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# How Herbicides Work

## Uptake, Translocation, and Mode of Action







OREGON STATE UNIVERSITY
EXTENSION SERVICE

## Contents



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## Herbicide and Plant Terminology

**Amino acid**—A building block of protein.

**Carotenoids**—Red, orange, and yellow pigments that capture light energy for photosynthesis and protect chlorophyll from excess light.

**Chlorophyll**—Green pigments that capture light energy for photosynthesis.

**Contact herbicide**—An herbicide that affects only the plant part contacted, rather than moving within the plant.

**Cuticle**—The waxy outer coating of a plant. Herbicides must penetrate the cuticle to enter the plant.

**Enzyme**—A substance that acts on other substances to produce end products such as proteins or lipids.

**Hormone**— A chemical substance that coordinates plant activities such as germination, growth, carbohydrate metabolism, reproduction, and death.

**Lipids**—Waxes and oils in plants, important in the synthesis of cell membranes.

**Metabolism**—The breakdown of a compound into its component parts.

**Mitosis**—The process of cell division and creation of new cells.

**Organelle**—A specialized structure in a cell.

**Phloem**—The plant's two-way transport system, which moves sugars and amino acids both up and down the plant.

**Photosynthesis**—The production of carbohydrates from light energy, water, and carbon dioxide.

**Stomata**—Openings within a plant leaf that allow the passage of oxygen, water vapor, and carbon dioxide.

**Translocation**—The movement of a substance within a plant through xylem and/or phloem.

**Xylem**—The plant's one-way transport system, which moves water and nutrients from the roots to the upper parts of the plant.

# How Herbicides Work:
## Uptake, Translocation, and Mode of Action

Effective weed management with herbicides depends on the coordination of several factors (Figure 1):

- Herbicide application and placement
- Herbicide uptake
- Herbicide translocation (movement within the plant)
- Herbicide metabolism (breakdown within the plant)
- Herbicide toxicity or activity

### Herbicide Application and Placement

Herbicides must be applied in a way that maximizes their contact with target weeds. This is particularly important for postemergence *contact* herbicides such as paraquat. These herbicides affect only the part of the plant they contact. Thus, even and thorough plant coverage results in the best weed control.

In contrast, some postemergence herbicides, such as glyphosate, move from the foliar application site to the target site within the plant through the plant's transport system. These products are known as *translocated* herbicides.

Soil-applied herbicides must be applied evenly across the field to maximize contact with germinating weeds. Proper seedbed preparation and soil moisture can eliminate soil clods that protect weed seeds from the herbicide.

Some soil-applied herbicides, such as trifluralin, do not move easily within the soil; they must be incorporated into the soil to maximize contact with weeds. Soil-incorporated herbicides become more

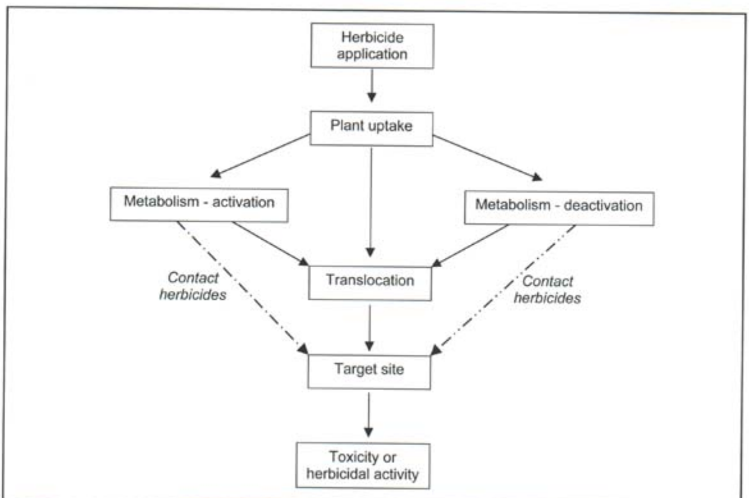



*Figure 1.—Routing of herbicides from the sprayer nozzle to the site of activity within a plant.*

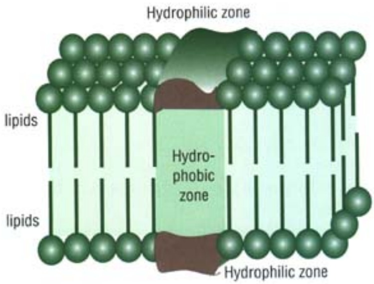



*Figure 2.—Cell membranes are made up of a double layer of lipids, with proteins traversing the two layers and protruding from the inner and outer surface. The exposed portions of the protein are hydrophilic; the embedded portion is hydrophobic.*

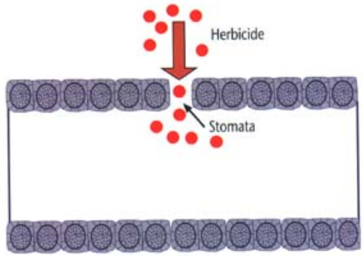



*Figure 3.—Openings in the leaf surface called stomata allow herbicides to enter the plant along with carbon dioxide. Water vapor and oxygen exit through the stomata.*

diluted when tilled in deeply. Thus, it is important to incorporate them evenly and only to the depth of germinating weeds. Poor herbicide incorporation often results in strips in the field where there is ineffective weed control.

## Herbicide Uptake

Postemergence herbicides must overcome several barriers to move from the leaf surface into the plant. Leaf hairs often intercept spray particles, holding them away from the leaf surface. The leaf surface itself is protected from dehydration by a waxy coating called the *cuticle*. Some herbicides will not penetrate the cuticle (particularly hydrophilic, or "water-loving," herbicides), while others become trapped within the cuticle (hydrophobic, or "water-hating," herbicides) (Figure 2). The cuticle becomes thicker during hot, dry weather, making it more difficult for herbicides to pass through. Spray additives can enhance herbicide penetration.

Postemergence herbicides also can enter the leaf through openings called *stomata*, which act like gates, allowing some compounds to enter while excluding others (Figure 3). In hot, dry weather, the stomata close, preventing herbicide penetration.

Soil conditions also play a role in herbicide uptake. Soil-applied herbicides must contact roots and/or shoots of the target plant. Surface-applied herbicides often move with water through the soil to reach plant roots. Thus, when soil moisture is limited, weed control might be compromised by a lack of weed exposure to the herbicide.

## Herbicide Translocation

A plant's transport system is composed of two "pipes": the xylem and the phloem (Figure 4). The *phloem* is a two-way system composed of living plant cells that moves sugars and amino acids both up and down the plant. The phloem transports sugars to the growing points during spring growth. In perennials, it moves sugars to the roots for storage after the plant flowers. Most perennial weed herbicides are phloem-mobile so that they can be transported to the roots.

