control methods. Often these methods are used together. One approach may be very effective on small infestations, but less practical on larger ones. Tailor the management plan to each particular situation. All management programs require many years of effort.

Prevention

The best way to manage weeds is by keeping them out of fields or rangelands. If they are not present, they do not require control. Stop new weeds from infesting an area.

- Make sure that weed seeds are not carried onto the area with contaminated crop seed, water, feed, manure, or on machinery.
- Prevent new weeds from going to seed. Control them prior to seed set.
- Control weeds along fencelines and roadways.
- Prevent the spread of perennial weeds by not dragging or moving vegetative parts with machinery.

The most common introduction of weeds into croplands is by planting crop seed contaminated with weed seed. Plant certified crop seed (seed certified free of noxious weed seeds) to prevent this.

Know which weeds may potentially invade new areas. Keep a close watch for them.

Mechanical Control

Mechanical methods are the oldest methods of weed control. These include hand-pulling, hoeing, blading, grubbing, mowing, burning, flooding, mulching, cultivation, and other tillage operations.

Tillage works by disturbing the root system. The objective is to dislodge or cut the root system so the plant dies from drying out before it can reestablish its roots. Tillage easily controls small weeds and is most effective in hot, dry weather with dry soils. To effectively control perennial weeds, repeat tillage each time new shoots emerge (about every 2 weeks) for one or two seasons. Make sure you cut off every plant.

Tillage also can kill weeds by burying them. For example, a row crop cultivator can throw soil over small weeds growing in the crop row. This is effective on most small annual weeds. Most annual weeds die when all growing points are buried. Burial is not effective on established perennial weeds since their underground parts will resprout.

Mowing reduces annual weed growth, but will not prevent seed production because most weeds just flower again closer to the ground. Mowing usually favors perennial weeds at the expense of annual weeds.

Flooding is another weed control method. Surround the weed-infested areas with dikes, then flood with 6 to 10 inches of water for 3 to 8 weeks in summer. This method is more effective in sandy soils than in heavy soils and works by denying oxygen to the roots and leaves. Flooding has little effect on weed seeds in the soil.

Fire removes undesirable plants from ditch banks, roadsides, and other waste areas and removes unwanted underbrush and broadleaved species in conifer forests. It provides annual weed control in some row crops. Burning also removes fire hazards, clears waterways, kills insect and fungus pests, lessens the amount of trash to be plowed or disced, and removes unsightly debris. Green plants may require two burnings, one to dry out and a second to burn the dried weed. Fire will not kill weed seeds buried in the soil, but can destroy seeds on plants and in surface litter under favorable conditions. *If you want to use burning in your management plan, check with the Washington Department of Ecology. New burn regulations went into effect in January 1993 requiring permits for agricultural burning.*

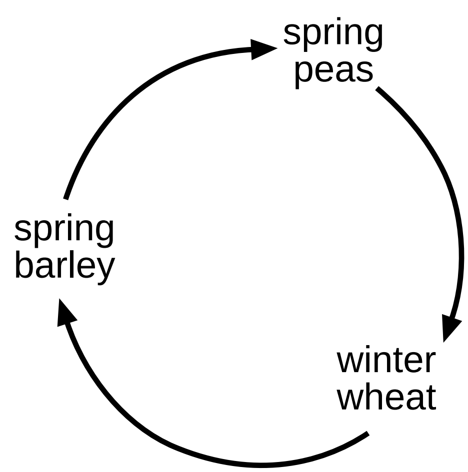
Mulching with bark chips, plastic, and other materials can control weeds. Emerging seedlings die because they never receive sunlight. The covering must keep out all light to kill the weeds.

Cultural Control

Cultural weed control methods use practices common to good land and water management to help the crop compete against weeds.

Crop competition is fundamental to a weed control program. Crops and crop varieties differ in how efficiently they compete for sunlight, water, and nutrients against weeds. If possible, select crops or crop varieties that have beneficial growth habits, such as rapid establishment and canopy closure or rapid regrowth after harvest (for example, alfalfa). Early weed competition is usually more detrimental to a crop than later competition when the crop is well-established. To reduce weed impact, establish a good, uniform crop stand quickly. Time the crop planting carefully so the crop will be as competitive as possible.

Crop rotation prevents or reduces buildup of high populations of certain weeds common to a particular crop. When following the same crop and cultural practices year after year on the same land, crop-associated weeds tend to multiply rapidly and compete successfully with the crop plants. For example, to manage jointed goatgrass, a winter annual weed in winter wheat, rotate to spring crops where tillage prior to spring planting kills the weed.



Winter wheat crop rotation

Rotating crops is an efficient way to reduce certain weed populations. When combined with chemical control, rotation offers an effective way to control most weeds. Crop rotation often improves crop quality and yields, reduces plant disease, nematode, and insect problems, and improves soil conditions. If using residual herbicides along with crop rotation, make sure the herbicide will not injure subsequent crops.

Nurse crops or companion crops sometimes are planted with the desired crop to suppress weed growth during crop establishment. You can either control nurse crops with chemicals once the primary crop becomes established or use an early maturing annual as a nurse crop that dies out as the desired crop becomes established. Nurse crops germinate and grow quickly which lessens weed pressure. For example, to establish alfalfa without using herbicides, plant oats (nurse crop) with the alfalfa to compete with the weeds until the alfalfa takes hold. Select nurse crops carefully because they can compete for available resources, just like weeds do.

Irrigating fields before planting may cause many weed seeds to germinate. Control germinated weeds with mechanical or chemical methods before planting the new crop.

Biological Control

Biological weed control is the introduction of a "natural enemy" of the weed that will not harm other plants or crops. The objective of biological control is reduction of weed populations to an acceptable level, not eradication. Biological control works particularly well in rangeland, forests, and noncropland areas where weeds live in a relatively undisturbed habitat and where other control methods are prohibitively expensive.

Insects are the most successful natural enemies to date. Other control agents include disease organisms and selective grazing by livestock, rodents, and fish. Scientists collect natural enemies from areas of the world where the weed is controlled by its natural enemies in its native habitat. Scientists then test to make sure the natural enemy (agent) attacks only the target weed and not any economically important plants or animals. The agent also must survive in the new environment. Once agents pass these tests, they are mass reared in the laboratory and released into the field. It may take 3 to 10 years for the agent to effectively suppress weeds to a noneconomic level.

Insects, disease organisms, or other predators control weeds by

- killing the plant directly,
- weakening the weed so other more aggressive plants can outcompete it,
- reducing weed reproduction by destroying flowers or seeds, or
- creating wounds, such as insect damage, which allows diseases to enter the weed and infect it.

Biological weed control can be very effective but has limitations. A single biological control agent cannot control a broad spectrum of unrelated weed species. Each natural enemy feeds on only one or several closely related weed species. Biological control is generally a slow process and does not provide immediate or total weed control. Some target weeds always must be present to sustain the biological control agent's population.

Biological control often uses several agents to attack one plant species in different ways. One agent may attack the seed, one the roots, and another the stem. This strategy increases the overall effectiveness of the program.

Some biological weed control agents in Washington

Problem weed	*Agent*	*Role*
Canada thistle	*C. litura*	root weevil
	U. cardui	stem gall fly
	O. ruficauda	seed head fly
Diffuse knapweed	*U. affinis*	seed head gall fly
	U. quadrifasciata	seed head gall fly
	S. jugoslavica	root boring beetle
	P. inspersa	root boring moth
Rush skeletonweed	*C. schmidti*	stem gall midge
	E. chondillae	bud gall mite
	P. chondrillina	rust fungus
Spotted knapweed	*U. affinis*	seed head gall fly
	U. quadrifasciata	seed head gall fly
	M. paucipunctella	seed head moth
	A. zoegana	root boring moth

Washington has several biological control success stories. Two leaf-feeding beetles and a gall-forming midge were successfully introduced to control St. Johnswort, *Hypericum perforatum* L., in rangeland. Rush skeletonweed, *Chondrilla juncea* L., is being brought under control by a fungus, a gall-forming midge, and a gall-forming mite. A program using the cinnabar moth and a flea beetle is successfully controlling tansy ragwort, *Senecio jacobaea* L. More programs (nearly 30) are ongoing and many biological control agents are under research and development.

