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Introduction to Weeds and Herbicides

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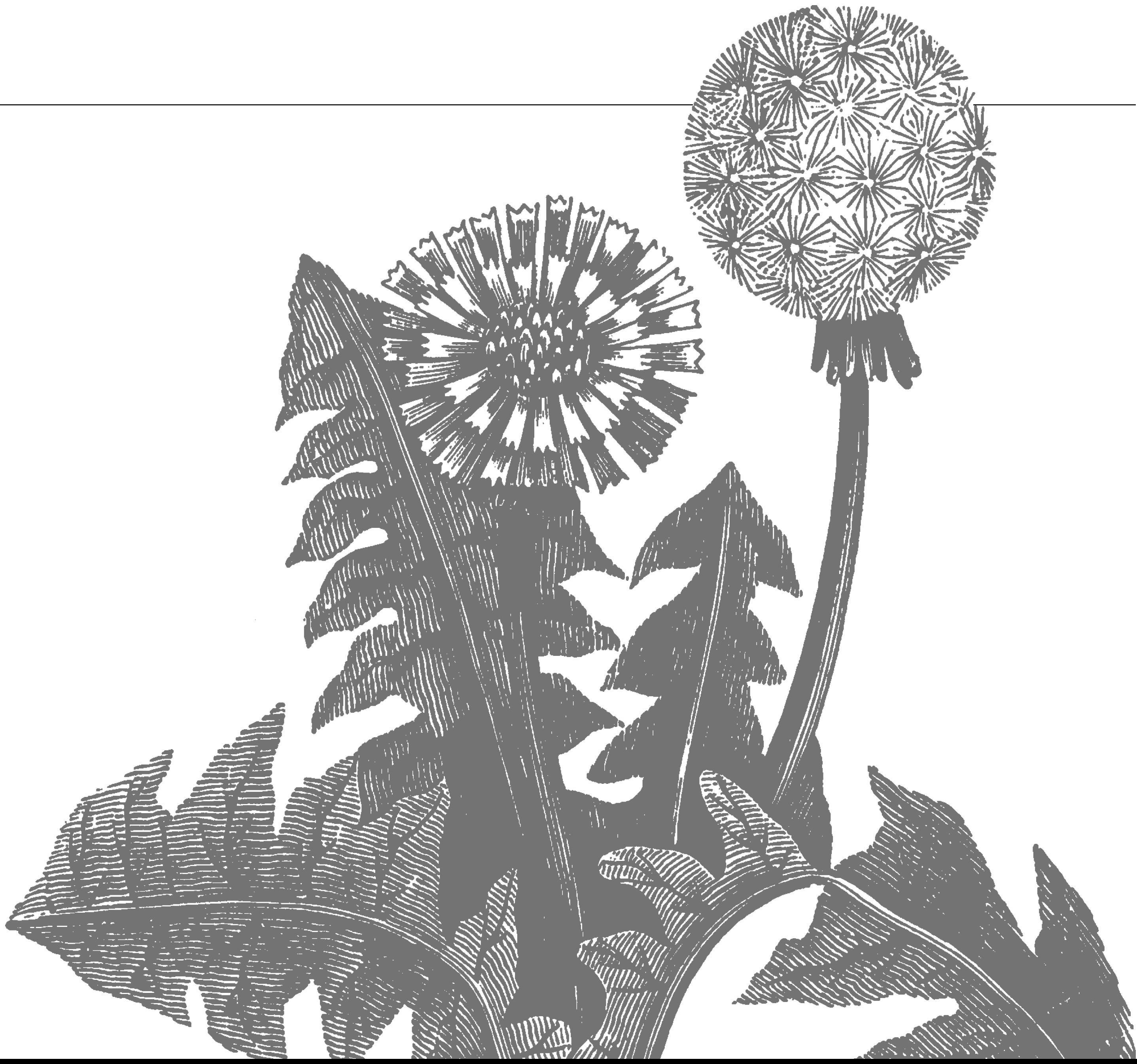

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This circular provides basic information on weeds and herbicides for farmers, crop-improvement association scouts, turf management specialists, nursery specialists, foresters, roadside vegetation specialists, and other crop production or vegetation management specialists. The information is important for anyone making recommendations or using herbicides for weed control. In addition, it can be used by extension and commercial personnel in preparing weed-control and pesticide update training programs.

Information is given on the growth habit of weeds and their spread by both seed and vegetative structures. Included is a discussion of seed dormancy, how it prevents seed germination when conditions are not favorable, and how it helps weed seed survive for up to 100 years in the soil.

Herbicides are classified by family (chemical structure), mode of action, and time and method of application. Classification by family will make it easier to understand the characteristics of individual herbicides, because herbicides of the same family usually work the same way. Understanding a herbicide's mode of action will clarify why that herbicide must be applied at certain times of the year, how it kills or suppresses weeds, and why certain weeds are not affected by certain herbicides. Knowing a herbicide's mode of action is also helpful in planning a weed control program to avoid repeated use of herbicides with the same mode of action, so the potential for herbicide resistance buildup is reduced. A herbicide's formulation dictates how the chemical will be applied, its compatibility with other chemicals and carriers, and its relative safety to the applicator. Herbicides have also been grouped according to their toxicity level.

Weeds

A plant with more undesirable characteristics than virtues is considered a weed. It may be native to an area or introduced from other parts of the country or world. About 60 percent of our worst weeds were introduced from some other part of the world.

In general, weeds are:

- able to grow and survive under unfavorable conditions, to persist and reproduce almost anywhere
- competitive and aggressive, capable of surviving in competition with almost any crop
- wild and rank, producing dense thickets or vines that crowd out or cover up more desirable species
- resistant to control and tolerant of herbicides, tillage, or cultural control methods, because they have biochemical tolerance or extensive root or rhizome systems with large carbohydrate reserves
- abundant, existing in dense populations; prolific seed producers
- spontaneous, establishing from seed that may have been dormant for many years or from parts of roots or rhizomes
- easily spread because seeds have special structures that aid dispersal by wind, water, or animals (especially birds)
- useless and undesirable, without forage value for livestock or food value for humans, wild animals, or birds
- harmful to people, animals, or crops; may cause allergies in people, be poisonous to people and animals, be parasitic or toxic to crops
- unsightly, dominant, aggressive, or unattractive in association with other plants

Names

All plants have a scientific name and a common name. The first word of the scientific name, always capitalized, is the genus. The second word is the species name. The genus and species are always written in italics or underlined. *Cyperus esculentus*, for example, is the scientific name for yellow nutsedge.

Common names of plants differ from place to place. For example, *Elytrigia repens* is called quackgrass by the Weed Science Society of America, wiregrass by Pennsylvanians, and couchgrass by Canadians and Britons. Although scientific names are awkward for general use, they are preferred in scientific literature to avoid confusion. Calling weeds by their common names is easier, but efforts to standardize common names have been only partly successful.

Weeds cost Pennsylvanians at least $125 million each year—more than $100 million in field and forage crops, $10 million in horticultural crops, and over $15 million in noncropland areas. Weeds can host insects, nematodes, disease-causing fungi, and viruses. They also compete with crops and interfere with planting, harvesting, and machinery efficiency. Some simply detract from the beauty of the landscape.

Distribution

Weeds reproduce by sexual or asexual means. Sexual reproduction occurs by seed and is the only way summer or winter annuals and biennials can reproduce.

Asexual reproduction is achieved through vegetative means—runners, roots, or rhizomes. Once established, most perennials (Canada thistle, hemp dogbane, horsenettle, etc.) spread by roots; quackgrass, johnsongrass, and wirestem muhly spread by rhizomes.

Some weed seeds are distributed by natural forces like wind and water. Dandelion and thistle seeds are adapted for wind dispersal. Others can float for a short time, and some are small enough to be carried long distances by water.