The *xylem* is a one-way pipe composed of dead cells that transports water and dissolved nutrients from the roots to the shoots. Water movement is driven by environmental factors such as soil moisture and the air's relative humidity. Water-soluble, soil-applied herbicides typically move in the xylem.

## Herbicide Metabolism

Herbicide selectivity often depends on the ability of tolerant plants to break down, or *metabolize*, herbicides before they cause injury. The resulting components, called herbicide *metabolites*, are attached to sugars or amino acids and sent to a part of the plant cell called a *vacuole*. Vacuoles act as trash bins for toxic compounds.

Some herbicides, such as clomazone, are inactive when applied. In this case, herbicide metabolism results in compounds that are toxic to the plant.

## Herbicide Toxicity or Activity

Several plant systems or processes (e.g., photosynthesis and pigment production) are involved in herbicide toxicity in susceptible species. This publication covers seven plant systems and the commonly used herbicides that act on them. These herbicides are grouped by the plant system involved:

- *Growth* regulators
- *Amino acid synthesis* inhibitors
- *Photosynthetic* inhibitors
- *Cell membrane* disruptors
- *Lipid synthesis* inhibitors
- *Meristematic* (growth) inhibitors
- *Pigment* inhibitors

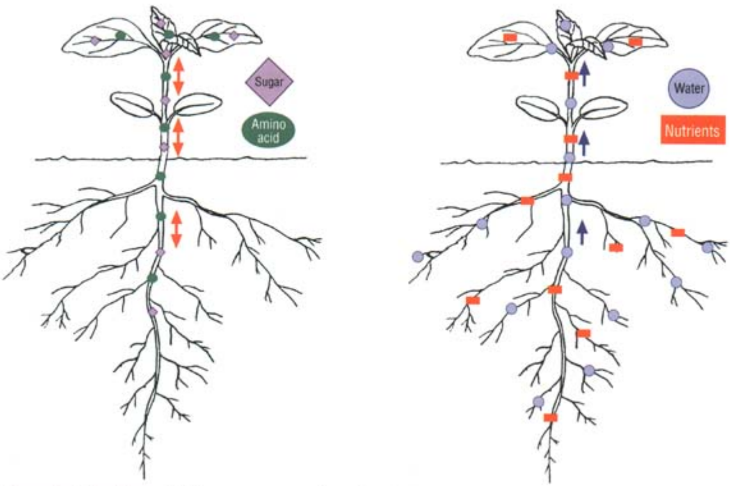



*Figure 4.—The phloem (left) moves sugars and starches both up and down the plant structure. The xylem (right) moves water and nutrients upward.*

## Growth Regulators

### Use

Growth regulators are used primarily for broadleaf weed control in grass crops. They are postemergence, foliar-applied herbicides. However, some have soil activity.

*Note:* Several growth regulator herbicides are prone to drift and injury of nontarget plants.

### Herbicide uptake

Growth regulators are absorbed by foliage and roots and are moved (translocated) primarily in phloem to new growth (Figure 5).

### Plant systems involved

*Plant hormones* are the chemical signals that coordinate plant activities such as germination, growth, carbohydrate metabolism, reproduction, and death. Key hormones include auxin, gibberellins, cytokinin, and ethylene.

### Mode of action

These herbicides upset normal hormone balance, thus disrupting cell enlargement, cell division, protein production, etc. The resulting abnormal or irregular growth often leads to plant death.

### Selectivity

**Grasses** absorb and transport growth regulator herbicides less effectively than broadleaves and metabolize them faster and into an irreversible form.

Within **broadleaf species**, selectivity is based on differences in herbicide metabolism. The more susceptible species metabolize growth regulators more slowly, thus allowing for longer exposure to toxic levels.

### Symptoms

**Broadleaf species** exhibit stem twisting (epinasty), malformed leaves (cupping, crinkling, parallel veins, and brittle or callus tissue (Plates 1 and 2).

## Growth Regulators

| Common name | Trade name(s) | Labeled crops in Oregon* |
|---|---|---|
| ***Phenoxy acetic acids*** | | |
| 2,4-D | Various names | Barley, corn, grass seed, oats, pasture and rangeland, wheat, non-cropland |
| 2,4-DB | Butyrac, Vine-Der | Alfalfa, birdsfoot trefoil, mint, clover |
| MCPA | Various names | Alfalfa, barley, grass seed, oats, pasture and rangeland, peas, wheat, clover, non-cropland |
| MCPB | Thistrol | Peas |
| ***Pyridines*** | | |
| Clopyralid | Stinger, Transline | Barley, beet seed, corn, mint, oats, pasture and rangeland, sugar beets, wheat, non-cropland |
| Fluroxypyr | Starane, Advance | Barley, chemical fallow, non-cropland, oats, wheat |
| Picloram | Tordon | Wheat, non-cropland, pasture and rangeland |
| Triclopyr | Garlon, Remedy | Non-cropland, pasture and rangeland |
| ***Benzoic acids*** | | |
| Dicamba | Banvel | Barley, chemical fallow, corn, grass seed, oats, pasture and rangeland, wheat, non-cropland |

*Only agronomic (not horticultural) crops are listed. Pesticide labels are subject to change. Always consult the label for current chemical recommendations before using any herbicide.

**Grass species** often display injury symptoms when these herbicides are applied during the seedling stage or flower formation.

- Corn plants: rolled leaves (onion-leafing), fused or malformed brace roots, brittle stalks
- Small grains: twisted leaves, sterile flowers, or multiple florets

## Weed resistance in the Pacific Northwest

- Yellow starthistle (*Centaurea solstitialis*): picloram (WA)
- Kochia (*Kochia scoparia*): dicamba (ID)

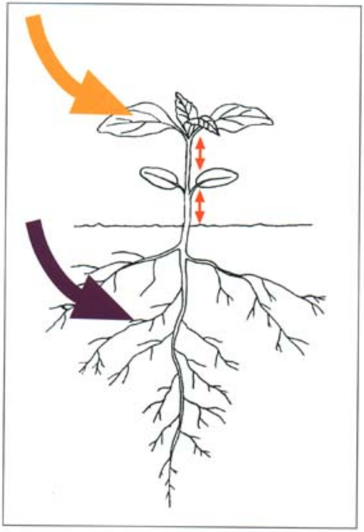


*Figure 5.—Growth regulators: Uptake through leaves and roots; transport through phloem.*

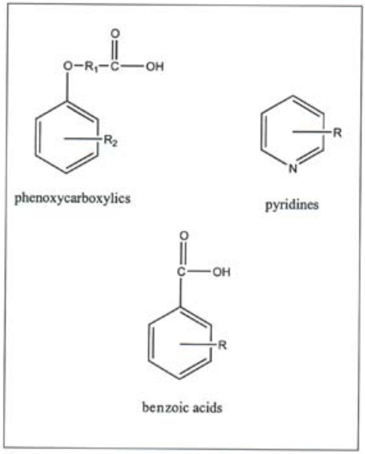



*Figure 6.—Chemical structure of growth regulator herbicides.*

# Amino Acid Synthesis Inhibitors

## Use

**Imidazolinone** and **sulfonylurea** herbicides selectively control annual and perennial broadleaf and grass weeds. Some soil-applied products provide residual weed control; the herbicide persists after application and injures or kills germinating weed seedlings.