Chemical Control

Herbicides are chemicals that kill, change, or inhibit plant growth. They are "phytotoxic," meaning injurious or toxic to plants. Since the mid-1940s chemical control has experienced dramatic growth. Although herbicides are efficient weed management tools, improper use or abuse of these chemicals continues to jeopardize the continued availability of some herbicides. You must understand the complexities associated with chemical weed control to use herbicides safely and effectively.

Herbicide Activity and Selectivity

To select the best herbicide for a particular weed in a crop, you must understand how herbicides:

- enter and move in plants;
- kill or control plants; and
- how they can be used to kill only the targeted weeds, not the crop or other plants (selective control).

Uptake and Movement —Contact versus Translocated

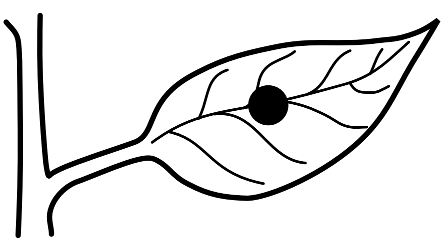
Herbicides are either applied: 1) directly to the plant, or 2) applied to the soil where the weed roots or emerging shoots absorb the herbicide. Plants absorb herbicides into their tissues, but herbicide movement and action can differ within a plant, influencing their effectiveness. **Herbicides only need to kill the shoots of annuals or biennials, but must move to the roots to control perennials.**

Contact herbicides generally are applied directly to plant foliage and kill only plant parts they directly contact. They do not move throughout a plant. They generally rupture cell membranes so the cell contents leak out. Activity is often very quick with visible damage occurring in a few hours. **You must obtain even herbicide distribution over the entire weed. Only the areas the chemical touches will die.**

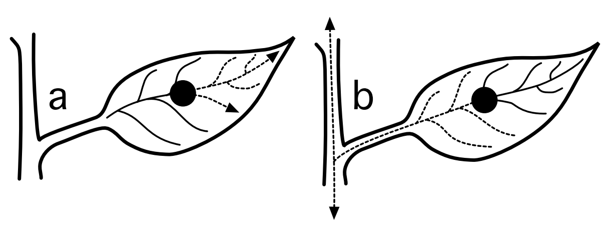
Contact herbicides effectively control some annual weeds, but kill only the shoots of perennial weeds, leaving the underground system to resprout. Repeated applications to perennial weeds may deplete the food reserves in underground plant parts, eventually causing death.

A common nonselective use of contact herbicides, like endothall, paraquat, and diquat, is the preharvest drying (desiccation) of crop foliage as in potato and seed crop production. In these cases, quick-acting herbicides having short-term residual activity kill the foliage of the crop to aid in harvesting. Another popular use of contact herbicides is to control emerged weeds before planting or before crop emergence. Some contact herbicides, such as Buctril and Basagran, are used selectively in crops to control certain weeds.

Translocated (systemic) herbicides are absorbed through the foliage, shoots, or roots and move throughout plants. If absorbed from the soil by roots, translocated herbicides move with water transported to the stem and leaves. Some of the translocated herbicide sprayed onto leaves will move to actively growing plant parts like shoot tips and roots. As a result, injury is often first seen at growing points. Death of the plant occurs later, days or weeks following herbicide absorption.



Contact herbicides do not move within the plant; they affect only the plant tissues they contact



Translocated herbicides move to the leaf and stem tips (a) or move upward or downward in the plant within the conductive tissues (b)

Some of these chemicals are selective and will control broadleaf weeds in grass crops or vice versa. Because they can move within the plant, some of these chemicals effectively control perennial weeds and do not have to be applied uniformly over the whole plant to produce good results. Most herbicides are translocated or systemic herbicides. Some examples are 2,4-D, MCPA, picloram, diuron, thifensulfuron, glyphosate, and dicamba.

Modes of Herbicide Action

Understanding how herbicides control weeds is often useful in selecting and applying the proper herbicide for a particular weed. It also may be useful in recognizing herbicide injury in plants. There are seven major modes of action.

Growth regulators disrupt the hormone balance and protein synthesis in plants, causing growth abnormalities. Growth regulators selectively kill broadleaf weeds in range and crop grasses. Grasses are generally tolerant to these chemicals, but injury can occur if applied at the wrong growth stage or at high rates. These herbicides translocate to the growing points of the plants, and injury symptoms appear in new plant tissue. An early symptom is often epinasty, the abnormal bending or twisting of shoot tips. Most growth regulators enter the plant through the leaves, but some root absorption may occur.

Growth Regulators

Chemical family	*Examples*
Phenoxy acetic acids	2,4-D, MCPA
Benzoic acids	Banvel
Pyridines	Stinger, Tordon, Garlon

Amino acid synthesis inhibitors prevent the production of amino acids that form proteins and are fundamental to normal plant development. These herbicides translocate through the plants from soil or foliar applications. Symptoms of activity include stunting, yellowing (chlorosis) or purpling of leaves.

Amino Acid Synthesis Inhibitors

Chemical family	*Examples*
Sulfonylureas	Glean, Harmony Extra, Accent, Express, Oust
Imidazolinones	Assert, Pursuit, Arsenal
Amino acid derivatives	Roundup, Touchdown

Lipid inhibitors prevent production of fatty acids that make cell membranes and are required for new plant growth. Lipid inhibitors are effective against most annual and perennial grasses; broadleaf plants are tolerant. They translocate through the plants from foliar applications. Symptoms of inhibition activity usually are stunting, yellowing (chlorosis), or browning of leaves.

Lipid Inhibitors

Chemical family	*Examples*
Cyclohexanediones	Select, Poast
Aryloxyphenoxypropionates	Hoelon, Fusilade

Seedling growth inhibitors interfere with new plant growth, stopping normal seedling root or shoot development. They must be applied to the soil to act on emerging weed seedlings. Symptoms include stunted or swollen roots on emerging seedlings, or seedlings that never emerge.

Seedling Growth Inhibitors

Chemical family	*Examples*
Dinitroanilines	Treflan, Prowl, Balan, Surflan
Acetanilides	Lasso, Dual
Thiocarbamates	Eptam, Eradicane, Far-Go, Sutan

Photosynthesis inhibitors interfere with photosynthesis (conversion of water and carbon dioxide to sugar in the presence of sunlight). The result is a buildup of toxic products. The triazine, phenylurea, and uracil herbicides are root- or foliar-absorbed and translocated to leaves; symptoms generally occur along the leaf margin first. Nitrile and benzothiadiazole herbicides do not translocate and must be applied postemergence for contact action. Symptoms appear where the contact occurs, including yellowing (chlorosis) or death (necrosis) of leaf tissue.

Photosynthesis Inhibitors

Chemical family	*Examples*
Triazines	Bladex, Princep, Lexone, Sencor, Aatrex
Phenylureas	Spike, Lorox, Karmex
Uracils	Sinbar, Hyvar
Benzothiadiazoles	Basagran
Nitriles	Buctril

Cell membrane disrupters destroy plant tissue by rupturing plant cell membranes. These are contact herbicides that have no mobility in the plant and must be applied postemergence. They are excellent for foliage burn-down and control of annual weeds. Symptoms include rapid browning (necrosis) of plant tissue.