Seeds may be dispersed by animals. Barbed seeds, like those of burdock and cocklebur, become attached to animal hair. Some seeds are eaten by domestic animals and passed through their digestive tracts, returned to the soil, and able to again infest fields. Johnsongrass seed, for example, was introduced near feedlots by beef calves from the South and then spread to surrounding fields. Weeds are spread by birds when intact seeds pass through their digestive tracts. Multiflora rose, mulberry, bitter nightshade, and mile-a-minute are commonly spread this way.

Most weed seeds are spread by people. Farmers and marketers move weed seeds from one location to another in agricultural products like grain, hay, and straw. Farmers move seeds around in machinery, especially balers and combines. With tillage equipment, they drag tubers of nutsedge or rhizomes of quackgrass and johnsongrass from field to field.

Dormancy

Dormancy is a survival mechanism that prevents seeds from germinating when conditions for survival are poor. It may be innate, induced, or enforced dormancy.

Innate dormancy inhibits germination at the time seeds are shed from the plant. After the seed shatters from the parent plant, time is required for immature embryos to develop, natural inhibitors to leach out, or extremes of temperature to crack hard seed coats and allow germination to occur. These conditions cause innate dormancy, and once lost, this type of dormancy cannot reoccur.

Induced dormancy is a temporary dormancy that occurs when a seed is exposed to hot or cold temperatures. It continues after temperatures change and prevents germination during the wrong time of year. The dormancy is broken by temperatures opposite those which induced it.

Summer heat induces dormancy in summer annual weeds like yellow foxtail and pigweed, preventing germination in the fall. Fall and winter cold breaks this dormancy (usually by Christmas), and the seeds germinate in spring when conditions are right. In winter annual weeds, the process is reversed.

Dormancy can be induced in many weed seeds when a crop canopy filters sunlight, shading the ground and reducing germination. Dormancy can be induced over and over again for as long as the seed remains viable.

Enforced dormancy takes place when environmental conditions—cold temperatures, lack of moisture or oxygen, and occasionally a high salt concentration in the soil—are unfavorable. When limitations are removed, seeds germinate freely. Summer annual weed seeds lose their induced dormancy by Christmas and, except for the cold temperatures, would germinate at that time.

Seeds of different weed species have various temperature requirements for germination. Common chickweed can germinate under snow cover, while common purslane will not germinate until the soil temperature reaches 70° to 75°F. Crop seeds generally are planted at or near the optimum soil temperature needed for quick germination, a temperature that is also ideal for some weed seeds.

Seeds require water for germination. Seeds in dry soils may remain dormant when all other factors promoting germination are favorable.

Oxygen availability also influences a seed's ability to germinate. Water may fill soil pores and exclude air, limiting germination in very wet soils. Or soil compaction may reduce the oxygen supply and prevent seeds from germinating. Deep plowing, tillage, or hoeing can bring buried seeds to the surface where they readily germinate upon exposure to oxygen.

Viability

Burning fields to destroy weed seeds gives varying results, depending on heat intensity and duration. Many common weed seeds are destroyed upon exposure to very high temperatures (175° to 212°F) for 15 minutes. But if the burning creates only moderate heat for a short time, it may break the dormancy of many seeds. Burning may stimulate germination because of higher soil temperatures, more light, less competition, and less litter.

Mowing weeds is often recommended to prevent seed production, but success depends on proper timing. Mowing before flower buds form often prevents production of viable seed, but some plants, such as dandelion and perennial sowthistle, can produce viable seed after the flower stalk has been removed.

Heat and organic acids in stored silage kill most weed seeds in 10 to 20 days. Some seeds, however, can germinate after four years in silo storage.

Spreading fresh manure can distribute live weed seed, but manure stored in a slurry tank for six months is generally free of living seeds. About 90 percent of the weed seeds fed to cattle in hay or grain are destroyed by the digestive system. By grinding feed in its gizzard, a chicken destroys about 99 percent of any weed seeds in the feed. As a result, chicken manure usually has fewer weed seeds than cattle manure.

Herbicides

Herbicides are chemicals used to kill plants or interrupt normal plant growth. These chemicals can be classified by (1) similarity of chemical structure, (2) mode of action, (3) time of application, or (4) method of application.

Chemical structures

A. Aliphatic nitrogen derivatives

1. Acid amides

acetochlor (Harness, Surpass, Topnotch)
alachlor (Lasso, Partner)
dimethenamid (Frontier)
flufenacet (Axiom)
isoxaben (Gallery)
metolachlor (Dual, Pennant)
napropamide (Devrinol)
pronamide (Kerb)
propachlor (Ramrod)
propanil (Stam)

2. Amino acids

glufosinate (Liberty, Finale)
glyphosate (Roundup Ultra, Rodeo)
sulfosate (Touchdown)

3. Carbamothioates

butylate (Sutan), butylate + safener (Sutan+)
cycloate (Ro-Neet)
EPTC (Eptam)
EPTC + safener (Eradicane)
molinate (Ordram)
pebulate (Tillam)
thiobencarb (Bolero)
triallate (Avadex BW, Far-Go)
vernolate (Vernam)

4. Phenyl carbamates

asulam (Asulox)
desmedipham (Betanex)
phenmedipham (Spin-Aid)

5. Ureas

diuron (Karmex)
fluometuron (Cotoran)
linuron (Lorox, Linex)
siduron (Tupersan)
tebuthiuron (Spike)

B. Aromatic carboxylic acids

1. Phenoxy herbicides

2,4-D (various)
2,4-DB (Butyrac 200, Butoxone)
2,4-DP, dichlorprop (various)
MCPA (various)
MCPB (Thistrol)
MCPP, mecoprop (various)

2. Benzoic acids

dicamba (Banvel, Clarity, Vanquish)

3. Phthalic acids

DCPA (Dacthal)

4. Pyridines

clopyralid (Stinger, Transline)
dithiopyr (Dimension)
picloram (Tordon)
triclopyr (Garlon)

C. Aryloxyphenoxypropionates

diclofop-methyl (Hoelon)
fenoxaprop-ethyl (Acclaim, Whip)
fluazifop-P-butyl (Fusilade DX)
haloxyfop-methyl (Verdict)
quizalofop-P-ethyl (Assure II)

D. Cyclohexanediones

clethodim (Select)
cycloxydim (Focus, Laser)
sethoxydim (Poast)

E. Dinitroanilines

benefin (Balan)
ethalfluralin (Sonalan)
oryzalin (Surflan)
pendimethalin (Prowl, PreM, Pentagon)
prodiamine (Barricade)
trifluralin (Treflan)

F. Heterocyclic nitrogen derivatives

1. Benzothiadiazoles

bentazon (Basagran)

2. Diphenyl ethers
acifluorfen (Blazer)
fomesafen (Flexstar, Reflex)
lactofen (Cobra)
oxyfluorfen (Goal)
3. Imidazolinones
imazamethabenz (Assert)
imazamox (Raptor)
imazapic (Cadre, Plateau)
imazapyr (Arsenal, Chopper)
imazaquin (Scepter, Image)
imazethapyr (Pursuit)
4. Isoxazolidinones
clomazone (Command)
isoxaflutole (Balance)
5. N-phenylphthalimides
flumiclorac (Resource)
fluthiacet-methyl (Action)
6. Pyridazinones
cloridazon/pyrazon (Pyramin)
norflurazon (Evital, Solicam, Zorial)
pyridate (Tough)
7. Pyrazolium and Bipyridyliums
difenzoquat (Avenge)
diquat (Valent Diquat)
paraquat (Gramoxone Extra, Cyclone)
8. Sulfonamides
flumetsulam (Broadstrike, Python)
cloransulam-methyl (Firstrate)
9. Sulfonylureas
benzsulfuron-methyl (Londax)
chlorimuron-ethyl (Classic)
chlorsulfuron (Glean, Telar)
halosulfuron (Battalion, Permit)
metsulfuron-methyl (Ally, Escort)
nicosulfuron (Accent)
oxasulfuron (Expert)
primisulfuron-methyl (Beacon)
prosulfuron (Peak)
prosulfuron + primisulfuron-methyl (Exceed, Spirit)
rimsulfuron (Matrix)
rimsulfuron + thifensulfuron-methyl (Basis)
sulfometuron-methyl (Oust)
thifensulfuron-methyl (Pinnacle)
thifensulfuron + tribenuron-methyl (Harmony Extra)
triasulfuron (Amber)
tribenuron-methyl (Express)
triflusulfuron (UpBeet)
10. Triazines
ametryn (Evik)
atrazine (various)
cyanazine (Bladex)
hexazinone (Velpar)
metribuzin (Lexone, Sencor)
prometon (Pramitol)
prometryn (Caparol)
simazine (Princep)
11. Triazolinones
carfentrazone (Aim)
sulfentrazone (Authority)
12. Uracils
bromacil (Hyvar X)
terbacil (Sinbar)
13. Other heterocyclic nitrogen derivatives
amitrole (Amitrol-T)