**Amino acid derivative** herbicides are nonselective.

## Herbicide uptake

**Imidazolinone** and **sulfonylurea** herbicides are absorbed by foliage and/or roots and moved in the xylem and phloem (Figure 7).

**Amino acid derivatives** are absorbed by foliage. Soil activity is minimal because the herbicide binds to soil soon after application. Glyphosate moves with carbohydrates in both the xylem and phloem (Figure 8). For effective control of perennial weeds, it must move downward through the phloem. Thus, it is most effective when applied in the fall, when plants are transporting carbohydrates for storage. Glyphosate moves with the carbohydrates to underground storage organs, where it depletes reserves for future growth.

## Amino Acid Synthesis Inhibitors

| Common name | Trade name(s) | Labeled crops in Oregon* |
|---|---|---|
| ***Imidazolinones*** | | |
| Imazamox | Raptor | Alfalfa |
| Imazapyr | Arsenal | Non-cropland |
| Imazethapyr | Pursuit | Alfalfa, lentils, peas, dry beans |
| Imazamethabenz | Assert | Wheat, barley, grass seed |
| ***Sulfonylureas*** | | |
| Chlorsulfuron | Glean, Telar | Wheat, barley, oats, chemical fallow, non-cropland |
| Halosulfuron | Battalion, Permit | Corn, sorghum |
| Metsulfuron | Ally, Escort | Barley, non-cropland, pasture and rangeland, wheat |
| Nicosulfuron | Accent | Corn |
| Primisulfuron | Beacon | Corn, grass seed |
| Prosulfuron | Peak | Wheat |
| Rimsulfuron | Matrix | Potatoes |
| Sulfometuron | Oust | Non-cropland |
| Sulfosulfuron | Maverick | Wheat |
| Thifensulfuron | Harmony GT, Pinnacle | Wheat, barley |
| Triasulfuron | Amber | Barley, pasture and rangeland, wheat |
| Tribenuron | Express | Barley, wheat, grass seed |
| Triflusulfuron | UpBeet | Sugar beets |
| ***Amino acid derivatives*** | | |
| Glyphosate | Various names | Non-cropland, chemical fallow, pasture and rangeland, preseeding in several crops |
| Glufosinate | Liberty, Rely | Grass seed |

*Only agronomic (not horticultural) crops are listed. Pesticide labels are subject to change. Always consult the label for current chemical recommendations before using any herbicide.

Glufosinate does not move within the plant and therefore provides little perennial weed control (Figure 9).

## Plant systems involved

*Proteins* are central to all plant functions. Proteins are composed of *amino acids*. *Enzymes* create various combinations of amino acids to form specific proteins. Some of the enzymes affected by these herbicides are:

- Acetolactate synthase (ALS)—an enzyme found in the *chloroplast* (the part of the cell containing chlorophyll). It regulates the production of three amino acids: valine, leucine, and isoleucine.
- Enolpyruvyl-shikimate-phosphate synthase (EPSPS)—responsible for the production of the amino acids phenylalanine, tyrosine, and tryptophane.
- Glutamine synthase (GS)—responsible for the production of the amino acid glutamine.

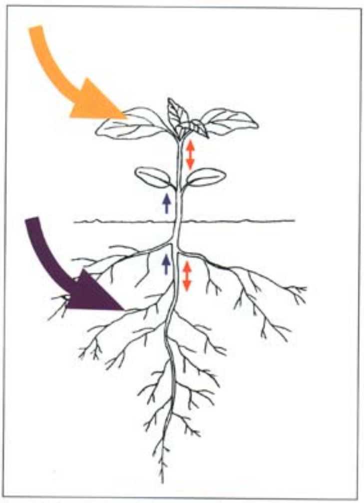


*Figure 7.—Imidazolinones and sulfonylureas: Uptake through leaves and roots and transport through both phloem and xylem.*

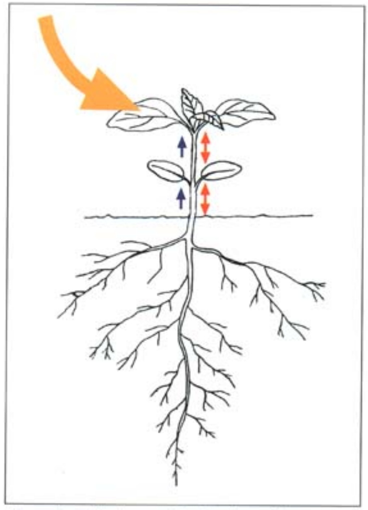


*Figure 8.—Glyphosate: Uptake through leaves and transport through both phloem and xylem.*

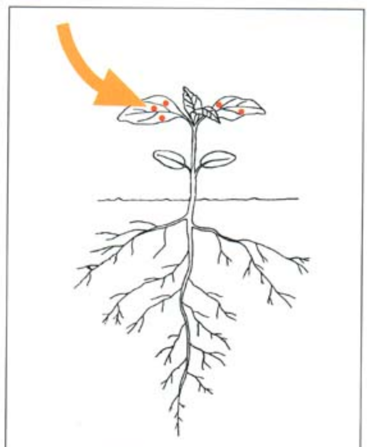


*Figure 9.—Glufosinate: Contact only.*

## Mode of action

*Amino acids* are the building blocks of proteins. By interfering with amino acid production, these herbicides reduce protein production, which in turn can cause a buildup of toxic by-products (Figure 10).

**Imidazolinone** and **sulfonylurea** herbicides bind to the acetolactate synthase (ALS) enzyme, which regulates the production of three amino acids. These amino acids are necessary for normal plant growth and function.

The **amino acid derivative** glyphosate binds to the EPSPS enzyme, which regulates the production of three amino acids. Seventy percent of the carbon captured by plants flows through this system.

**Glufosinate** inhibits the production of glutamine, which is essential for nitrogen metabolism and electron flow in photosynthesis. The resulting buildup of unstable chlorophyll eventually breaks down cell membranes. Therefore, symptoms often resemble those caused by cell membrane disruptors.

## Selectivity

Selectivity of **imidazolinone** and **sulfonylurea** herbicides is based on the tolerant plant's ability to break down the herbicide before it becomes toxic.

**Amino acid derivative** herbicides exhibit little selectivity or metabolism. When glyphosate is ineffective, the cause often is a thick layer of plant cuticular waxes that limits herbicide penetration.