Cell Membrane Disrupters

Chemical family	*Examples*
Bipyridyliums	Gramoxone Extra, Diquat
Diphenyl ethers	Blazer, Goal

Pigment inhibitors prevent plants from forming chlorophyll (green pigments) used in photosynthesis. These soil-applied herbicides translocate to plant leaves. Without chlorophyll production, the affected leaves turn white or translucent. Emerging weeds appear white prior to dying. Because emerged plants constantly replace chlorophyll, amitrole turns plants white following treatment.

Pigment Inhibitors

Chemical family	*Examples*
Isoxazolidinones	Command
Pyridazinones	Solicam, Evital
Triazoles	Amitrol

Selective versus Nonselective Activity

A major advantage of chemical weed control over some tillage operations is that some herbicides only kill targeted weeds. Herbicides that control weeds while doing little or no damage to the crop are *selective herbicides. Nonselective herbicides* kill or control almost all plants—weeds and desirable vegetation.

The selectivity of a herbicide refers to whether a plant is susceptible (injured or killed) or tolerant (survives without injury).

Selectivity depends on many interrelated factors. It is influenced by the kind and amount of herbicide applied, how and when applied, and under what environmental conditions. Even closely related plants may respond differently to applications of the same herbicide. Selectivity may be lost through applicator mistakes or by applying herbicides when desirable plants are stressed or are at the wrong growth stage. **You must understand the reasons for herbicide selectivity to avoid injuring crops.** Two groups of herbicide selectivity factors exist: plant factors and chemical and application factors.

Plant Factors. The uniqueness of each plant species arises from its particular combination of structures and chemical processes (physiology). The extent to which a herbicide affects any plant species depends on the plant structure and physiology.

Structure. To be effective, the herbicide spray must remain on the plant leaves and stems and enter the plant. Leaf angle, size, hairiness, and thickness of wax and cuticle greatly affect the retention and absorption of foliar herbicide applications. Plants with upright leaves, extremely hairy leaves, or hard-to-wet leaves (waxy leaves) are less likely to retain herbicide spray. These differences may help make a plant either susceptible or tolerant.

Plant Physiology. Selectivity primarily depends on how the plant responds after the herbicide enters the plant. The herbicide interferes with vital plant processes to kill susceptible weeds. (See section on *Modes of Herbicide Action*). However, for a given herbicide, certain plant species can naturally alter the herbicide into nonharmful chemicals. This alteration is known as metabolism or detoxification. As the plant metabolizes a herbicide, the plant uses the breakdown products to make new plant materials. If a plant can not metabolize the herbicide fast enough, injury or death occurs. For example, this type of selectivity allows atrazine use in corn. Corn rapidly metabolizes atrazine, whereas most weeds cannot metabolize the herbicide fast enough to avoid being killed. In certain cases, cold weather can slow a crop's ability to metabolize herbicides and some crop injury may occur.

Chemical and Application Factors. Several physical factors affect herbicide selectivity:

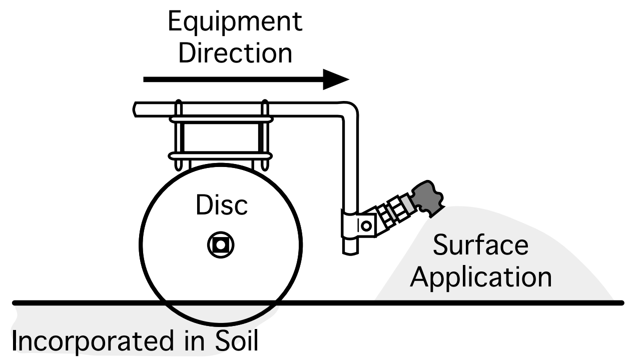
- how much herbicide is applied,
- the particular formulation used,
- where it is applied,
- when it is applied, and
- the addition of adjuvants.

Application Rate. Some herbicides are selective at lower rates of application; however, when applied at a higher rate the herbicide becomes nonselective. For example, diuron is selective at low rates and provides nonselective residual control at higher rates.

Formulation. Both the active ingredient(s) and how the herbicide is formulated influence selectivity. One example is using a granular formulation to control nonemerged weeds among emerged crop plants. In this case, the formulation allows the herbicide to bounce or roll off the crop and fall to the soil. It then becomes available for uptake from the soil by emerging weed seedlings. A number of herbicides are available in both granular and liquid formulations.

Application Timing. Many herbicides are effective only if applied at the proper time. The time of application may be given on the label with respect to the crop or to the weed. You must understand the following label terms as they relate to application timing.

PREPLANT TREATMENT is any application made before seeding or transplanting. A common preplant treatment is preplant soil incorporated applications, which mix the herbicide in the soil zone where weeds germinate.

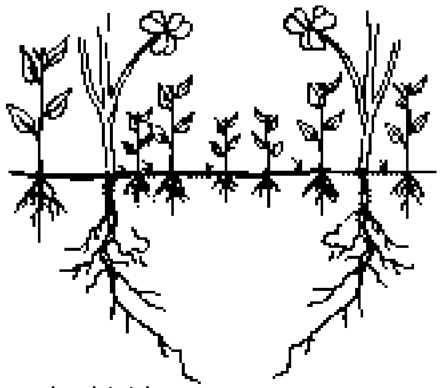


Preplant soil incorporated application. Disc follows and incorporates spray application.

PREEMERGENCE TREATMENT is a treatment made prior to emergence of a crop or weed. Several possible variations occur: preemergence to the weeds, the crop, or both crop and weeds. Therefore, the statement on the herbicide label: "preemergence to the crop," "preemergence to the weeds," or "preemergence to both crop and weeds," clearly establishes treatment timing.

POSTEMERGENCE TREATMENT is any treatment made after emergence of a specified crop or weed. Apply the herbicide after the crop, weeds, or both are up. This is usually a foliar application. A statement on the herbicide label may indicate an application "preemergence to the crop" and "postemergence to the weeds."

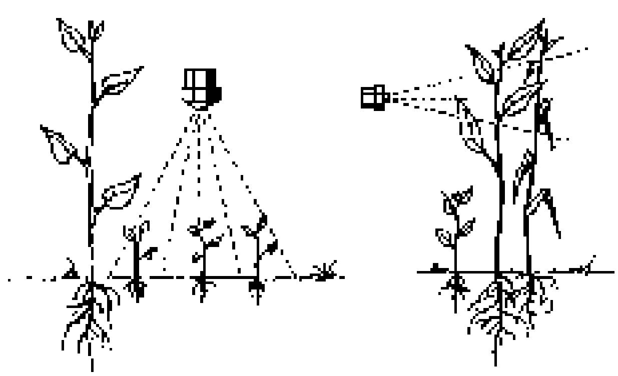
Placement. Accurate placement of nonselective herbicides can minimize or eliminate injury to desirable plants. An example is the use of simazine or diuron to control weeds in orchards and vineyards. These products are toxic to fruit trees and grapevines. Placing and keeping these herbicides in the soil above the root zone of the trees or vines, allows the herbicides to control the weeds but not to contact the tree or vine roots.



Selectivity achieved by keeping herbicide in weed root zone but above crop root zone.

In other instances, you can properly place herbicides by using different kinds of application equipment employing shielding devices, directed sprays, and wiper or roller treatments.

DIRECTED SPRAYS limit herbicide contact with the crop. Direct spray to the lower part of the plant stem or trunk to keep droplets off the crop leaves while spraying small weeds.