G. Methanearsonates
CAMA (Super Dal-E-Rad-Calar)
DSMA (Ansar 8100)
MSMA (Ansar 6.6, Bueno 6, Daconate, Weed-hoe, Weed-E-Rad)
cacodylic acid (Phytar 560)

H. Benzonitriles
bromoxynil (Buctril)
dichlobenil (Casoron, Dyclomec, Norosac)

I. Nonclassified organic herbicides
bensulide (Betasan, Prefar)
chloropicrin (Picfume, Larvicide 100, Clor-O-Pic)
chloropicrin + methyl bromide (Brom-O-Gas, Dowfume)
diesel oil
endothall (Aquathol, Endothal, Hydrothol)
ethofumesate (Prograss)
fosamine (Krenite)
fluridone (Sonar)
kerosene
metham (Vapam)
methyl bromide (Meth-O-Gas)
oxadiazon (Ronstar)
Stoddard solvent

J. Nonclassified inorganic herbicides
sodium metaborate (Ureabor)
sodium tetraborate (Polybor)
sodium chlorate (Sodium Chlorate)

Modes of action

Mode of action is defined as the entire sequence of events from introduction of a herbicide into the environment to the death of plants. It is the sum total of all the disruptions in biochemical reactions and/or cell membrane integrity that directly or indirectly affect normal plant growth and development.

Systemic herbicides

Systemic, or translocated, herbicides are absorbed by roots or leaves after application and distributed throughout the plant. Most herbicides are systemic and do not kill weeds by contact action; others work by contact action (*see p. 8*).

Herbicides that regulate growth

Phenoxys:
2,4-D MCPA
2,4-DB MCPB
2,4-DP MCPP
Benzoic acids:
dicamba (Banvel, Clarity, Vanquish)
Pyridines:
clopyralid (Stinger, Transline)
picloram (Tordon)
triclopyr (Garlon)

These herbicides produce responses similar to those of natural growth-regulating substances called auxins. Application of artificial auxins, such as 2,4-D, upsets normal growth as follows:

- Cells of leaf veins rapidly divide and elongate, while cells between veins cease to divide. This results in long, narrow, strap-like young leaves.
- Water content increases, making treated plants brittle and easily broken.
- Cell division and respiration rates increase, and photosynthesis decreases. Food supply of treated plants is nearly exhausted at their death.
- Roots of treated plants lose their ability to take up soil nutrients, and stem tissues fail to move food effectively through the plant.

The killing action of growth-regulating chemicals is not caused by any single factor but results from the effects of several disturbances in the treated plant.

Injury symptoms. Broadleaved plant leaves become crinkled, puckered, strap-shaped, stunted, and malformed; leaf veins appear parallel rather than netted, and stems become crooked and brittle, with shortened internodes. In grasses (e.g., corn), new leaves do not unfurl but remain tightly rolled in onion-like fashion, and stems become brittle, curved, or crooked, with short internodes. A lesser effect is the fusion of brace roots noticed later in the season.

Herbicides that inhibit amino acid and protein synthesis

Amino acids:
glufosinate (Liberty, Finale)
glyphosate (Roundup Ultra, Rodeo)
sulfosate (Touchdown)
Imidazolinones:
imazamethabenz (Assert)
imazamox (Raptor)
imazapic (Cadre, Plateau)
imazapyr (Arsenal, Chopper)
imazaquin (Scepter, Image)
imazethapyr (Pursuit)
Sulfonamides:
flumetsulam (Broadstrike, Python)
cloransulam-methyl (FirstRate)
Sulfonylureas:
benzsulfuron-methyl (Londax)
chlorimuron-ethyl (Classic)
chlorsulfuron (Glean, Telar)
halosulfuron (Battalion, Permit)
metsulfuron-methyl (Ally, Escort)
nicosulfuron (Accent)
oxasulfuron (Expert)
primisulfuron-methyl (Beacon)
prosulfuron (Peak)
prosulfuron + primisulfuron-methyl (Exceed, Spirit)
rimsulfuron (Matrix)
rimsulfuron + thifensulfuron-methyl (Basis)
sulfometuron-methyl (Oust)
thifensulfuron-methyl (Pinnacle)
thifensulfuron + tribenuron-methyl (Harmony Extra)
triasulfuron (Amber)
tribenuron-methyl (Express)
triflusulfuron (UpBeet)

These herbicides work by interfering with one or more key enzymes that catalyze the production of specific amino acids in the plant. When a key amino acid is not produced, the plant's metabolic processes begin to shut down. The effect is like that of an assembly line worker not doing his or her job. Different herbicides affect different enzymes that catalyze the production of various amino acids, but the result is generally the same—the shut-down of metabolic activity with eventual death of the plant.

Injury symptoms. Plants sensitive to these herbicides stop growth almost immediately after foliar treatment; seedlings die in two to four days, established perennials in two to four weeks. Plants become straw-colored several days or weeks after treatment, gradually turn brown, and die.
Sublethal doses of glyphosate may cause growth hormone effects such as twisted stems and feather-like leaves, especially noticeable on grapes. Grass leaves may fail to unfold, resulting in an onion-like appearance.

Herbicides that inhibit fatty acid (lipid) biosynthesis

Aryloxyphenoxypropionates:
diclofop-methyl (Hoelon)
fenoxaprop-ethyl (Acclaim, Whip)
fluazifop-P-butyl (Fusilade DX)
quizalofop-P-ethyl (Assure II)
Cyclohexanediones:
clethodim (Select)
cycloxydim (Focus, Laser)
sethoxydim (Poast)

These herbicides are rapidly absorbed by grasses and are translocated to the growing points, where they inhibit meristematic activity, stopping growth almost immediately. They are most effective on warm-season grasses such as johnsongrass, shattercane, corn, fall panicum, giant foxtail, crabgrass, and wild proso-millet. Cool-season grasses like quackgrass, annual and perennial ryegrass, orchardgrass, timothy, and small grains are not as sensitive. For example, diclofop (Hoelon) is safe for use on winter wheat and barley and is labeled for annual grass control in these crops in the northwestern United States.

Injury symptoms. Growing points are killed first, with the resulting death of the leaves' inner whorl. Older outer leaves of seedlings appear healthy for a few days and those of perennials for a couple of weeks, but eventually they also wither and die. After several weeks the growing points begin to rot, allowing the inner leaves to be pulled out of the whorl. Sensitive grasses commonly turn a purplish color before dying.

Herbicides that inhibit photosynthesis

Benzonitriles:
bromoxynil (Buctril)
Isoxazolidinones:
clomazone (Command)
isoxaflutole (Balance)
Phenyl carbamates:
desmedipham (Betanex)
phenmedipham (Spin-Aid)
Pyridazinones:
cloridazon/pyrazon (Pyramin)
norflurazon (Evital, Solicam, Zorial)
pyridate (Tough)
Substituted ureas:
diuron (Karmex)
fluometuron (Cotoran)
linuron (Lorox, Linex)
tebuthiuron (Spike)
Triazines:
ametryn (Evik)
atrazine (various)
cyanazine (Bladex)
hexazinone (Velpar)
metribuzin (Lexone, Sencor)
prometon (Pramitol)
prometryn (Caparol)
simazine (Princep)
Uracils:
terbacil (Sinbar)
bromacil (Hyvar X)
Other chemistry:
amitrole (Amitrol-T)
bentazon (Basagran)
fluridone (Sonar)
propanil (Stam)

In the presence of light, green plants produce sugar from carbon dioxide and water. Energy is needed for carbon, hydrogen, and oxygen atoms to rearrange and form sugar. To supply this necessary energy, electrons are borrowed from chlorophyll (the green material in leaves) and replaced by electrons split from water. If chlorophyll electrons are not replaced, the chlorophyll is destroyed and the plant's food manufacturing system breaks down. For lack of energy, the plant slowly starves to death.