## Symptoms

**Imidazolinone** and **sulfonylurea** herbicides cause grass plants to be stunted and show yellowing between leaf veins (Plate 3). Some grass

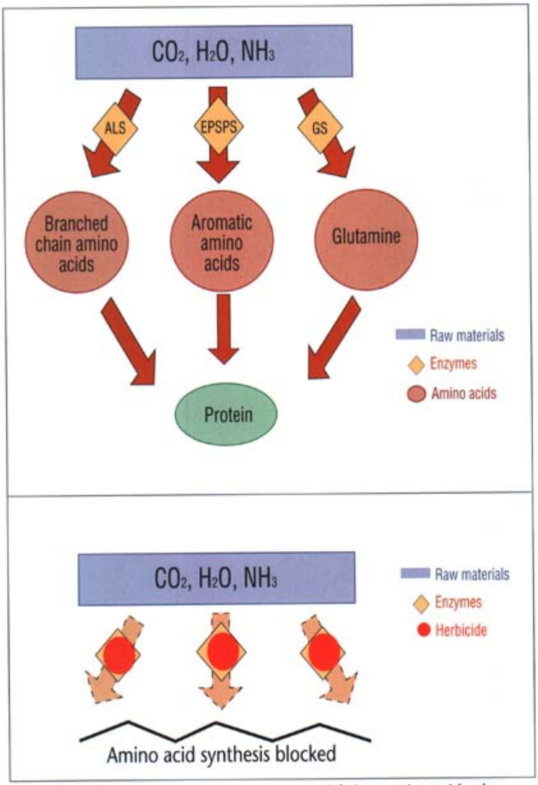



*Figure 10.—Top: Enzymes convert raw materials into amino acids, the building blocks of protein. Bottom: Amino acid synthesis inhibitors bind to enzymes, thus reducing the production of amino acids.*

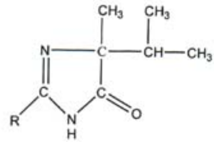
species, such as corn, often have pruned roots or few lateral roots. Broadleaf species might be stunted, with yellow between leaf veins. Leaf veins on beans and other broadleaves often are purple (Plate 4).

With **amino acid derivative** herbicides, injury symptoms might appear slowly as amino acids are depleted and plant membranes weakened. Plant foliage first turns yellow and then brown, usually within 10 to 14 days after application. These herbicides are nonselective, so most species show symptoms.

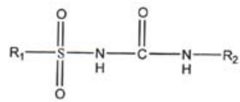
## Weed resistance in the Pacific Northwest

### Imidazolinone and sulfonylurea herbicides

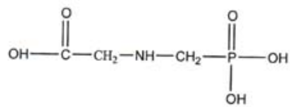
- Kochia (*Kochia scoparia*): chlorsulfuron (OR, WA, ID), metsulfuron-methyl (OR), triasulfuron (OR)
- Prickly lettuce (*Latuca serriola*): chlorsulfuron (OR, WA, ID), metsulfuron-methyl (OR, ID), triasulfuron (OR)
- Russian thistle (*Salsola iberica*): chlorsulfuron (OR, WA, ID), metsulfuron-methyl (OR), triasulfuron (OR)
- Downy brome (*Bromus tectorum*): primisulfuron (OR), sulfosulfuron (OR)
- Mayweed chamomile (*Anthemis cotula*): chlorsulfuron (ID)
- Small-seeded false flax (*Camelina microcarpa*): chlorsulfuron (OR)



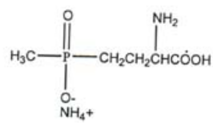
imidazolinones



sulfonylureas



amino acid derivative (glyphosate)



amino acid derivative (glufosinate)

*Figure 11.—Chemical structure of amino acid synthesis inhibitors.*

## Photosynthetic Inhibitors

### Use

**Triazine, urea,** and **uracil** herbicides selectively control annual or perennial grass and broadleaf species.

**Benzothiadiazole** and **nitrile** herbicides are used as postemergence contact herbicides.

### Herbicide uptake

**Triazine, urea,** and **uracil** herbicides do not prevent germination or emergence. They are taken up by the roots or foliage and transported with water by the xylem to older leaves, where photosynthesis is most active (Figure 12).

**Benzothiadiazole** and **nitrile** herbicides are not mobile within a plant and they are broken down rapidly by soil microorganisms (Figure 13). Thus, thorough plant coverage is critical.

### Plant systems involved

**Photosynthesis** is the conversion of light energy into compounds that provide energy for many cellular functions and are the building blocks for sugar, the plant's food.

### Mode of action

Photosynthetic inhibitors interrupt energy flow during photosynthesis (Figure 14). The result is a buildup of highly reactive compounds that cause the membranes separating plant parts to break down.

### Selectivity

Selectivity in photosynthetic inhibitors is based on differences in how plants break down the herbicide. With triazines, ureas, and uracils, planting depth below the herbicide and lack of uptake by tolerant species also leads to selectivity.

## Photosynthetic Inhibitors

| Common name | Trade name(s) | Labeled crops in Oregon* |
|---|---|---|
| ***Triazines*** | | |
| Atrazine | Various names | Chemical fallow, corn, peas, wheat |
| Cyanazine | Bladex | Corn |
| Metribuzin | Lexone, Sencor | Alfalfa, barley, grass seed, lentils, peas, potatoes, wheat |
| Simazine | Princep | Alfalfa seed, non-cropland |
| Hexazinone | Velpar | Alfalfa, non-cropland, pasture and rangeland |
| ***Ureas*** | | |
| Diuron | Direx, Karmex | Alfalfa, barley, grass seed, mint, non-cropland, oats, peas, wheat |
| Linuron | Lorox, Linex | Non-cropland, wheat |
| Tebuthiuron | Spike | Non-cropland, pasture and rangeland |
| ***Benzothiadiazoles*** | | |
| Bentazon | Basagran | Alfalfa, beans, corn, mint, peas |
| ***Nitriles*** | | |
| Bromoxynil | Buctril, Bromox, Moxy | Alfalfa, barley, corn, grass seed, mint, non-cropland, oats, wheat |
| ***Uracils*** | | |
| Terbacil | Sinbar | Alfalfa, grass seed, mint |

*Only agronomic (not horticultural) crops are listed. Pesticide labels are subject to change. Always consult the label for current chemical recommendations before using any herbicide.