Spray is directed at weeds below (left) or above (right) the crop

Unused spray is caught (right) and returned to spray tank

WIPER TREATMENTS apply contact or translocated herbicides selectively to weeds. Wicks made of rope, rollers covered with carpet or other material, or absorbent pads (comprised of sponge or fabric) are kept wet with herbicide solution and brought into direct contact with the weeds. The herbicide is "wiped" onto the weeds, but does not touch the crop because of height differences between the crop and weeds. This treatment is for tall weeds growing above the crop or for shorter weeds between rows, depending on the design and placement of the wiper parts.

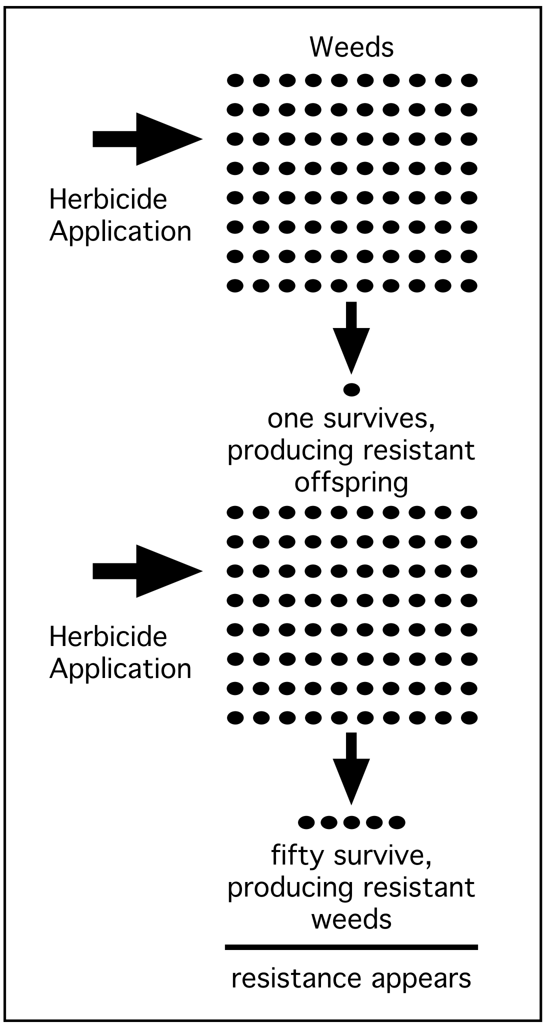
Herbicide Resistance

Herbicide-resistant weeds are an increasingly important problem. To understand the problem, you must know the difference between weeds that are naturally tolerant and weeds that have become resistant over time. Given any herbicide treatment, some weeds are tolerant and survive while susceptible weeds die. Weeds now resistant to a herbicide were susceptible years ago. Tolerant weeds occur naturally, resistant weeds appear after misuse of herbicides.

The first reports of herbicide resistance in North America came from Washington in the mid-1960s when a nursery owner could no longer control common groundsel with simazine. Several other weed species have since developed resistance to triazine herbicides, such as atrazine and simazine. Later, ryegrass and wild oats developed resistance to Hoelon. Several weeds have developed resistance to the sulfonylurea herbicides, such as Glean, Finesse, and Harmony Extra. As weeds become resistant, the herbicides can no longer control those weeds. Since few new herbicides are being developed, we cannot afford to lose the use of current herbicides to resistant weeds. We must use strategies to prevent resistance development.

Resistant weeds result from slight, natural genetic variations in individuals in a weed population resulting in a herbicide no longer being able to affect a few of the plants. Thus, they are resistant. There may be very few, perhaps one resistant plant for each one million plants of that weed species.

An effective herbicide may control 999,999 plants out of a million. But one resistant plant may survive and produce resistant seed. If the same herbicide is used next year, 50 resistant plants may grow in the field and produce more seed. When the same herbicide is used the following year, control is still excellent, but the number of resistant plants increases each year until poor control becomes noticeable. To make matters worse, in most cases resistant weeds can survive high rates of the herbicide and resistance is genetically dominant, (i.e., if a resistant plant and a sensitive plant cross, the offspring will be resistant). Fortunately, resistant weeds usually are still susceptible to other herbicides having different modes of action.



Development of resistant weeds

We must avoid practices that favor herbicide-resistant weeds. Use the following resistance management strategies:

- *Use other methods of weed control* along with herbicides. This may include cultivating row crops, delayed seeding to allow mechanical control of the first flush of weeds, or mulching.
- *Rotate crops regularly,* when possible. Switching from a winter crop to a spring-planted one provides the opportunity to prepare the land at a different time of the season and perhaps kill the resistant individuals. By shifting to another crop, we may use herbicides that the resistant weeds are susceptible to.
- *Rotate among herbicide families* annually if crop rotation is not a good option. To be effective, the herbicide must have a different mode of action than the one originally used. Weeds resistant to Hoelon also are resistant to Fusilade, Poast, and Assure. Glean-resistant weeds also are resistant to Oust and Harmony Extra, and often to Arsenal, Pursuit, and Assert.
- *Resist the temptation to use higher rates* when weed control starts to decline. If the uncontrolled individuals in the population are genetically resistant, increasing the herbicide dosage will not kill them. It will simply eliminate the susceptible types, allowing the most resistant types to flourish. Using higher than normal rates may actually make resistance develop faster.
- *Kill all the targeted weeds* if possible. Hand weeding a 5,000-acre wheat ranch is not possible. But in small fields of row crops, this may be extremely cheap in the long term. If a new herbicide provides 99% control the first year, the remaining 1% might just be escapees, but they might be genetically resistant. Eliminate them while they are still few in numbers.
- Herbicide combinations generally are used to increase the number of weed species controlled. Using combinations will slow the development of resistance only in those weeds that ***both*** herbicides affect. The species controlled by only one of the herbicides can develop resistance as rapidly as if that herbicide were used alone. Using two herbicides to control the same weed may not be as economically wise as *herbicide rotations.*

Use these procedures ***before*** resistance becomes evident. Once resistance develops, large numbers of resistant seed reside in the soil. Eliminating the resistant type one year will not solve the problem. Once you notice a herbicide-resistant weed problem, you will likely have the problem forever.

If you are not sure which herbicides have the same modes of action, refer to *Modes of Herbicide Action*, or check with your local extension agent, herbicide supplier, or product representative. Any of these professionals can find out for you.

Calibration

Calibration

The effectiveness of any herbicide depends on the proper application and placement of the chemical. The purpose of calibration is to ensure that application equipment uniformly applies the correct amount of material over a given area. Even if you may have the correct chemical mixture, it is still possible to apply the wrong amount if your equipment is not calibrated properly. Too little herbicide results in poor weed control. Application of too much herbicide may result in crop damage, illegal residues in foods, pollution, environmental and human health problems, and a waste of money. Herbicide delivery rate can change with equipment wear, gauge error, nozzle wear, wheel slippage, and speedometer error.

Application equipment suppliers often provide charts and tables to help you determine equipment set-up and approximate desired delivery rates; however, such sources of information only estimate delivery rates. Charts and tables cannot account for equipment wear and inaccurate gauges, and speedometers. You must calibrate equipment to obtain more reliable determinations of equipment delivery rates.

Calibration is simply determining the equipment's delivery rate, or the amount of material delivered (applied) from the application equipment over a known area.

You must make several decisions before every herbicide application.

- Determine and possibly adjust the equipment's delivery rate (calibration).
- Determine how much product (granules or liquid) is necessary for the job.
- Determine the appropriate amount of carrier for the amount of product to be used.

The product label, calibration, and your calculations answer these questions.

