

## Herbicide Site of Action and Injury Symptoms

Herbicides kill plants by disrupting an essential physiological process. This is accomplished by the herbicide specifically binding to a single protein for many herbicides. The target protein is referred to as the herbicide “site of action.” Herbicides in the same family generally have the same site of action. The mechanism by which a herbicide kills a plant is known as its “mode of action.” For example, triazine herbicides interfere with photosynthesis by binding to the D1 protein involved in photosynthetic electron transfer. Thus, the site of action for triazines is the D1 protein, whereas the mode of action is the disruption of photosynthesis. An understanding of herbicide mode of action is essential for diagnosing crop injury or off-target injury problems and for designing weed management programs with a low risk of selecting for herbicide-resistant weed populations.

### ACCase Inhibitors

The ACCase enzyme is involved in the synthesis of fatty acids. Two herbicide families attack this enzyme. Aryloxyphenoxypropanoate (commonly referred to as “fops”) and cyclohexanedione (referred to as “dime”) herbicides are used postemergence, although some have limited soil activity (e.g. fluzifop). ACCase inhibitors are active only on grasses, and selectivity is due to differences in sensitivity at the site of action, rather than differences in absorption or metabolism of the herbicide. Most herbicides in this class are translocated within the phloem of grasses. The growing points of grasses are killed and rot within the stem.

<sup>1</sup>Herbicides listed in italics in this section are tank-mix components representing a different chemical family.

At sublethal rates, irregular bleaching of leaves or bands of chlorotic tissue may appear on affected leaves.

Resistant weed biotypes have evolved following repeated applications of these herbicides. An altered target site of action is responsible for the resistance. *Mode of action: ACCase.*

#### Product Active ingredients<sup>1</sup>

##### Aryloxyphenoxypropanoate

Assure II _____	quizalofop-p-ethyl
Fusilade DX _____	fluzifop-p-butyl
Fusion _____	fluzifop-p-butyl + fenoxaprop
Hoelon* _____	diclofop

##### Cyclohexanedione

Poast, Poast Plus _____	sethoxydim
Select _____	clethodim

### ALS Inhibitors

Several chemical families interfere with acetolactate synthase (ALS), an enzyme involved in the synthesis of branched-chain amino acids, specifically valine, leucine, and isoleucine. These amino acids are necessary for protein synthesis and plant growth. Generally, these herbicides are absorbed in plant roots and foliage and are readily translocated in the xylem and phloem. The herbicides accumulate in meristematic regions of the plant and the herbicidal effects are first noted there. Symptoms include plant stunting, chlorosis (yellowing), and tissue necrosis (death) and are evident 1 to 4 weeks after herbicide application, depending upon the plant species and environmental conditions. Soybeans and other affected broad-leaves often develop reddish veins on undersides of leaves.

Symptoms in corn include reduced secondary root formation, stunted roots, shortened internodes, leaf malformations (chlorosis, window-paning) and nutrient deficiency. However, symptoms typically are not distinct or consistent. Factors such as soil moisture, temperature, and soil compaction can enhance the occurrence of injury or may mimic the herbicide injury. Some ALS inhibiting herbicides have long soil residual properties and may carry over and injure sensitive rotational crops. Herbicide resistant weed biotypes possessing an altered site of action have evolved after repeated applications of these herbicides. *Mode of action: ALS.*

#### Product Active ingredients

##### Imidazolinones

Lightning _____	imazethapyr + imazapyr
Pursuit _____	imazethapyr
Pursuit Plus _____	imazethapyr + pendimethalin
Raptor _____	imazamox
Scepter _____	imazaquin
Squadron _____	imazaquin + pendimethalin

##### Sulfonanilides

FirstRate/Amplify _____	cloransulam-methyl
Gangster _____	flumioxazin + cloransulam-methyl
Hornet WDG _____	flumetsulam + clopyralid
Python _____	flumetsulam