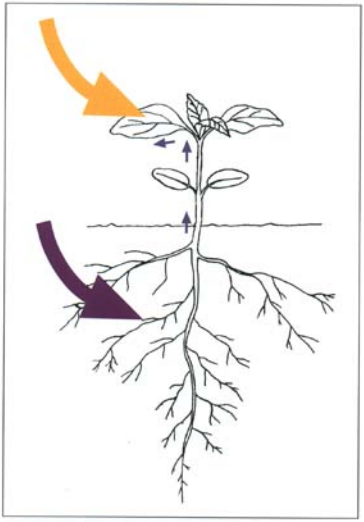


*Figure 12.—Triazine, urea, uracils: Uptake through leaves and roots; transport in xylem.*

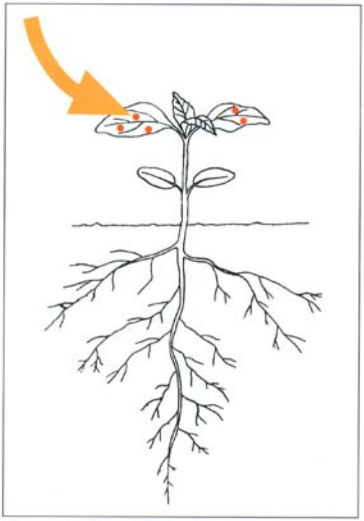


*Figure 13.—Benzothiadiazoles and nitriles: Contact only.*

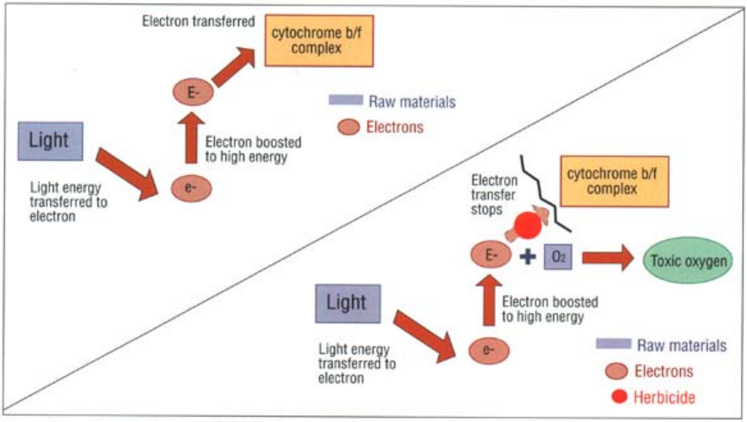



*Figure 14.—Top: In photosynthesis, light energy is captured by the plant and transferred to electrons. The electrons are then boosted to a high-energy state and transferred to the cytochrome b/f complex. Bottom: Photosynthetic inhibitors stop the transfer of high-energy electrons to the cytochrome b/f complex. The electrons then bind with oxygen to form toxic compounds.*

## Symptoms

**Triazine, urea,** and **uracil** herbicides are mobile in plants and cause injury on older leaves. Symptoms include yellowing between leaf veins, beginning at the outer leaf margins on broadleaf plants and at the tip on grass plants (Plate 5).

**Benzothiadiazole** and **nitrile** herbicides are nonmobile. Injury symptoms are similar to those caused by mobile photosynthetic inhibitors. However, because these herbicides do not move well within the plant, initially only the foliage that comes in contact with the herbicide shows symptoms. If coverage and initial damage is great enough, the remainder of the plant will become chlorotic (yellow) and die.

## Weed resistance in the Pacific Northwest

### *Triazine, urea, and uracil herbicides*

- Annual bluegrass (*Poa annua*): diuron (OR), atrazine (OR)
- Common groundsel (*Senecio vulgaris*): simazine (WA)
- Redroot pigweed (*Amaranthus retroflexus*): terbacil (OR)
- Powell amaranth (*Amaranthus powellii*): terbacil (WA)

### *Benzothiadiazole and nitrile herbicides*

- Common groundsel (*Senecio vulgaris*): bromoxynil (OR)

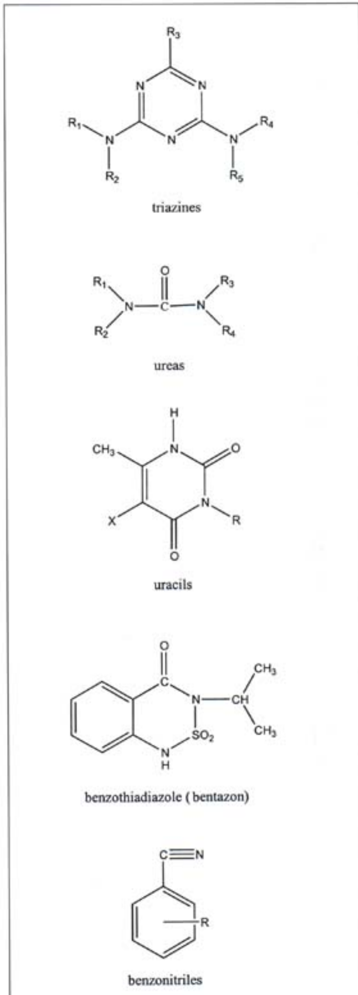



*Figure 15.—Chemical structure of photosynthetic inhibitors.*

# Cell Membrane Disruptors

## Use

**Cell membrane disruptors** are postemergence contact herbicides with little soil activity. (Oxyfluorfen is an exception; it can injure crops, although it does not provide residual weed control.)

**Bipyridyliums** provide nonselective control of annual plants. Diquat often is used as a preharvest crop desiccant to aid in crop drying.

**Diphenylethers** and **triazolinones** are used primarily to control emerged annual broadleaf weeds.

## Herbicide uptake

Cell membrane disruptors are activated by sunlight. These herbicides are not translocated or metabolized within plants (Figure 16). Therefore, thorough coverage is necessary.

## Plant systems involved

*Cell membranes* separate the specialized parts of a cell (*organelles*). These membranes control the passage of selected materials into and out of organelles. When the integrity of a membrane is compromised, the organelle's contents leak (Figure 17). Some of these materials are toxic to other parts of the cell.

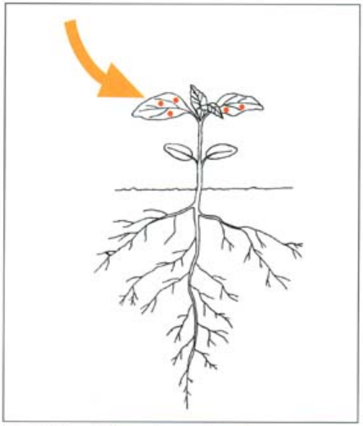


*Figure 16.—Cell membrane disruptors: Contact only.*

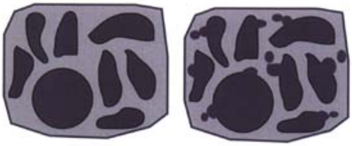


*Figure 17.—Left: Organelles are specialized structures within a cell. Right: When cell membranes are compromised, the contents of organelles leak. Some of these materials are toxic to other parts of the cell.*

# Cell Membrane Disruptors

| Common name | Trade name(s) | Labeled crops in Oregon* |
|---|---|---|
| ***Bipyridyliums*** | | |
| Diquat | Diquat | Clover seed, potatoes, non-cropland |
| Paraquat | Gramoxone Extra | Alfalfa, beans, chemical fallow, clover seed, corn, grass seed, hops, mint, non-cropland, pasture and rangeland, potatoes, sugar beets, wheat |
| ***Diphenylethers*** | | |
| Oxyfluorfen | Goal | Grass seed, mint |
| ***Triazolinones*** | | |
| Carfentrazone | Aim | Corn, grass seed, wheat |

*Only agronomic (not horticultural) crops are listed. Pesticide labels are subject to change. Always consult the label for current chemical recommendations before using any herbicide.