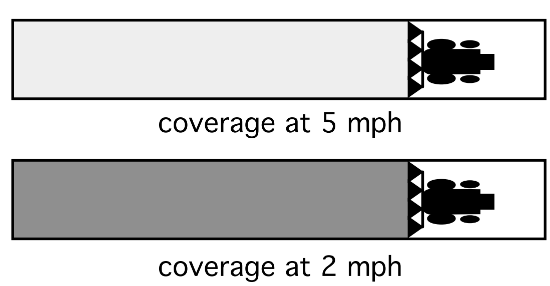
To properly calibrate, you may need a bucket marked in gallons, a scale, a stopwatch, tools, a container marked in ounces for nozzle output, a tape measure, and flags or stakes for marking distances. Unless your equipment is new, it probably has some pesticide residue in and on the various equipment components. Therefore, wear a pair of rubber gloves. A pocket calculator helps reduce mathematical errors.

Granular Applicator Calibration
Calibrating granular application equipment requires you to measure the amount of granules spread over a known area. Calibrate using the herbicide granule to be applied, because each granule type flows differently. Recalibrate each time you switch the type or rate of granular herbicide.

Variables that Determine Granular Applicator Output —Two variables affect the amount of granules applied per unit area: the size of the gate opening and the ground speed of the applicator.

The rate that granules flow out of the applicator depends on the size of the gate opening. A larger opening allows more granules to flow for a higher delivery rate. Changing the size of the gate opening significantly increases or decreases the delivery rate.

The speed at which the granular applicator travels also affects total output per unit area. When travel speed increases, less material is applied per unit area, and when speed is



Effects of travel speed on delivery rate

reduced, more material is applied (except with wheel-driven applicators). When small changes to the delivery rate are necessary, adjust travel speed.

Adjust the gate opening or travel speed to fine-tune your application equipment. It may take many adjustments before the applicator is calibrated correctly.

Conduct the calibration test over a measured area where the granules can be collected (tarped area, driveway) or use a collection device. The catch container must not interfere with the chemical delivery. Use the following steps to calibrate a granular applicator.

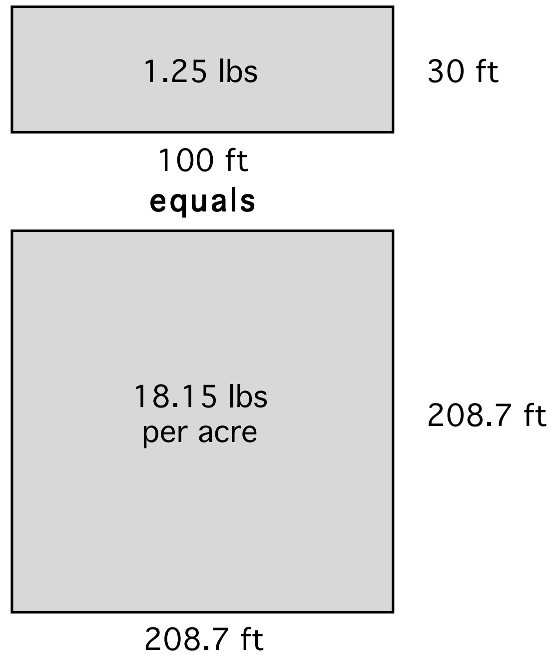
1. Measure a known area (e.g., measure swath width, multiply swath width by course length to find covered area).
2. Set up a collection device: an attachment or a tarp on the ground.
3. Apply at proper speed and gate setting.
4. Collect and weigh the amount of chemical "spread" over the measured area.
5. The delivery rate is the weight of material collected for the area covered.
6. Convert units to a pound per acre basis, or whatever basis the label states.
7. Adjust gate setting or speed to get desired output.

EXAMPLE:
Prior to planting alfalfa you choose to apply a granular formulation of a preplant herbicide. The spreader covers a swath of 30 feet. At the set speed and gate openings, collect granules in a collection device while covering a 100-foot course. The collected material weighs 1.25 lbs. The label states an application rate of 20 pounds of product per acre.

- What is the equipment's delivery rate *in pounds per acre*?
  - Delivery rate is the amount applied per unit area, 1.25 lbs per 3,000 sq ft
  - Convert 3,000 sq ft to an acre (43,560 sq.ft = 1 acre)

$$\frac{1.25 \text{ lbs}}{3000 \text{ sq ft}} \times \frac{43560 \text{ sq ft}}{\text{acre}} = 18.15 \text{ lbs per acre}$$

  - The rate is less than desired and needs to be increased



It is easy to adjust delivery rates. For small changes you may alter the speed of travel. For large changes, you may need to adjust the size of the opening to increase or restrict the flow.

Repeat calibration for any change in conditions (temperature, humidity, lot number of granules), when using a different chemical, driving at a different speed, or changing the agitator speed.

Sprayer Calibration

Proper sprayer function is essential for accurate sprayer calibration; therefore, follow the procedures outlined below before calibrating the equipment.

- Be sure sprayer nozzle tips are appropriate for the spray application to be made. Consult nozzle manufacturer's recommendations and the herbicide label.
- Thoroughly clean all nozzles, nozzle tips, and screens to ensure proper operation. Use a soft brush, not wire or any hard material. Add water to the spray tank and visually check nozzle output during sprayer operation. Discard and replace nozzle tips producing distorted spray patterns.
- Check spray volume output of all nozzles and replace nozzle tips that differ by more than

10% of the average output of all nozzles or replace all the nozzles if more than one is off.

- Check all pressure gauges. If a gauge is rusty or of questionable accuracy, replace it.

Variables That Determine Sprayer Output—Three variables affect the amount of spray solution applied per area: nozzle output, nozzle spacing or spray width, and ground speed of the sprayer.

Nozzle output varies with the pressure and the size of the nozzle tip. Increasing the pressure or using a nozzle tip with a larger orifice (opening) increases the output. Increasing pressure does not give a proportional increase in the output. For example, doubling the pressure does not double the flow rate; you must increase the pressure fourfold to double the flow rate.

Effects of sprayer pressure on delivery rate (speed constant)

Sprayer pressure (psi)	Sprayer delivery rate (gal/acre)
10	10
40	20
160	40

Therefore, adjust pressure for minor changes in spray delivery rate, not major ones. Operating pressure must be maintained within the recommended range for each nozzle type to obtain a uniform pattern and to minimize drift.

An easy way to make a large change in flow rate is to change the size of the nozzle tips. Depending on operating pressure, the speed of the sprayer, and the nozzle spacing, small changes in nozzle size can significantly change sprayer output per acre. Nozzle manufacturers' catalogs give information for selection of the proper tip size.

For ground sprayers, delivery rate is inversely proportional to the speed of the sprayer; that is, as speed increases, the amount of spray applied per unit area decreases at an equal rate. If spray pressure remains constant, doubling the sprayer's ground speed will reduce the amount of spray per area by one-half. Wheel-driven sprayers do not conform to this rule because the speed of travel also affects the pressure.

Effects of sprayer speed on delivery rate (constant pressure)

Sprayer speed (psi)	Sprayer delivery rate (gal/acre)
1	40.0
2	20.0
3	13.3
4	10.0

Sprayer calibration determines the amount of spray volume the equipment delivers per unit area. Most labels direct the user to apply a specific amount of herbicide per acre, but some label instructions include directions for an amount of herbicide to be applied per 1,000 sq ft or some other area measure. Calibrate the sprayer and determine the delivery rate in the units used on the label (gallons per acre, per 1,000 sq ft, etc.).

Boom Sprayer Calibration. The following calibration method is only one of many used for boom sprayers.