Bromoxynil, phenyl carbamate, pyridazinone, substituted urea, triazine, and uracil herbicides all block chlorophyll electron replacement. As preemergence treatments, these herbicides permit normal seed germination and seedling emergence, but cause seedlings to lose their green color soon afterward. With the seed's food supply gone, the seedlings die. These herbicides are more effective on seedling weeds than on established perennial weeds.

Injury symptoms. In broadleaved plants, early seedling growth appears normal, but shortly after emergence (when energy reserves in cotyledons are depleted), leaves become mottled, turn yellow to brown, and die. Amitrole, clomazone, isoxaflutole, and norflurazon inhibit chlorophyll formation and the plants gradually become white (albino).

Grasses germinate and grow normally until energy reserves in the seed are depleted (two-leaf or three-leaf stage); then the leaves turn light green to white and the seedling dies.

Herbaceous and woody perennials starve very slowly, because they have large energy reserves in roots or rhizomes to live on while photosynthesis is inhibited. The herbicide may have to effectively inhibit photosynthesis for a full growing season to kill trees or brush. This kind of kill may be slow, but it is sure.

Herbicides that inhibit seedling growth

Acid amides:
acetochlor (Harness, Surpass, Topnotch)
alachlor (Lasso, Partner)
dimethenamid (Frontier)
flufenacet (Axiom)
isoxaben (Gallery)
metolachlor (Dual, Pennant)
napropamide (Devrinol)
pronamide (Kerb)
propachlor (Ramrod)
propanil (Stam)
Carbamothioates:
butylate (Sutan)
butylate + safener (Sutan+)
cycloate (Ro-Neet)
EPTC (Eptam)
EPTC + safener (Eradicane)
molinate (Ordram)
pebulate (Tillam)
thiobencarb (Bolero)
triallate (Avadex BW, Far-Go)
vernolate (Vernam)
Phenyl carbamates:
asulam (Asulox)
desmedipham (Betanex)
phenmedipham (Spin-Aid)
Benzonitriles:
dichlobenil (Casoron, Dyclomec, Norosac)
Other Chemistry:
dithiopyr (Dimension)

Herbicides in this group cause abnormal cell development or prevent cell division in germinating seedlings. They stop the plant from growing by inhibiting cell division in the shoot and root tips, while permitting other cell duplication processes to continue. Then follows a slow decline in plant vigor.

Injury symptoms. The leaves of broadleaved plants turn dark green, become wrinkled, and fail to unfold from the bud. The roots become shortened, thickened, brittle, and club-like. Germinating grasses normally do not emerge. If they do, young leaves fail to unfold, resulting in leaf looping and an onion-like appearance. The tip of the terminal leaf becomes rigid, not free-flapping (flag-like).

The dinitroanilines prevent cell division primarily in developing root tips and are effective only on germinating grasses and some dicots.
Dinitroanilines:
benefin (Balan)
ethalfluralin (Sonalan)
oryzalin (Surflan)
pendimethalin (Prowl, PreM, Pentagon)
prodiamine (Barricade),
trifluralin (Treflan)
Other chemistry:
bensulide (Prefar, Betasan)
DCPA (Dacthal)
siduron (Tupersan)

Injury symptoms. Seeds of treated broadleaved plants germinate but either fail to emerge, or they emerge as severely stunted seedlings that have thickened, shortened lower stems, small leaves, and short, club-shaped roots. Interestingly, seedlings of taprooted plants such as soybeans and alfalfa are not affected, nor are established plants with roots more than a couple inches deep commonly affected.

Grass seeds germinate but generally fail to emerge. Injured seedlings have short, club-shaped roots and thickened, brittle stem tissue. Seedlings die from lack of moisture and nutrients because of the restricted root system.

Membrane disrupter (contact) herbicides

Contact herbicides kill weeds by destroying cell membranes; they appear to burn plant tissues within hours or days of application. Total coverage is necessary for maximum activity. Some are foliar—they must be applied to a plant's foliage because they are inactive in soil, and weeds are controlled only through this initial contact. Foliar-applied contact herbicides are:
Bipyridyliums:
paraquat (Gramoxone Extra, Cyclone)
diquat (Valent Diquat)
Diphenyl ethers:
acifluorfen (Blazer)
fomesafen (Flexstar, Reflex)
lactofen (Cobra)
N-phenylphthalimides:
flumiclorac (Resource)
fluthiacet-methyl (Action)
Nonselective oils:
kerosene
fuel oil
diesel oil
Selective oils:
Stoddard solvent
Other chemistry:
ametryn (Evik)
bentazon (Basagran)
bromoxynil (Buctril)
difenzoquat (Avenge)
endothall (Endothal, Aquathol, Hydrothal)
linuron (Lorox)
pyridate (Tough)
Methanearsonates:
CAMA (Super Dal-E-Rad-Calar)
DSMA (Ansar 8100)
MSMA (Ansar 6.6, Bueno 6, Daconate, Weed-hoe, Weed-E-Rad)
cacodylic acid (Phytar 560)

The following herbicides may be foliar or soil applied and continue to give residual control for several weeks or months after application.
Diphenyl ethers:
oxyfluorfen (Goal)
Triazolinones:
carfentrazone (Aim)
sulfentrazone (Authority)
Other chemistry:
oxadiazon (Ronstar)
Inorganic herbicides:
sodium chlorate (Sodium Chlorate)

sodium borate (Polybor)
mixture of sodium chlorate and borate

Injury symptoms. All contact herbicides cause cellular breakdown by destroying cell membranes, allowing cell sap to leak out. Some may also inhibit photosynthesis. If conditions do not allow a quick kill by contact, a secondary effect of paraquat, diquat, linuron (Lorox), ametryn (Evik), and pyridate (Tough or Lentagran) is the inhibition of photosynthesis by oxidizing chlorophyll and causing a buildup of toxic materials. The result is rapid death of treated tissues. The activity of these herbicides is delayed in the absence of light.

Soil sterilants

Soil sterilants are nonselective chemicals that keep the soil free of vegetation for one or more years. Many herbicides can be used as soil sterilants if applied at very high rates.
Organic herbicides:
bromacil (Hyvar X)
imazapyr (Arsenal, Chopper)
prometon (Pramitol)
monuron + borax (Ureabor)
tebuthiuron (Spike)
Inorganic herbicides:
sodium chlorate (Sodium Chlorate),
sodium borate (Polybor)
mixture of sodium chlorate and borate

Injury symptoms. Organic soil sterilants are all photosynthetic inhibitors and produce symptoms as described above. Inorganic herbicides are contact herbicides that kill plant tissue in a few hours or days. The residue remains in the soil to provide continued weed control for up to two or more years.

Soil fumigants

Soil fumigants are highly toxic, volatile liquids or gases used to control soil pests. Most fumigants must be released under a gas-tight cover to prevent vapor escape. After 24 to 48 hours, the cover can be removed and the remaining gases allowed to escape. After 48 hours to two weeks, all vapors will dissipate, leaving no biologically active residue.
Organic herbicides:
chloropicrin (Picfume, Larvicide 100, Clor-O-Pic)
chloropicrin + methyl bromide(Dowfume, Brom-O-Gas)
metham (Vapam)
methyl bromide (Meth-O-Gas)

Injury symptoms. Vapors of soil fumigants commonly penetrate soil 4 to 6 inches and kill weeds, weed seeds, nematodes, fungi, and insects. These are the only herbicides that effectively kill dormant weed seeds. Weeds already present soon turn brown and die. Since weed seeds are killed, no new weeds will invade the area until weed seed is reintroduced. Some deeply buried weed seed may survive the treatment and will germinate if brought to the surface.