## Mode of action

Cell membrane disruptors rapidly enter plant leaves and interrupt photosynthesis. The resulting buildup of highly reactive compounds destroys lipid and cell membranes, causing cells to leak and collapse.

## Selectivity

**Bipyridylium** herbicides are not metabolized and therefore are nonselective.

**Diphenylether** and **triazolinone** herbicides are metabolized into an inactive form by tolerant species.

## Symptoms

Herbicide activity is rapid, particularly with bipyridyliums. Plant symptoms resemble frost injury and might appear within minutes of herbicide application. Contacted leaves first look "bronzed" and then die (Plate 6). Because these are contact herbicides, new growth often is symptom-free and healthy, particularly in well-established or perennial plants.

## Weed resistance in the Pacific Northwest

None reported

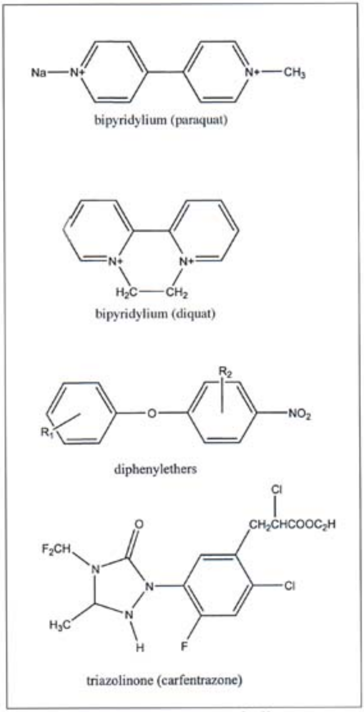



*Figure 18.—Chemical structure of cell membrane disruptors.*

# Lipid Synthesis Inhibitors

## Use

Lipid synthesis inhibitors selectively control grasses.

## Herbicide uptake

These herbicides are foliar applied and move within the phloem to new growth (Figure 19).

## Plant systems involved

*Lipids* are the waxes and oils in plants. They are important in the synthesis of cell membranes. Without cell membranes, new cells are not produced and the plant dies.

## Mode of action

These herbicides bind to the acetyl-CoA carboxylase (ACCase) enzyme, which produces lipids (Figure 20). Plants die slowly as growth is inhibited.

## Selectivity

Selectivity between broadleaf and grass species is based on differences in the form of the ACCase enzyme.

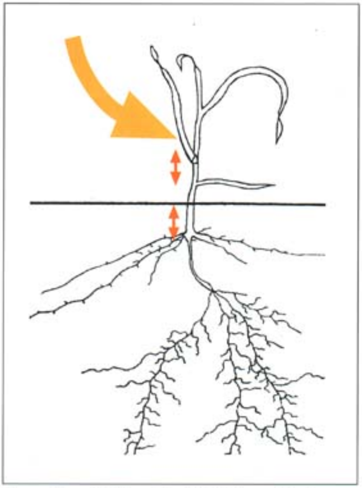


*Figure 19.—Lipid synthesis inhibitors: Uptake through leaves; transport through phloem.*

## Lipid Synthesis Inhibitors

| Common name | Trade name(s) | Labeled crops in Oregon* |
|---|---|---|
| ***Cyclohexanediones*** | | |
| Clethodim | Select | Sugar beets |
| Sethoxydim | Poast, Poast Plus | Alfalfa, dry beans, beet seed, birdsfoot trefoil, clover, grass seed, mint, peas, potatoes, rape seed, sugar beets |
| Tralkoxydim | Achieve | Barley, wheat |
| ***Arloxyphenoxypropionates*** | | |
| Clodinafop | Discover | Wheat |
| Diclofop | Hoelon | Barley, wheat |
| Fenoxaprop | Acclaim, Whip, Horizon | Barley, grass seed, wheat |
| Fluazifop | Fusilade | Alfalfa, beet seed, carrot seed, grass seed |
| Quizalofop | Assure II | Dry bean, mint, peas, rape seed, sugar beets |

*Only agronomic (not horticultural) crops are listed. Pesticide labels are subject to change. Always consult the label for current chemical recommendations before using any herbicide.

## Symptoms

Herbicide damage symptoms appear first on new growth, primarily in the whorl of grass leaves. Affected leaves are easily pulled from the plant and look rotten or decayed at the base (Plate 8). Leaves turn yellow and then brown as growth ceases.

## Weed resistance in the Pacific Northwest

- Italian ryegrass (*Lolium multiflorum*): diclofop (ID, OR, WA)
- Wild oat (*Avena fatua*): diclofop (ID, OR, WA), fenoxaprop (ID, OR)

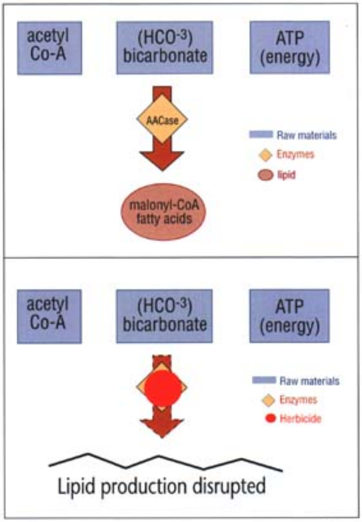



*Figure 20.—Top: Enzymes convert raw materials to lipids (fatty acids). Bottom: Lipid synthesis inhibitors bind to these proteins, reducing the production of lipids.*

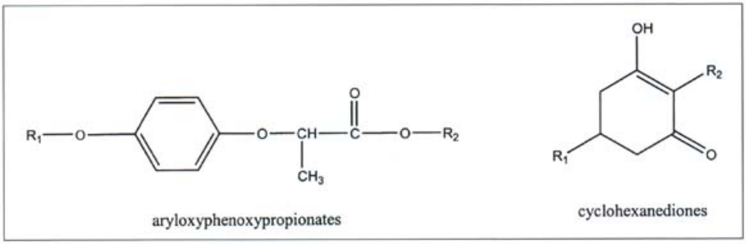



*Figure 21.—Chemical structure of lipid synthesis inhibitors.*

# Meristematic (Growth) Inhibitors

## Use

### *Shoot inhibitors*

**Thiocarbamates** are used primarily for grass and sedge control. When used with a safener, EPTC and butylate can be used on corn.