\* Restricted use pesticides

### Sulfonylureas

Accent _____	nicosulfuron
Accent Gold _____	nicosulfuron + rimsulfuron + clopyralid + flumetsulam
Basis _____	rimsulfuron + thifensulfuron methyl
Basis Gold* _____	rimsulfuron + nicosulfuron + atrazine
Beacon _____	primisulfuron
Canopy XL _____	chlorimuron + sulfentrazone
Celebrity Plus _____	nicosulfuron + dicamba + diflufenzopyr
Cimarron _____	metsulfuron
Classic _____	chlorimuron-ethyl
Equip _____	foramsulfuron + iodosulfuron + safener
Exceed, Spirit _____	prosulfuron + primisulfuron
Express _____	tribenuron
Harmony GT _____	thifensulfuron methyl
NorthStar _____	primisulfuron + dicamba
Option _____	foramsulfuron + safener
Permit _____	halosulfuron
Steadfast _____	nicosulfuron + rimsulfuron + atrazine
Synchrony STS _____	chlorimuron-ethyl + thifensulfuron methyl
Steadfast ATZ _____	nicosulfuron + rimsulfuron + atrazine
Yukon _____	halosulfuron methyl + dicamba

### **Microtubule Inhibitors**

Dinitroaniline (DNA) herbicides inhibit cell division by interfering with the formation of microtubules.

Dinitroaniline herbicides are soil-applied and absorbed mainly by roots. Very little herbicide translocation into plants occurs, thus the primary herbicidal effect is on root development. Soybean injury from DNA herbicides is characterized by root pruning. Roots that do develop are thick and short. Hypocotyl swelling also occurs. The inhibited root growth causes tops of plants to be stunted and often to demonstrate a dark green color. Corn injured by DNA carryover demonstrates root pruning and short, thick roots. Leaf margins may have a reddish color. Since DNAs are subject to little movement in the soil, such injury is often spotty due to localized concentrations of the herbicide. Early season stunting from DNA herbicides typically does not result in significant yield reductions. *Mode of action: microtubule.*

### **Product Active ingredients**

Balan _____	benefin
Commence _____	trifluralin + clomazone
Prowl, Pentagon,	
Pendimax _____	pendimethalin
Sonalan _____	ethalfluralin
Surflan _____	oryzalin
Treflan,	
Trifluralin/Trust _____	trifluralin

### **Synthetic Auxins**

Several chemical families cause abnormal root and shoot growth by upsetting the plant hormone (auxin) balance. These herbicides are primarily effective on broadleaf species. Uptake can occur through seeds or roots with soil-applied treatments or leaves when applied postemergence. Synthetic auxins translocate throughout plants and accumulate in areas of high growth activity. Corn injury may occur in the form of onion leafing, proliferation of roots, or abnormal brace root formation. Corn stalks may

become brittle following application; this response usually lasts for 7 to 10 days following application. The potential for injury increases when applications are made to corn larger than 10 to 12 inches in height. Soybean injury from synthetic auxin herbicides is characterized by cupping and crinkling of leaves. Soybeans are extremely sensitive to dicamba; however, early season injury resulting only in leaf malformation usually does not affect yield potential. Soybeans occasionally develop symptoms characteristic of dicamba in the absence of this herbicide. This response is poorly understood, but usually develops during periods of rapid growth or following stress from other postemergence herbicide applications. Dicamba has a high vapor pressure and may move off target due to volatilization. *Mode of action: auxin.*

### **Product Active ingredients**

<u>Benzoics</u>	
Banvel/Oracle/	
Sterling _____	dicamba DMA
Celebrity Plus _____	dicamba + nicosulfuron + diflufenzopyr
Clarity _____	dicamba DGA
Distinct _____	dicamba + diflufenzopyr
Marksman/	
Stratos/	
Sterling Plus* _____	dicamba + atrazine
NorthStar _____	dicamba + primisulfuron
Yukon _____	dicamba + halosulfuron