- *Test nozzles.* Make sure all nozzles have the same output and have good spray patterns.
- *Determine travel speed.* Select a reasonable operating speed for the terrain, soil condition, and durability of the spray equipment. Record the tachometer or speedometer readings and the gear setting used to maintain the selected speed. Fill tank at least half full to simulate application conditions. Time how long it takes the spray equipment to travel a set distance (e.g., 200 ft) in similar field conditions; this accounts for wheel slippage. Time equipment in both directions and calculate the average

time. Use the following formula to calculate speed in mph:

$$\frac{\text{distance in feet} \times 60}{\text{time in seconds} \times 88} = \text{mph}$$

EXAMPLE:

$$\frac{200 \text{ ft} \times 60}{30 \text{ seconds} \times 88} = 4.5 \text{ mph}$$

- *Determine nozzle output.* Select and record the spray pressure at which the system will be operated (check label and nozzle recommendations for guidelines). Adjust to desired pressure while pump is operating at normal speed and water is actually flowing through the nozzles. (Minimize off-target drift by operating at the lower end of a nozzle's pressure range).

  Collect spray from nozzles (in ounces) at the pressure to be used for a time interval easily converted to one minute (e.g., 30 sec x 2). The more nozzles you collect from, the more accurate the calibration. Calculate the average output from the nozzles sampled.

  EXAMPLE:
  16 oz + 16.5 oz + 17 oz + 16 oz + 16.5 oz = 82 oz
  82 ÷ 5 nozzles = 16.4 oz in 30 sec = 32.8 oz per min

  Convert to gallons per minute.

$$\frac{32.8 \text{ oz per minute}}{128 \text{ oz per gal}} = 0.256 \text{ gals per minute (GPM)}$$

- *Measure nozzle spacing.* Measure the distance between two nozzles, center to center.

  EXAMPLE: 20 inches.

- *Calculate the delivery rate in gallons per acre (GPA).* Use the following formula by inserting speed in mph, nozzle spacing in inches, and the average gallon per minute output of a nozzle.

$$\frac{5940 \times \text{nozzle output in GPM}}{\text{mph} \times \text{nozzle spacing in inches}} = \text{GPA}$$

EXAMPLE:

$$\frac{5940 \times 0.256}{4.5 \times 20} = 16.9 \text{ gals per acre}$$

Sprayer Calibration Example

Sprayer is set up with 24 nozzles at 20-inch spacings, 40-foot boom swath, and 40 psi. Set course at 100 feet. It takes the equipment 17 seconds to travel 100 feet in fourth gear with full throttle. The 6 nozzles delivered 17 oz, 16.5 oz, 17.5 oz, 17 oz, 16.75 oz, and 17.25 oz in 30 seconds.

- calculate speed

$$\frac{100 \text{ ft} \times 60}{17 \text{ seconds} \times 88} = 4.0 \text{ mph}$$

- find average nozzle output

  17 + 16.5 + 17.5 + 17 + 16.75 + 17.25 = 102 oz

  102 ÷ 6 = 17 oz

- calculate GPM (gallons per minute)

  17 oz in 30 sec = 34 oz per min

$$\frac{34 \text{ oz per min}}{128 \text{ oz per gal}} = \text{GPA} = 0.265 \text{ gpm}$$

- measure nozzle spacing

  20 inches

- use this formula to calculate gallons per acre

$$\frac{5940 \times \text{nozzle output in GPM}}{\text{mph} \times \text{nozzle spacing in inches}} = \text{GPA}$$

$$\frac{5940 \times 0.265}{4.0 \times 20} = 19.7 \text{ gals per acre}$$

Sprayer calibration results are valid only for the speed, nozzles, pressure, and spray width (nozzle spacing) used during the calibration process. Significant changes in any one of these factors will require another calibration check. Calibrate your sprayer more than once per season.

Another method of calibration is to spray an acre. Measure how much water it takes to cover one acre, which is the gallon per acre output for the sprayer. For example, a sprayer has a 60-foot swath. To cover one acre the sprayer needs to travel 726 feet (43,560 sq ft ÷ 60 ft = 726 ft). After spraying the 726-ft course, it took 32 gallons to exactly refill the spray tank to the level prior to spraying the acre. This means the sprayer is delivering 32 gallons per acre. Always accurately measure the water. Check all nozzles for uniform output with this method.

Compressed Air Sprayer Calibration. Most compressed air sprayers are small, hand-operated units carried by the operator; consequently, application factors such as speed, spray width, and pressure depend on who is spraying.

The following is just one of several possible methods used to calibrate hand-pressurized sprayers.

1. Measure and mark a square area 18.5 ft x 18.5 ft, preferably on a surface that will easily show the spray pattern width (for example, a paved parking lot).
2. Starting with an empty liquid spray tank and using a container graduated in ounces, add 2 quarts (64 ounces) of water to the spray tank.
3. Pressurize the sprayer and spray the area within the marked square. Maintain uniform operator walking speed, nozzle height, and tank pressurization.
4. Depressurize the spray tank by opening the filler cap; drain the spray wand back into the tank by holding the spray wand above the tank and opening the spray valve on the wand.
5. Using a container marked in ounces, determine the number of ounces remaining in the sprayer.
6. Calculate the number of ounces sprayed by subtracting the number of ounces left in the sprayer from the 64 ounces originally added to the spray tank.
7. The number of ounces sprayed on the defined area is equal to the gallon per acre delivery of that sprayer. For example, if the number of ounces used to cover the marked area (342.25 sq ft or 1/128 of an acre) was 36 oz, then the sprayer is actually delivering about 36 gallons per acre.
8. Again, this applies only to the operator who calibrated the sprayer.

Changing Sprayer Delivery Rate. It is easy to adjust sprayer delivery rates. If your sprayer is delivering less than or more than enough spray to each acre, you can change the rate by using one of three methods:

- *Change the nozzle orifice.* The larger the hole in the nozzle tip, the more spray is delivered. This is usually the preferred method when making substantial changes in sprayer output.
- *Change the speed of the sprayer.* Slower speed means more spray is delivered over the area; faster speed means less spray is delivered over the area. Doubling the ground speed of the sprayer reduces the sprayer delivery rate by one-half, except for wheel-driven sprayers. Speed changes may be practical for small adjustuments in delivery rate, but not for large adjustments.
- *Change the pump pressure.* Lower pressure means less spray is delivered; with higher pressure, more spray is delivered. This is usually not a good method for large adjustments because large changes in pressure will alter the nozzle pattern. To double output, you must increase the pressure fourfold.

Equipment adjustments alter delivery rates

	to *Increase* GPA	to *Decrease* GPA
Nozzles	larger	smaller
Sprayer speed	slower	faster
Pressure	increase	decrease

Mixing and Calculations

Calculating the correct amount of product needed and proper mixing are essential for safe, effective, legal applications. Directions for mixing are given on the herbicide label and calculations are generally necessary. Mixing and calculations vary depending on the type of herbicide used.

Label rates may vary depending on site conditions. Read the label carefully to determine the proper rate of application.

To determine the actual amount of product needed for the application, know the total area to be treated and read the label carefully for the proper rate. The units of application rate vary among labels and written recommendations. Most labels give the application rate in the amount of *product* per acre. Many recommendations state the application rate in amount of *active ingredient* (ai) or *acid equivalent* (ae) per acre. Always convert rates to the amount of product when calculating how much product you will need.

These formulas will help you calculate the amount of product and active ingredient equivalents for dry and liquid formulations.

Dry Formulations
Formulas to convert commercial product and ai
- amount product x % ai = *amount ai*
- amount ai ÷ % ai = *amount product*

Liquid Formulations
Formulas to convert commercial product and ai
- gal product x lb ai/gal = *lbs ai*
- lbs ai ÷ lb ai/gal = *gal product*

Following are some examples of these variations. Determine how much product is needed to cover 16 acres for each of the different rates.