Times of application

The following terms describe herbicides based on when they are applied.

- *Preplant incorporated:* applied to soil and incorporated before crop is planted. Example: butylate (Sutan+) on corn.
- *Preplant:* applied to soil before crop is planted. Example: Lasso or Dual on soybeans.
- *Preemergence:* applied after crop is planted but before it emerges. Example: atrazine on corn.
- *Postemergence:* applied after crop emerges. Example: dicamba (Banvel) on corn.

Although these terms normally refer to application in relation to crops, they may also imply application in relation to weeds. Always be certain whether reference is being made to the crop or to the weed. In no-till situations, it is possible for an herbicide application to be preplant or preemergence to the crop, but postemergence to weeds. Some herbicides, such as alachlor (Lasso) or napropamide (Devrinol), must be preplant or preemergence to the weed for maximum activity.

Methods of application

The following terms refer to the ways herbicides can be applied.

- *Broadcast:* applied over the entire field
- *Band:* applied to a narrow strip over the crop row
- *Directed:* applied between the rows of crop plants with little or no herbicide applied to the crop foliage
- *Spot treatment:* applied to small weed-infested areas within a field

Formulations

Herbicides are not sold as pure chemicals but as mixtures or formulations of one or more herbicides with various additives. Surfactants (emulsifiers, wetting agents) or various diluents may increase the effectiveness of a pure herbicide. The type of formulation determines toxicity to plants, uniformity of plant coverage, and stability in storage. Herbicides are formulated to permit uniform and easy application as liquid sprays or dry granules.

Liquid sprays

Solutions are homogeneous mixtures of two or more substances. A solution may be either clear or colored and cannot be separated by mechanical means. An example is 2,4-D amine dissolved in water.

Emulsions are formed when one liquid is dispersed in another, as 2,4-D esters dispersed in water. Emulsions appear milky when dispersed in water, and the liquids may separate without agitation.

Micro-encapsulated formulations are tiny, ball-shaped capsules created when chemical reactions between two polymers cause them to form a “skin” around a liquid. These capsules are then dispersed in water. When added to more water in the spray tank, the whole mixture appears milky and the encapsulated herbicide may separate without agitation. Such formulations include Lasso Micro-Tech and Topnotch.

Wettable powders are finely divided, solid particles that may be dispersed and suspended in water. Suspensions of wettable powders appear cloudy. Wettable powders are nearly insoluble and require agitation to remain in suspension. Atrazine and linuron are formulated as wettable powders.

Dry flowables or water-dispersible granules are wettable powders formed into prills so they pour easily into the sprayer tank without clumping and producing a cloud of dust. Nearly insoluble, they require agitation to remain in suspension. Atrazine and linuron are also formulated as dry flowables.

Flowables or water-dispersible liquids are wettable powders already suspended in water so they can be poured or pumped from one tank to another. Flowables are nearly insoluble in water and require agitation to remain in suspension. Atrazine and linuron are also formulated as flowables.

Fumigants are gases at room temperature when not pressurized. They commonly come as liquids in pressurized containers as, for example, liquid ammonia. The liquid must be injected or released under a gastight tarp to prevent its being lost to the air. Specialized application equipment is required.

Premixes are not formulations but two or more herbicides mixed by the manufacturer. The actual formulation can be any of those discussed above and commonly combines two or more herbicides that are used together anyway. The primary reason for using premixes is convenience. Since 1980, about 50 premixes have been released for use on corn and soybeans, and the future will surely bring more.

Granules

Herbicides in granular formulations are applied dry with a carrier. The carrier may be fertilizer, clay, lime, vermiculite, or ground corn cobs. The performance of granulated herbicides, compared with that of sprayable formulations, varies with the herbicide. Granular forms generally require more rainfall for activation than do sprayable formulations.

Advantages:
- water is not needed for application
- equipment required for application is relatively inexpensive
- selectivity may be improved because granular particles fall off leaves and sift through crop canopy to the ground

Disadvantages:
- heavy or bulky materials that are troublesome to store or ship
- small granules are subject to drift
- application is not as uniform as that of sprays

Pellets

Pellets are like granules but are compressed into larger cylinders about 1/4 inch long. Herbicides formulated as pellets usually contain from 5 to 20 percent active material and are hand-applied to control clumps of brush. They also may be applied with cyclone-type spinner spreaders mounted on helicopters or aircraft for brush control in forests or permanent pastures. Pellets gradually break down from rainfall and leach into the soil for root uptake.

Mixing and applying

Be aware that improper sprayer calibration, nonuniform application, calculation errors, or use of the wrong chemicals can cause herbicide injury to the crop.

Apply only the recommended amount of herbicide. Slight increases in rates could result in crop injury or leave residues that might injure succeeding crops.

Recalibrate sprayers frequently to adjust for increased output resulting from normal nozzle wear. Be sure there is sufficient agitation in the sprayer tank to prevent settling of wettable powders, dry flowables, or flowables.

Do not stop in the field with the sprayer on, spill herbicide when loading, or dump unused herbicides in anything except a holding tank.

Take the following steps when mixing herbicides:

1. Always be sure the sprayer has been calibrated properly for application at recommended rates.
2. Calculate the amount of herbicide to add to the sprayer tank based on the active material in each gallon of herbicide concentrate, or the percentage of active ingredient of dry herbicide formulation.
3. Read and follow the instructions on the manufacturer's label pertaining to personal hazards in handling.

- Fill the sprayer tank with at least half the volume of water or fertilizer solution you will ultimately need.
- Start moderate agitation and keep it going.
- Add compatibility agents if needed. For maximum benefit, they must be in the solution before herbicides are added. (To determine pesticide compatibility, see the next section.)
- Add, mix, and disperse dry herbicides (wettable powders, dry flowables, or water dispersible granules). These formulations contain wetting and dispersing agents that aid in mixing.
- Add liquid flowables and mix thoroughly. Liquid flowables also contain wetting and dispersing agents.
- Add emulsifiable concentrates (ECs) or micro-encapsulated herbicides and mix thoroughly.
- Finish by adding water soluble formulations (2,4-D amine, etc.).
- Add any surfactants and crop oil concentrates last. Crop oils, especially, do not mix and disperse well if added first.
- Add the remainder of water or liquid fertilizer and maintain agitation until tank is empty.

Caution: Never mix concentrated herbicides in an empty tank. Never allow a sprayer containing mixed chemicals to stand without agitation, because heavy wettable powders may clog nozzles or settle into corners of the sprayer tank where they are difficult to remove.

Compatibility

Pesticides are not always compatible with each other or with the water or liquid fertilizer carrier. Lack of compatibility may only result in the formation of a jell, precipitate, or sludge that plugs up screens and nozzles. However, extreme incompatibility may produce a settling out of material that can harden like concrete in the bottom of the tank and in hoses, pumps, and other internal parts of the sprayer. The result may be total loss of the pesticide and use of the sprayer.

Herbicides may be combined with liquid fertilizers to minimize trips over the field. However, little information exists concerning the compatibility of herbicides with specific fertilizer solutions. Herbicide-fertilizer solution combinations may form a jell or precipitate that settles to the bottom of the sprayer tank or will not flow through the sprayer equipment.

Tank-mixing several pesticides, although convenient, may create other problems. Foliar activity may be enhanced and could result in crop leaf burn, or the activity of one or more of the pesticides may be reduced (“antagonism”).

To prevent the main water tank or liquid-fertilizer measuring tank from becoming contaminated, commercial applicators may want to mix the herbicides and other ingredients in a separate holding tank. The herbicide mixture is then sucked into the main line as the truck tank is being filled, and thorough mixing is provided by the truck’s agitation system. Compatibility problems are more likely to result when concentrated herbicides are mixed together, so a compatibility test should be done before new mixtures are tried.