**Acetamides** and **chloracetamides** are used for control of several broadleaf and grass weeds.

### *Root inhibitors*

**Benzamides and dinitroanilines** are used primarily for grass control, but also controls some broadleaf seedlings.

## Herbicide uptake

### *Shoot inhibitors*

**Acetamides** and **chloracetamides** are taken up primarily through the developing shoots of grasses and the roots of broadleaf species. Most of these herbicides move poorly within the plant and therefore have little effect when applied to foliage.

## Meristematic (Growth) Inhibitors

| Common name | Trade name(s) | Labeled crops in Oregon* |
|---|---|---|
| ***Shoot inhibitors*** | | |
| **Acetamides** | | |
| Napropamide | Devrinol | Mint |
| **Chloracetamides** | | |
| Acetochlor | Harness, Surpass, Topnotch | Corn |
| Alachlor | Lasso | Dry beans, corn |
| Dimethenamid | Frontier | Dry beans, corn, grass seed |
| Metolachlor | Dual | Dry beans, corn, peas, potatoes |
| Propachlor | Ramrod | Corn |
| **Thiocarbamates** | | |
| Butylate | Sutan+ (w/ safener) | Corn |
| EPTC | Eptam, Eradicane (w/ safener) | Alfalfa, dry beans, beet seed, birdsfoot trefoil, clover, corn, potatoes, sugar beets |
| Ethofumesate | Nortron | Beet seed, grass seed, sugar beets |
| Triallate | Fargo | Barley, peas, wheat |
| Cycloate | Ro-neet | Beets, beet seed, sugar beets |
| ***Root inhibitors*** | | |
| **Benzamides** | | |
| Pronamide | Kerb | Alfalfa, birdsfoot trefoil, chemical fallow, clover, grass seed, peas, sugar beets |
| **Dinitroanilines** | | |
| Benefin | Balan | Alfalfa, birdsfoot trefoil, clover crops |
| Ethalfluralin | Sonalan, Curbit | Alfalfa seed, dry beans, peas |
| Pendimethalin | Prowl | Alfalfa seed, dry beans, carrot seed, corn, grass seed, lentils, non-cropland, peas, potatoes |
| Trifluralin | Treflan, Trifluralin | Alfalfa, barley, dry beans, carrot seed, hops, peas, potatoes, radish seed, rape seed, sugar beets, wheat |

*Only agronomic (not horticultural) crops are listed. Pesticide labels are subject to change. Always consult the label for current chemical recommendations before using any herbicide.

**Thiocarbamates** are taken up primarily by the shoots of emerging grasses, but also can be absorbed in small amounts by roots and seed. They are translocated short distances in the xylem to growing points, including the developing foliage (Figure 22).

### *Root inhibitors*

**Benzamides** and **dinitroanilines** are absorbed by seedling roots and are not translocated well within the plant (Figure 23). Therefore, the developing root must contact the herbicide in the soil.

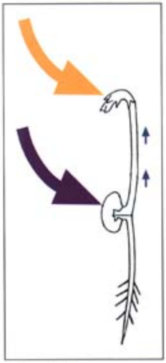


*Figure 22.—Thiocarbamates: Uptake through shoot and root; transport through xylem.*

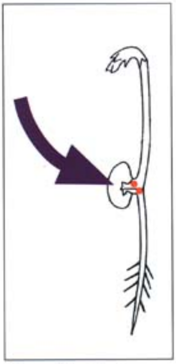


*Figure 23.—Root inhibitors: Contact only.*

## Plant systems involved

### *Shoot inhibitors*

*Cell membranes* are composed of long-chain fatty acids and lipids.

### *Root inhibitors*

*Mitosis* is the process by which cells divide. When combined with cell stretching or enlargement, mitosis results in plant growth. *Microtubules* are the framework that regulates new cell shape and orientation.

## Mode of action

### *Shoot inhibitors*

When fatty acid and lipid production is inhibited, cell membrane growth ceases and the integrity of the cell is compromised.

**Acetamide** and **chloracetamide** herbicides inhibit synthesis of proteins involved in cell division and enlargement. Cell membranes leak and growth ceases.

**Thiocarbamates'** mode of action is not completely understood, but these herbicides are thought to have multiple modes of action. In general, they inhibit cell division and elongation and might interfere with hormone production.

### *Root inhibitors*

**Benzamide** and **dinitroaniline** herbicides inhibit cell division and enlargement in developing roots (Figure 24). When microtubule production is disrupted, cell growth is irregular. Cells continue to expand until membranes leak.

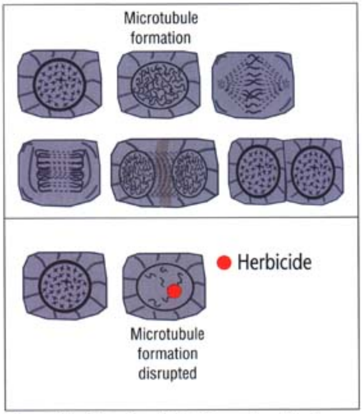



*Figure 24.—Top: In cell division, microtubules provide the framework for new cells. Bottom: Root inhibitors disrupt the production of microtubules.*

## Selectivity

Selectivity is based on herbicide metabolism and on a lack of absorption by tolerant plants. Selectivity also is based on herbicide placement, i.e., crop seed placed below the herbicide-treated area is unaffected.

## Symptoms

With **acetamide** and **chloracetamide** herbicides, grass leaves fail to unroll completely and might be bunched within the whorl (called *buggy-whipping*) (Plate 9). Broadleaf leaves often are puckered (Plate 10). The leaf midrib also might be shortened, while the meaty part of the leaf continues to grow past the end of the midrib (called *stringing*) (Plate 11).

With **thiocarbamate** herbicides, seedling plants appear aboveground, but leaves do not emerge. Grass leaves never unfurl from the whorl, thus forming a large loop (buggy-whipping). Injury in broadleaf plants includes crinkled, dark green leaves.

**Benzamide** and **dinitroaniline** herbicides prevent the emergence of most susceptible plants. Plants exhibit swollen or "clubbed" roots and a lack of lateral roots or root hairs (Plate 12). Grass species might turn purple or red as the lack of root hairs inhibits phosphorus uptake (Plates 13 and 14). Stems might be brittle, and affected plants often break or lodge in windy conditions.