- 6 lbs dry product per acre

  6 lbs product/A x 16 acres = 96 lbs product

- 1 lb ai per acre of a 75% wettable powder (need to convert ai to product)

  1 lb ai/A ÷ 0.75 lb ai/ lb product = 1.33 lbs product/A

  1.33 lbs product/A x 16 acres = 21.3 lbs product

- 1 pint liquid product per acre

  1 pt/A x 16 acres = 16 pints or 2 gallons

- 1 lb ai per acre of a 4 lb ai per gal emulsifiable concentrate (need to convert ai to product)

  1 lb ai/A ÷ 4 lb ai/gal = 0.25 gals product/A

  0.25 gals/A x 16 acres = 4 gallons product

Often, mixing two or more chemicals together in the tank will save time, money, and increase the number of weeds controlled. Fertilizers also are commonly added with some herbicides. It is *legal* to tank-mix chemicals if all products are labeled for the application site, but *not if the label prohibits* mixing specific pesticides.

You can not tank-mix if the combination of products exceeds the highest rate allowed by either herbicide label. For example, the highest labeled rate of Buctril® is 1.5 pints/acre (equals 0.38 lb ai/A of bromoxynil). If you want to tank-mix 1.5 pints/A Buctril® (equals 0.38 lb ai/A of bromoxynil) and 1.5 pints/A Bronate® (equals 0.38 lb ai/A of bromoxynil + 0.38 lb ai/A of MCPA), the combination is illegal because it exceeds the highest rate of bromoxynil, 0.38 lb ai/A. If both products were mixed at the 1.5 pint/acre rate, the total amount of bromoxynil would be 0.76 lb ai/A. This is greater than allowed.

Illegal application of bromoxynil

1.5 pints/A Buctril®	0.38 lb ai/A of bromoxynil
1.5 pints/A Bronate®	+ 0.38 lb ai/A of bromoxynil
total in tank mix	0.76 lb ai/A of bromoxynil*

* this is *over* the legal limit of 0.38 lb ai/A

Legal application of bromoxynil

0.75 pints/A Buctril®	0.19 lb ai/A of bromoxynil
0.5 pints/A Bronate®	+ 0.13 lb ai/A of bromoxynil
total in tank mix	0.32 lb ai/A of bromoxynil*

* this is under the legal limit of 0.38 lb ai/A

Unless the label actually recommends a particular mixture, the products may be incompatible. If they are incompatible, they may form gelatin or crystals or may become inactive. Herbicide mixtures are advantageous because they give better weed control, but some also may cause crop injury. Prior to tank-mixing products, read the label and make sure tank-mixing is legal. Then conduct a jar test for physical compatibility. Many labels give directions for compatibility tests. If not, mix the products with their carrier in a small jar at proper concentrations. Watch and feel for a reaction. Heat is often generated during reactions. If the products do not mix properly, compatibility agents often can solve the problem. Repeat the jar test with the compatibility agent. If everything looks fine, test the tank mix on a small portion of the field to make sure the combination is still effective and safe to the crop ***before*** mixing hundreds of dollars' worth of solution.

When labels include tank mix recommendations, the manufacturer has already conducted the compatibility and performance tests.

Tank-mix herbicides in the following sequence to lessen incompatibility problems, unless otherwise directed by the label. First, partially fill the tank with carrier. Next, add dry or flowable formulations and get them into suspension by agitation before adding the emulsifiable concentrates. Next, add those products that form true solutions with the carrier and finish with adjuvants. Finally, add the remaining carrier to bring the spray mix to the full volume required for the job.

Many herbicide products recommend adding adjuvants to the tank mix to increase product effectiveness. *Surfactants* include spreaders and stickers that change the surface tension of the spray solution. By reducing the surface tension of the spray solution, spray droplets are more likely to remain on leaves without bouncing or rolling off. They also spread over a greater area on the leaves. Some herbicides need penetrants to aid herbicide uptake through waxy leaves and stems. Weeds densely covered with hairs may require adding a spreader so the droplets pass through the hairs to reach the leaf.

Buffers are adjuvants that adjust the pH of the spray solution. They usually reduce the pH in order to (a) avoid hydrolysis of certain pesticides in alkaline water, or (b) improve uptake through the plant cuticle. Acidic herbicides like 2,4-D and dicamba penetrate into the plant better if applied in an acidic solution. Other adjuvants include thickeners and foaming agents. Read the label directions for recommendations and rates.

The following calibration and mixing problems will help you become familiar with the calculations often used in herbicide applications.

Calibration Calculations

1. A wheel-driven sprayer travels 4.5 mph, keeping pressure at 40 psi. The boom has 18 nozzles spaced 20 inches apart, a 30-foot swath. A calibration course is set at 100 feet, which is covered in an average of 15 seconds. From five nozzles, 12 oz is the average volume collected over the course. What is the sprayer delivery rate in gallons per acre?

   A. The method using the formula

   $$\frac{5940 \times \text{nozzle output in GPM}}{\text{mph} \times \text{nozzle spacing in inches}} = \text{GPA}$$

   step 1. find nozzle output in GPM

   12 oz in 15 sec = 48 oz per min

   $$\frac{48 \text{ oz per min}}{128 \text{ oz per gal}} = 0.375 \text{ GPM}$$

   step 2. complete the formula

   $$\frac{5940 \times 0.375}{4.5 \times 20} = 24.75 \text{ GPA}$$

   B. A method using straight math

   step 1. determine area covered.

   area = swath width x course length

   30 ft. x 100 ft. = 3,000 sq ft

   step 2. determine spray output of entire boom in *gallons*

   12 oz./nozzle x 18 nozzles = 216 ounces

   216 ounces ÷ 128 oz./gal. = 1.69 gals

   step 3. convert delivery rate to acres

   $$\frac{1.69 \text{ gals}}{3000 \text{ sq ft}} \times \frac{43560 \text{ sq ft}}{\text{acre}}$$

   = 24.5 GPA

2. A boom sprayer has an auxiliary pump set at 30 psi. A speed course test indicates equipment travels 200 feet in 23 seconds. The boom has 48 nozzles at 20-inch spacings, covering an 80-foot swath. In 15 seconds, 8.25 ounces of spray is the average collected from four nozzles. What is the sprayer delivery rate in gallons per acre?

A. The method using the formula

$$\frac{5940 \times \text{nozzle output in GPM}}{\text{mph} \times \text{nazzle spacing in inches}} = \text{GPA}$$

step 1. determine MPH

$$\text{MPH} = \frac{\text{distance covered in feet} \times 60}{\text{time in seconds} \times 88}$$

$$\frac{200 \times 60}{23 \times 88} = 5.9 \text{ MPH}$$

step 2. determine GPM (gallons per minute delivery)

$$\frac{8.25 \text{ oz}}{15 \text{ seconds}} \times 4 = 33 \text{ oz per min}$$

$$\frac{33 \text{ oz per min}}{128 \text{ oz per gal}} = 0.258 \text{ GPM}$$

step 3. complete the formula

$$\text{GPA} = \frac{5940 \times 0.258}{5.9 \times 20} = 13 \text{ GPA}$$

B. A method using straight math

step 1. determine area covered in **15 seconds**.

$$\frac{200 \text{ ft}}{23 \text{ seconds}} = 8.7 \text{ ft/sec}$$

8.7 ft/sec x 15 seconds =130.5 feet

80 ft swath x 130.5 ft length = 10,440 sq ft

step 2. determine spray output of entire boom in *gallons* for **15 seconds**

8.25 oz/nozzle x 48 nozzles = 396 oz

396 oz ÷ 128 oz/gal = 3.1 gals

step 3. convert delivery rate to acres (both area and gallons were measured for 15 sec.)

$$\frac{3.1 \text{ gals}}{10440 \text{ sq ft}} \times \frac{43560 \text{ sq ft}}{\text{acre}} = 12.9 \text{ GPA}$$

Mixing Problems

1. Boom sprayer has an 80-foot boom, travels 6 mph, and the auxiliary pump is set at 30 psi. The spray tank is 600 gallons. Equipment is calibrated to deliver 12.9 GPA. An 80-acre alfalfa field has a weed problem and needs a broadcast treatment. The selected herbicide states the recommended rate based on organic matter and clay content to be 2/3 to 3/4 pounds product per acre.