Use only labeled tank mixtures or mixtures recommended by experienced scientists whose recommendations are backed by research. For all unlabeled tank mixtures, a jar test for compatibility is strongly recommended. The compatibility of herbicide-fertilizer combinations should be tested before large batches are mixed. In some cases, adding a compatibility agent (Compex, Unite, or comparable surfactants) may aid in maintaining component dispersion.

The following “two-jar test” may be used to test the compatibility of herbicides with each other or herbicides and other pesticides with liquid fertilizers.

1. Add 1 pint of carrier (water, liquid fertilizer) to each of two quart jars.
2. Add 1/4 teaspoon of compatibility agent to one jar (equivalent to 2 pints per 100 gallons of spray solution). (Table 1)
3. Add the required amount of pesticide to each jar (Tables 2 and 3) in the order suggested in step 3 above for tank-mixing herbicides. Shake well after each addition to simulate continuous agitation.
4. When all ingredients are added, shake both jars for 15 seconds and let stand for 30 minutes or more. Then, inspect the mixture for flakes, sludge, gels, or nondispersible oils, all of which may indicate incompatibility.

Table 1. Compatibility agent rate per 100 gallons for use in 1 pint of solution.

Compatibility agent (A) rate	Ml of (A) per pint of carrier	Teaspoons[a]
1 pt/100 gal	0.6 ml	1/8
2 pt/100 gal	1.2 ml	1/4
3 pt/100 gal	1.8 ml	3/8
4 pt/100 gal	2.4 ml	1/2

[a]One teaspoon = 4.93 ml.

Table 2. Dry pesticide rates for compatibility test.

Gallons of carrier to be applied per acre	Teaspoons of wettable powder pesticide to be added per pint of liquid carrier[a]		
(gal)	(1 lb/A)	(2 lb/A)	(4 lb/A)
10	3.5	7.1	14.2
20	1.8	3.5	7.1
40	0.9	1.8	3.5
60	0.6	1.2	2.4

[a]One teaspoon = 1.6 gram based on an 80 percent wettable powder formulation.

Table 3. Liquid pesticide rates for compatibility test.

Gallons of carrier to be applied per acre	Teaspoons of wettable powder pesticide to be added per pint of liquid carrier[a]		
(gal)	(1 qt/A)	(2 qt/A)	(4 qt/A)
10	2.4	4.8	9.6
20	1.2	2.4	4.8
40	0.6	1.2	2.4
60	0.4	0.8	1.6

[a]One teaspoon = 4.93 ml.

■ If, after standing for 30 minutes, the components in the jar with no compatibility agent are dispersed, the herbicides are compatible and *no* compatibility agent is needed.
■ If the components are dispersed *only* in the jar containing the compatibility agent, the herbicide is compatible only if a compatibility agent is added.
■ If the components are not dispersed in either jar, the herbicide-carrier mixture is not compatible and should not be used.

Should the herbicide-carrier mixture prove compatible in this test procedure, it may be applied to the field. Wettable powders that settle slightly and readily remix with shaking can be kept in suspension if vigorous agitation is maintained in the sprayer.

Herbicide selectivity

Were it not for the fact that most herbicides can be applied just before crop planting or emergence and even over the top after crop emergence without excessive injury, herbicides would be of little value. Most of the herbicides labeled for use today will selectively remove some of the weeds without injuring the crop. Selectivity is accomplished primarily by two methods: selectivity by placement and true selectivity.

Selectivity by placement

Selectivity accomplished by avoiding or minimizing contact between the herbicide and the desired crop is called selectivity by placement. An example is wiping or directing a herbicide like glyphosate on a weed without exposing the desired plant. Selectivity by this means is as good as any, as long as the excess herbicide is not washed off the weeds and leached into the root zone where it might be root absorbed. Selectivity by placement also is accomplished when a herbicide that does not leach readily is applied to the soil surface for control of shallow rooted weeds but does not leach into the root zone of a more deeply rooted crop such as fruit trees or established alfalfa.

True selectivity

Selectivity that is true tolerance as a result of some morphological, physiological, or biochemical means is referred to as true selectivity. The herbicide can be applied to the foliage of the crop or to soil in which the crop is growing without danger of injury. Although true tolerance may be the best type of selectivity, it is not perfect. Such things as crop growth stage, cuticle thickness, hairiness of the leaf surface, location of the growing point, air temperature and humidity, spray droplet size, and the surface tension of spray droplets all can influence herbicide activity. When conditions are ideal for herbicide activity, even true selectivity may not adequately prevent crop injury.

Morphological differences include such plant characteristics as size and orientation of the leaf, waxiness or hairiness of the leaf surface, location of the growing point, and rooting depth. Generally, the more waxy or hairy the leaf surface, the more difficult it is for a foliar applied herbicide to penetrate. The more protected the growing point (as in grasses), the less likely it is that foliar herbicides will reach the growing point. The more deeply rooted the crop is, the more difficult it is to get a soil applied herbicide to the crop roots and the less likely that there will be sufficient uptake for injury.

Physiological differences include differential herbicide uptake across the plasma lemma, differential translocation of herbicides within the plant, combining with some component within the cell wall, complexing with something in the cell cytoplasm, or channeling the herbicide into “sinks” where the herbicide will have no effect. These factors all can contribute to tolerance but any one factor seldom will provide tolerance by itself.

Metabolic factors include genetic insensitivity due to an altered site of herbicide action that prevents herbicide activity. Roundup Ready soybeans produce an excess of the enzyme that Roundup normally inhibits, so Roundup Ready soybeans are not affected, even though normal amounts of the herbicide are absorbed by the crop plant. Corn plants metabolize and convert atrazine to an innocuous metabolite so rapidly that the herbicide does not have time to inhibit photosynthesis, which provides crop tolerance as long as the metabolic system is not overwhelmed by an excess of the pesticide or a combination of pesticides. In the case of corn treated with an organophosphate insecticide and followed with a post treatment of Accent or Beacon, both the insecticide and herbicide are being metabolized by the same pathway. This pathway is unable to rapidly metabolize both the herbicide and insecticide, so the Accent or Beacon causes corn injury. Metabolic insensitivity or the ability to metabolize the herbicide usually are the best types of true tolerance.

Safe herbicide use

Use herbicides only when necessary, only at recommended rates and times of application, and only for those crops and uses listed on the label. Correct use is essential to ensure that chemical residues on crops do not exceed the limits set by law. Recommended herbicides do not generally injure people, livestock, wildlife, or crops if used properly and if recommended precautions are observed. However, any herbicide is potentially dangerous if improperly handled or used.

Follow these basic pesticide safety procedures:

- Make sure that you are familiar with current federal and state pesticide laws and regulations and that you have a license, if required.
- Avoid drift of spray or dust that may endanger other crops or animals. Cover feed pans, troughs, and watering tanks in livestock areas. Protect beehives.
- To protect yourself and others, follow all safety precautions on the label. Know and observe the general rules for safe pesticide use, and record the date, time, location, and amount of each pesticide used.
- Wear protective clothing and use protective equipment according to instructions on the pesticide label.
- Never eat, drink, or smoke while applying pesticides.
- Avoid spilling spray materials on skin or clothing. If such an accident occurs, wash immediately with soap and water.
- Bathe after applying pesticides and change into freshly laundered clothing. Wash clothing after applying pesticides, keeping in mind that, until laundered, such clothing must be handled according to the same precautions as the pesticide itself. Wash pesticide-contaminated clothing apart from other laundry, and take care in disposing of the wash water.
- Store pesticides in their original containers in a locked, properly marked cabinet or storeroom, away from food or feed.
- Do not store herbicides with other pesticides; avoid the danger of cross-contamination.
- Be sure to triple rinse all empty containers before disposing of them in an approved landfill.
- If you suspect poisoning, contact your nearest Poison Control Center, hospital emergency room, or physician. Take the pesticide label with you and give it to the attending physician.

Livestock

Herbicides sprayed on plants generally are not toxic to livestock, but animals can be poisoned by eating unused herbicides left in open containers or by drinking water contaminated with herbicides.