## Weed resistance in the Pacific Northwest

- Wild oat (*Avena fatua*): pronamide (OR)
- Annual bluegrass (*Poa annua*): ethofumesate (OR)

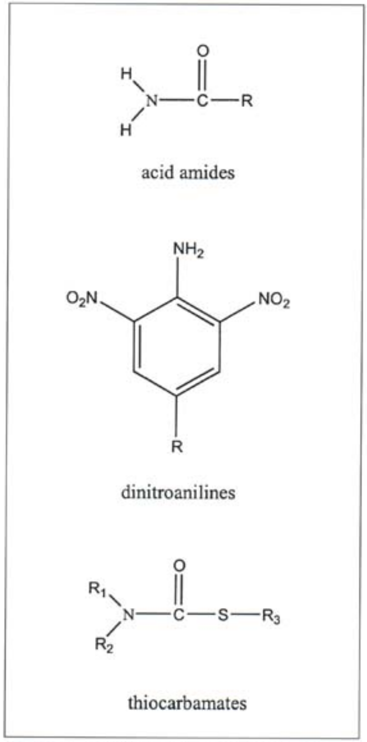



*Figure 25.—Chemical structure of meristematic inhibitors.*

## Pigment Inhibitors

### Use

**Amitrole** is used most often for non-cropland control of poison oak and poison ivy.

**Norflurazon** selectively controls both grass and broadleaf species.

**Clomazone** is applied preemergence or incorporated preplant to avoid drift problems. It controls grass species and a few broadleaves, such as velvetleaf.

**Isoxaflutole** is applied preemergence or incorporated preplant for control of broadleaf and grass weed species.

### Herbicide uptake

**Amitrole** is absorbed slowly but is translocated easily throughout the plant (Figure 26). It has a short soil residual.

**Clomazone** is translocated easily from the roots to actively growing foliage (Figure 27). In its applied form, it is not toxic; it must be metabolized within the plant to have herbicidal activity.

**Isoxaflutole** is absorbed by the roots or foliage and translocated in the xylem and phloem (Figure 27).

**Norflurazon** is absorbed by roots and translocated to the foliage (Figure 27).

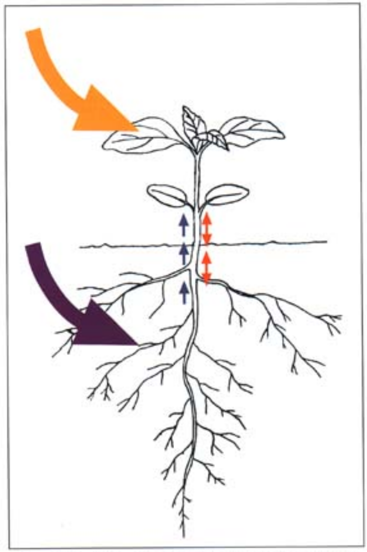


*Figure 26.—Triazoles: Uptake through leaves and roots; transport through xylem and phloem.*

## Pigment Inhibitors

| Common name | Trade name(s) | Labeled crops in Oregon* |
|---|---|---|
| ***Chlorophyll biosynthesis inhibitors*** | | |
| **Triazoles** | | |
| Amitrole | Amitrol | Non-cropland |
| ***Carotenoid biosynthesis inhibitors*** | | |
| **Isoxazoles** | | |
| Isoxaflutole | Balance | |
| **Pyridazinones** | | |
| Norflurazon | Solicam | Alfalfa, hops, non-cropland |
| ***Chlorophyll and carotenoid biosynthesis inhibitors*** | | |
| **Isoxazolidinones** | | |
| Clomazone | Command | Peas |

*Only agronomic (not horticultural) crops are listed. Pesticide labels are subject to change. Always consult the label for current chemical recommendations before using any herbicide.

*Figure 27.—Isoxazoles, pyridazinones, and isoxazolidinones: Uptake through roots; transport through xylem.*

## Plant systems involved

**Carotenoids** and **chlorophyll** are the key pigments involved in capturing sunlight for photosynthesis. Chlorophyll (the plant's green pigment) captures light energy, which the plant then converts to usable forms. Carotenoids (red, orange, and yellow pigments) capture energy and protect chlorophyll from excess light, which can result in the production of toxic by-products.

## Mode of action

Pigment inhibitors affect the formation of chlorophyll and carotenoids, thus causing bleaching or whitening. Without the protection of carotenoids, toxic by-products from light harvesting accumulate and break down the chlorophyll membrane.

## Selectivity

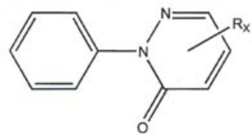
In most cases, selectivity is based on metabolism of the herbicide into an inactive form (norflurazon, isoxaflutole). In the case of clomazone, tolerant species do not metabolize the herbicide into the active form.

## Symptoms

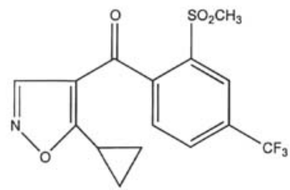
Pigment inhibitors cause a very characteristic bleaching of new growth. As the plant dies, the bleached areas might become brown and dry.

## Weed resistance in the Pacific Northwest

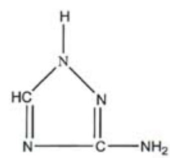
- Annual bluegrass (*Poa annua*): norflurazon (OR)



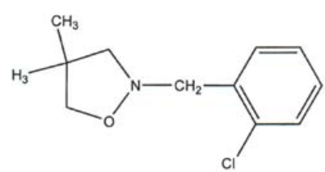
phenylpyridazinones



isoxazole (isoxaflutole)



triazole (amitrole)



isoxazolidinone (clomazone)

*Figure 28.—Chemical structure of pigment inhibitors.*

## Damage Symptoms

### Growth regulators

*Plate 1.—Parallel veins (fanleaf) caused by 2,4-D on grape.*

*Plate 2.—Epinasty caused by clopyralid on potato.*

### Amino acid synthesis inhibitors

*Plate 3.—Chlorosis caused glyphosate on bean.*

*Plate 4.—Purple veins caused by imazethapyr on corn.*

### Photosynthetic inhibitors

*Plate 5.—Marginal necrosis caused by bentazon on bean.*

## Cell membrane disruptors

*Plate 6.—Necrotic spots caused by paraquat on soybean.*

*Plate 7.—Buggy-whipping caused by oxyfluorfen on onion.*

## Lipid synthesis inhibitors

*Plate 8.—Decayed base caused by diclofop on grass.*

## Meristematic inhibitors

*Plate 9.—Rolled leaf caused by alachlor on corn.*

*Plate 10.—Crinkling/puckering caused by alachlor on soybean.*

## Meristematic inhibitors (continued)

Plate 11.—*Stringing/leaf strapping caused by EPTC on bean.*

Plate 12.—*Clubbed roots caused by trifluralin on bean.*

Plate 13.—*Purple coloration (phosphorus deficiency) caused by trifluralin on orchardgrass.*

Plate 14.—*Root pruning caused by napropamide on perennial ryegrass.*

## Pigment inhibitors

Plate 15.—*Bleaching caused by amitrole on potato.*

Photos courtesy of Don Morishita, Ray William, Arnold Appleby, and Carol Mallory-Smith.

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