- How many acres will a tankload cover?
  acres = tank in gallons ÷ GPA
  600 gallons ÷ 12.9 GPA = 46.5 acres

- How much spray solution is needed to treat the remaining 33.5 acres (80 acres - 46.5 acres) of alfalfa?
  33.5 acres x 12.9 gals/A = 432 gallons of spray

- How much product should be added for each tank batch (600 and 432 gals) if applied at the maximum rate?

  600 gallons covers 46.5 acres —>

  46.5 acres x 0.75 lbs product/A = 34.9 lbs product

  432 gallons covers 33.5 acres —>

  33.5 acres x 0.75 lbs product/A = 25.1 lbs product

2. To treat the same 80-acre alfalfa field, with the same set-up as above, determine the amount of product necessary for each tank batch for a recommended rate of 0.5 lbs active ingredient per acre for a 75% wettable powder.

- How much product is needed per acre to equal the 0.5 lb ai/A rate?

Formulas to convert commercial product and ai
- amount product x % ai = *amount ai*
- amount ai ÷ % ai = *amount product*

0.5 lbs ai ÷ 0.75 (%ai) = 0.67 lbs product

- How much product should be added for each tank batch (600 and 432 gals) if applied at the 0.5 lb ai/A (0.67 lbs product/A)?

  600 gallons covers 46.5 acres —>

  46.5 acres x 0.67 lbs product/A = 31.2 lbs product

  432 gallons covers 33.5 acres —>

  33.5 acres x 0.67 lbs product/A = 22.4 lbs product

3. Twenty acres of rangeland has a widespread weed infestation. The label recommends 3 to 4 pints of product per acre for weed control. The spray equipment has a 400-gallon tank and delivers 18 GPA.

- How much spray solution is needed to treat the area?

  20 acres x 18 GPA = 360 gallons

- What is the ***minimum*** amount of product (in ***gallons***) needed to treat the area?

  20 acres x 3 pints/A = 60 pints

  60 pints ÷ 8 pints/gallon = 7.5 gallons

4. To treat the same 20-acre rangeland, with the same set-up as in number 3, determine the amount of product necessary for a recommended rate of 1.5 lbs active ingredient per acre for a 2 lb ai/gal emulsifiable concentrate.

- How much product is needed per acre to equal the 1.5 lb ai/A rate?

> Formulas to convert commercial product and ai
> - gal product x lb ai/gal = *lbs ai*
> - lbs ai ÷ lb ai/gal = *gal product*

  1.5 lbs ai ÷ 2 lbs ai/gal = 0.75 gals product

- How much product should be added to make up 360 gallons of spray if applied at 1.5 lb ai/A (0.75 gals/A)?

  20 acres x 0.75 gals/A = 15 gallons of product

Laws Affecting Weed Management

Washington State Noxious Weed Law—WAC 17.10

The goal of the Washington State Noxious Weed Law is to protect the state from the introduction and spread of noxious weeds. These weeds pose a threat due to their destructive or competitive natures, and are very difficult to control. The law lists weeds that must be controlled, contained, or eradicated, depending on each listing.

Control is defined as the prevention of all seed production.

Containment is the confinement of the noxious weed infestation to an identified area.

Eradication means the elimination of a weed species.

The Washington State Noxious Weed Control Board determines the noxious weeds of the state and adopts them into regulation (WAC 16-750). These weeds are then classified depending on the size of the infestation and the ability to control them. Each weed is classified as a Class A, Class B, Class B designate, or Class C weed.

Class A weeds. These are noxious weeds with very limited distribution. They are targeted for eradication.

Class B weeds. These are noxious weeds with established populations in some regions of the state, but are rare or absent in other regions. The goal with Class B weeds is to contain them to current regions and prevent further spread.

Class B designate weeds. To prevent further spread of Class B weeds, these weeds have been designated for mandatory control within specified regions of the state.

Class C weeds. These include other noxious weeds that pose a threat. Control is determined at the county or weed district level.

Washington State Seed Law —RCW 15.49

Washington State Seed Law protects the state from introductions of noxious weed seeds that pose a threat due to their destructive or competitive natures, and that are very difficult to control. The law prevents the legal sale or distribution of such seed for planting purposes.

Washington State Quarantine Law —RCW 17.24

The purchase, transport, distribution, or sale of many noxious weeds is prohibited under the state quarantine law. The Washington State Department of Agriculture (WSDA) regulates nurseries, garden stores, and other outlets that sell plant material to ensure noxious weeds are not being sold as ornamentals. Purple loosestrife and Scotch broom are noxious weeds introduced to Washington as garden plants.

Registration Restrictions for Groundwater Protection —WAC 16-228-164

In addition to federally designated restricted use pesticides, WSDA has declared several pesticides (insecticides and herbicides) state restricted use under the Rules Relating to General Pesticide Use.

Restricted use herbicides

alachlor	diuron	prometon
atrazine	hexazinone	simazine
bromacil	metolachlor	tebuthiuron
cyanazine	metribuzin	
DCPA	picloram	

To apply restricted use products in this state, the applicator must have the appropriate pesticide application certification (license) for agricultural weed control or must work under the direct supervision of someone who has the proper pesticide license.

Along with the restrictions on who can legally apply these herbicides, many labels have clear groundwater advisories listed in the "Environmental Hazards" section. Heed the precaution and do not use herbicides that may leach in vulnerable areas.

Registration Restrictions for Herbicides in Aquatic Sites —WAC 16-228-166

Only use herbicides with aquatic labeling in aquatic environments. All aquatic herbicides are restricted use and require an Aquatic Pest Control or Aquatic Irrigation endorsement on the license, or a Private Applicator License. In addition, all aquatic applications require a "short-term water quality modification permit" from the Washington State Department of Ecology.

Herbicide Sale and Use Regulations —WAC 16-228-162, 16-230 through 16-232

The distribution, use, and application of all *high volatile esters* and *dust formulations* of dicamba and phenoxy hormone-type herbicides (such as, 2,4-D and MCPA) are prohibited throughout the state.

Liquid formulations of dicamba and phenoxy hormone-type herbicides, registered with the state and distributed in larger than one-gallon containers in counties east of the crest of the Cascade Mountains, can only be distributed by licensed pesticide dealers to certified applicators. In addition, regulations regarding adjuvants, application dates and times, equipment configurations and other details are explained in statewide regulations or in county regulations under the authority of the Washington State Department of Agriculture.

Diquat, paraquat, and endothall are restricted use desiccants and defoliants in all counties east of the crest of the Cascade Mountains. The regulation stipulates equipment configurations, adjuvants, timing, and more restrictive rules for areas in Walla Walla County.

Other Rules

WSDA has other rules relating to herbicide sale and use. These include rules regarding picloram (Tordon) use in Spokane County and certain pesticide use (except home and garden) in Benton, Franklin, and Walla Walla counties.

It is the applicator's responsibility to be aware of different rules across the state. WSDA pesticide rules can be found in Washington Administrative Code (WAC 16-228) Rules Relating to General Pesticide Use. Most of these supplemental rules exist due to corrective measures taken by the Department of Agriculture to rectify problem situations such as drift or water contamination.

Washington State University Extension

College of Agricultural, Human, and Natural Resource Sciences

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