Certain unpalatable or poisonous plants treated with herbicides may become palatable to livestock. Be certain that livestock cannot get to poisonous plants that have been sprayed with herbicides.

The nitrate content of several kinds of weeds may increase after they have been sprayed with 2,4-D, Banvel, or similar herbicides. Cattle browsing on these treated plants may become ill. Remove all animals from sprayed areas for several days or until it has rained or the weeds have died.

Game and fish

Controlled spraying may benefit wildlife by maintaining desirable cover. Herbicides recommended for control of aquatic weeds usually have beneficial results for fish populations. Be sure to apply these herbicides properly. Do not drain or flush equipment where chemicals may wash into ponds or streams, and do not leave open containers where curious animals might find them.

Crop safety

Farmers are occasionally concerned about possible herbicide injury to crops. Most injuries of this kind are caused by misuse, contaminated equipment, or drift. Unfavorable weather conditions combined with herbicide residues from a previous crop planting can potentially injure crops.

Cleaning contaminated equipment

Sprayers used to apply 2,4-D-type herbicides can be used to apply other chemicals before crops are planted or before crop plants emerge, but this equipment must be thoroughly cleaned before applications are made on emerged crops (except grasses). Ester formulations are harder to remove than amine or salt formulations.
To remove esters, flush out the entire system with a water-detergent solution immediately after spraying. Then fill the tank and prime the system with an ammonia solution of 1 gallon of household ammonia to 100 gallons of water, and leave it undisturbed for 12 to 24 hours. Take the nozzles apart and soak the caps, screens, bodies, etc., in ammonia solution. (Five pounds of Sal soda or 8 pounds of trisodium phosphate can be substituted for ammonia.) Rinse the system thoroughly with water and let it circulate through the sprayer.

After using amine or salt formulations or other liquid herbicides, clean the equipment by flushing the entire system with a water-detergent solution and rinsing with clean water.

Wettable powder residues must be removed immediately after use. Flush the entire system with clean water, then remove the sprayer nozzles and clean any residue from the screens. Rinse the system with a detergent solution followed by clean water. Replace the nozzles. (The herbicide label may suggest special cleaning procedures.)

To test for residual herbicide contamination, spray a few plants of a susceptible crop four to five days before using the sprayer on large areas.

Drift

Drift is the movement of any pesticide through the air to areas not intended for treatment. During application, droplet or particle drift occurs as spray droplets or dust particles are carried by air movement from the application area to other places. Vapor drift takes place after application, as herbicides evaporate (volatilize) and yield fumes (gases) that are carried on wind currents and deposited on soils or plants in untreated areas.

Drift may injure sensitive crops, ornamentals, gardens, livestock, wildlife, or people, and may contaminate streams, lakes, or buildings. It may contaminate crops and cause illegal or intolerable residues. Excessive drift may mean poor performance in the desired spray area because the application rate is lower than expected.

Highly active chemicals present the greatest drift hazard, because extremely small amounts can cause severe problems. For example, growth-regulating herbicides such as 2,4-D, dicamba, and picloram, at a rate of 1 ounce per acre, can deform sensitive crops such as tobacco, grapes, or tomatoes. Vapor drift from Command that has not been incorporated can cause bleaching of chlorophyll in sensitive plants within a quarter mile of application.

Vapor drift problems can often be avoided by using nonvolatile formulations. Essentially, no vapor drift hazard is involved in the use of amine formulations of 2,4-D. Soil incorporation of Command and a new micro-encapsulated formulation greatly reduces vapor loss of this herbicide.

Particle drift depends on the size of the particle or droplet, and droplet size depends on pressure and nozzle design. Very small particles of fog or mist present the greatest drift hazard. To minimize particle drift, calibrate equipment to create droplets about the size of light rain. Most nozzles can be adjusted to a pressure that permits droplet formation as a result of surface tension. If nozzles are operated at this pressure, a minimum of mist-sized droplets will be formed. For some nozzles, this pressure may be as little as 10 psi; for others, it may be 30 psi.

The distance particles will drift increases with the height of release. Wind velocities usually are lower close to the ground. Therefore, sprays should be released as close to the soil surface or vegetation as adequate coverage permits.

Drift hazard usually is minimized if prevailing winds are blowing away from sensitive crops, but a sudden shift in wind direction could result in serious damage. If possible, do not apply pesticides when wind speed is greater than 5 mph.

High temperatures increase the loss of volatile herbicides. Esters of 2,4-D rapidly evaporate at temperatures above 80°F. The use of such ester formulations should be restricted to fall, winter, and early spring, because sensitive plants are not present, and because lower temperatures reduce vapor drift hazard.

Drift control should be considered with each pesticide application. You can prevent severe drift problems by:

- using low volatile or nonvolatile formulations
- using low spray delivery pressures (10-30 psi)
- using drift-control agents when spraying under less-than-ideal conditions
- avoiding application of volatile chemicals at high temperatures
- spraying when wind speed is low or when the wind is blowing away from areas that should not be contaminated
- leaving border areas unsprayed if they are near sensitive crops

Evaluating herbicide injury

Insects, diseases, severe weather (hail, lightning, drought, flooding), fertilizer burn, and nutrient deficiencies are among the causes of symptoms often attributed to herbicide injury. Cool, wet weather can increase the potential for injury, particularly with preemergence herbicides. When evaluating crop injury, careful consideration of the following will help you diagnose the problem.

1. Pattern in the field of plant injury or uncontrolled weeds.

- A pattern of injury that starts on one side of an area and diminishes gradually and uniformly away from that area is typical of application drift.
- A pattern of injury occurring in irregular patches that follow air drainage could indicate herbicide volatilization and movement of vapors.
- Strips of injured areas or surviving weeds at predictable intervals indicate possible skipping or overlapping application.

- Poor control at the edges of a field can result from only half coverage by the last nozzle on the boom and/or more sunlight availability along the edge of the field.
- Injury limited to the end rows or ends of the field is usually due to overlapping applications or high herbicide rates where you turn at the ends.
- A definite break between the normal or uninjured part of the field and the rest of the field usually indicates some major difference in soil type or pH between the two sides.
- A pattern of obvious over application as indicated by bare ground (both crop and weeds killed), followed by improved crop survival and appearance with good weed control, followed by lack of crop injury or weed control indicates inadequate or poor agitation in the sprayer tank. The evidence is even stronger if this pattern repeats itself at intervals that correspond to each new load.

2. What is the history of the problem area—fertility program, cropping sequence, land preparation, soil pH, soil texture and organic matter, and seed source?
3. What was the temperature, moisture, rainfall, and prevailing wind at and immediately following herbicide application?

Persistence

The residual life or length of time a herbicide persists in the soil is the length of time it can be expected to control weeds. Residual toxicity, if not considered, may injure the next crop planted in a herbicide-treated field.

Inactivation, breakdown, and disappearance of herbicides are influenced by the following factors.

Microbial degradation. Microorganisms feed on all types of organic matter, including organic herbicides. Some herbicides are more readily attacked by microorganisms than others, often because of minor differences in chemical structure that permit rapid decomposition in some cases and block decomposition in others. Soil temperature, aeration, pH levels, organic matter, and moisture levels favorable for microbial growth promote rapid herbicide breakdown. Microbial degradation takes place primarily in the top foot of soil where microbial activity is the greatest.

Runoff. Water moving over the surface of a field or treated area can carry herbicide with it. The greatest loss of herbicide occurs when the herbicide is applied to the soil surface and is washed off by the first rain after application. If the herbicide is incorporated or leached into the soil with light rains or irrigation, most loss occurs only with erosion after the herbicide is adsorbed to soil particles.

Leaching. Water carries herbicides into and ultimately out of the root zone. The portion lost to leaching depends on soil texture, herbicide solubility, and amount and intensity of rainfall. As a rule, herbicides leach most from sandy soils and least from clay soils or soils high in organic matter.

Adsorption. After application, herbicides may become adsorbed (bound) to clay and organic matter particles. The extent of adsorption increases as the percentage of organic matter and/or clay increases. Adsorption reduces the amount of chemical available to plants and slows leaching.

Chemical degradation. Herbicides may be inactivated upon reaction with salts, acids, and other substances in the soil. These reactions are affected by the same environmental factors that influence microbial breakdown. Chemical degradation can occur anywhere in the soil profile and is the primary process responsible for herbicide dissipation below the top foot of soil where microbial activity is limited or nonexistent.

Volatilization. Some herbicides may be rapidly lost as vapors after application. Loss as vapor reduces the persistence of dinitroaniline and thiocarbamate herbicides and of dichlobenil and Command. The rate of vapor loss is influenced by soil moisture, temperature, and adsorption.

Evaporation of herbicides increases as sand content, soil moisture, and soil temperature increase. Incorporation into soil immediately after application reduces this kind of loss.

Photodecomposition. Sunlight may inactivate herbicides, a factor that may contribute to a decline in effectiveness of unincorporated trifluralin (Treflan) and benefin (Balan). Exposure to light for two or more hours reduces the effectiveness of trifluralin and related herbicides, and can be avoided by soil incorporation.

Plant uptake. Herbicides may be absorbed by plant roots or leaves and inactivated within the plant. This effect generally accounts for a relatively small amount of herbicide removal, but in some cases, such as atrazine, simazine, or cyanazine removal by a healthy corn crop, the amount removed is significant.

Crop removal. If a crop is harvested or removed from the treated area before rain has washed the herbicide off the foliage or before the plant has had time to metabolize the residue, the herbicide will be removed with the crop. This seldom happens, because herbicides are not commonly used close to harvest. However, if grass clippings are collected shortly after treatment and used to mulch a garden, there may be enough herbicide on the grass to damage the garden plants.

Toxicity

Toxicity usually is measured as LD_{50} (lethal dose), which is the amount of a toxicant required to kill 50 percent of the test animals. The lower the LD_{50}, the less pesticide it takes to kill the animal. Below is a list of the most commonly available herbicides in order of decreasing oral toxicity.

Highly toxic herbicides
(LD_{50} < 50 mg/kg)
The probable lethal dose of a highly toxic herbicide for a 150-pound man is a few drops to 1 teaspoon. The label contains the signal words “Danger/Poison” and has a skull and crossbones.
chloropicrin (Picfume, Larvicide100)
chloropicrin + methyl bromide (Dowfume)
endothall (Endothal, Aquathol, Des-i-cate)
metham (Vapam)
methyl bromide (Meth-O-Gas)
sodium arsenite[a,b]

Moderately toxic herbicides
(LD_{50} = 50 to 500 mg/kg)
The probable lethal dose of a moderately toxic herbicide for a 150-pound man is 1 teaspoon to 1 ounce. The signal word on the label reads “Warning.”
bromoxynil (Buctril)
copper sulfate (bluestone)
cyanazine (Bladex)
difenzoquat (Avenge)
diquat (Valent diquat)
endothal (Endothal dimethylamine salt)
paraquat (Gramoxone Extra, Cyclone)

Slightly toxic herbicides
(LD_{50} = 500 to 5,000 mg/kg)
The probable lethal dose of a slightly toxic herbicide for a 150-pound man is 1 ounce to 1 pint or 1 pound. The signal word on the label reads “Caution.”
acetochlor (Harness/Topnotch)
acifluorfen (Blazer)[c]
alachlor (Lasso)[c]
ametryn (Evik)[c,d]
atrazine (various)[d]
bensulide (Betasan)
bentazon (Basagran)
butylate (Sutan+)[d]
cacodylic acid (Phytar 560, Rad-E-Cate)
CAMA (Super Dal-E-Rad-Calar)
clomazone (Command)
clopyralid (Stinger, Transline)[c]
cloridazon (Pyramin)
cycloate (Ro-Neet)
cycloxydim (Focus, Laser)
2,4-D (various)
2,4-DB (Butyrac 200, Butoxone)
2,4-DP, dichlorprop (various)
dicamba (Banvel, Clarity, Vanquish)
dichlobenil (Casoron, Dyclomec, Norosac)
diclofop-methyl (Hoelon)
dimethenamid (Frontier)[d]
diuron (Karmex)[d]
DSMA (Ansar 8100, Drexel DSMA)[d]
EPTC (Eptam)[d]
EPTC + safener (Eradicane)[d]
fenoxaprop-ethyl (Acclaim, Whip)[d]
fluazifop-P-butyl (Fusilade DX)
flufenacet (Axiom)
fluridone (Sonar)
glufosinate (Liberty, Finale)
hexazinone (Velpar)[d]
linuron (Lorox)[c]
MCPA (amine)[d]
MCPB (Thistrol)
MCPP, mecoprop (various)
mefluidide (Embark, Vistar)
metolachlor (Dual, Pennant)
metribuzin (Sencor, Lexone)
molinate (Ordram)
MSMA (Ansar 6.6, Bueno 6, Daconate, Weed-hoe, Weed-E-Rad)[d]
pebulate (Tillam)
prometon (Primatol)[d]
prometryn (Caparol)[d]
propachlor (Ramrod)[c]
propanil (Stam, Stampede)
pyridate (Tough)
quizalofop-P-ethyl (Assure II)
sethoxydim (Poast)
sodium chlorate[d]
sulfentrazone (Authority)
tebuthiuron (Spike)
terbacil (Sinbar)
thiobencarb (Bolero)
triallate (Avadex BW, Far-Go)
triclopyr (Garlon)[d]
vernolate (Vernam)

Almost nontoxic herbicides
(LD_{50} > 5,000 mg/kg)
The probable lethal dose of an almost nontoxic herbicide for a 150-pound man is more than 1 pint or 1 pound. The signal word on the label reads “Caution.”
amitrole (Amitrol-T)
asulam (Asulox)
benefin (Balan)
benzsulfuron-methyl (Londax)
bromacil (Hyvar X)[d]
chlorimuron-ethyl (Classic)[d]
chlorsulfuron (Glean, Telar)
clethodim (Select)
DCPA (Dacthal)
desmedipham (Betanex)
dithiopyr (Dimension)[c]
ethalfluralin (Sonalan)
ethofumesate (Prograss)
flumetsulam (Broadstrike, Python)
flumiclorac (Resource)
fluometuron (Cotoran)
fluthiacet-methyl (Action)
fomesafen (Flexstar, Reflex)
fosamine (Krenite)
glyphosate (Roundup Ultra, Rodeo)
halosulfuron (Battalion, Permit)
imazamethabenz (Assert)
imazamox (Raptor)
imazapic (Cadre, Plateau)
imazapyr (Arsenal, Chopper)[d]
imazaquin (Scepter, Image)
imazethapyr (Pursuit)
isoxaben (Gallery)
isoxaflutole (Balance)
lactofen (Cobra)
mefluidide (Embark, Vistar)
metsulfuron-methyl (Ally, Escort)
napropamide (Devrinol)
nicosulfuron (Accent)
norflurazon (Zorial, Solicam)
oryzalin (Surflan)
oxadiazon (Ronstar)[d]
oxyfluorfen (Goal)
pendimethalin (Prowl or PreM)
phenmedipham (Betanal)
prodiamine (Barricade)
picloram (Tordon)
primisulfuron-methyl (Beacon)
pronamide (Kerb)[d]
prosulfuron (Peak)
prosulfuron + primisulfuron-methyl (Exceed)
rimsulfuron + thifensulfuron-methyl (Basis)
siduron (Tupersan)
simazine (Princep)
sodium borate[d]
sulfometuron-methyl (Oust)
thifensulfuron-methyl (Pinnacle)[d]
thifensulfuron + tribenuron-methyl (Harmony Extra)
triasulfuron (Amber)
trifluralin (Treflan)
tribenuron-methyl (Express)

Dermal response:
[a] is absorbed and poisonous
[b] causes burns and blisters
[c] is moderately irritating
[d] is mildly irritating

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