### Phenoxy

(many) _____	MCPA
(many) _____	2,4-D
Butoxone, Butyrac	2,4-DB



### Diphenyl Ethers

Blazer,

UltraBlazer \_\_\_\_\_ acifluorfen

Cobra \_\_\_\_\_ lactofen

Flexstar, Reflex \_\_\_ fomesafen

Goal \_\_\_\_\_ oxyfluorfen

### Phenylphthalimides

Resource \_\_\_\_\_ flumiclorac

Valor \_\_\_\_\_ flumioxazin

## **Enolpyruvyl Shikimate Phosphate Synthase (EPSPS) Inhibitors**

Glyphosate is a substituted amino acid that interferes with amino acid synthesis by inhibiting the EPSPS enzyme.

This enzyme is involved in the synthesis of several essential amino acids.

Glyphosate is nonselective and is very tightly bound in soil so no root uptake occurs. Applications must be made to plant foliage. Translocation occurs out of leaves to all plant parts including underground storage organs of perennial weeds. Translocation is greatest when plants are actively growing. Injury symptoms are fairly slow in appearing. Leaves slowly wilt, turn brown, and die. Sub-lethal rates of glyphosate sometimes produce phenoxy-type symptoms with feathering of leaves (parallel veins) or proliferation of vegetative buds.

*Mode of action: EPSPS.*

<b>Product</b>	<b>Active ingredients</b>
----------------	---------------------------

Roundup Ultra/

Roundup UltraMax/

Roundup UltraDry/

Roundup WeatherMAX/

Glyphomax/Glyphomax Plus/

Rodeo/Touchdown/

Touchdown Total/

Touchdown HiTech/

Touchdown CF/

Cornerstone/

Cornerstone Plus/

others \_\_\_\_\_ glyphosate

ReadyMaster ATZ\* \_ glyphosate +  
atrazine

Extreme \_\_\_\_\_ glyphosate +  
imazethapyr

## **Glutamine Synthetase Inhibitors**

Glufosinate (Liberty) inhibits the enzyme glutamine synthetase, causing a buildup of ammonia in the plant which becomes phytotoxic. Glufosinate is relatively fast acting and provides effective weed control in three to seven days. Symptoms appear as chlorotic lesions on the foliage followed by necrosis. There is limited translocation of glufosinate within plants. The herbicide has no soil activity. Liberty is nonselective except to crops that carry the Liberty-Link gene. *Mode of action: GS.*

<b>Product</b>	<b>Active ingredients</b>
----------------	---------------------------

Liberty \_\_\_\_\_ glufosinate

Liberty ATZ\* \_\_\_ glufosinate +  
atrazine

## **Hydroxyphenyl Pyruvate Dioxygenase (HPPD) Inhibitors**

Isoxaflutole (Balance Pro) and mesotrione (Callisto) bind to HPPD, an enzyme involved in the synthesis of carotene pigments. Injury symptoms include bleaching or chlorosis. Although the chemicals have the same site of action, they are not chemically related. The herbicides are absorbed both by roots and foliage. *Mode of action: bleacher.*

<b>Product</b>	<b>Active ingredients</b>
----------------	---------------------------

Balance\* \_\_\_\_\_ isoxaflutole

Balance Pro\* \_\_\_ isoxaflutole

Epic\* \_\_\_\_\_ isoxaflutole +  
flufenacet

Callisto \_\_\_\_\_ mesotrione

Camix \_\_\_\_\_ mesotrione +  
s-metolachlor

Lexar \_\_\_\_\_ mesotrione +  
s-metolachlor +  
atrazine

Lumax \_\_\_\_\_ mesotrione +  
atrazine +  
s-metolachlor

## **Diterpene Inhibitors**

Clomazone interferes with the synthesis of the same pigments as the HPPD inhibitors, but acts at a different enzyme within the metabolic pathway. Sensitive plants exposed to the herbicide turn white. Clomazone is xylem mobile and taken up in roots and shoots. Differential metabolism of clomazone confers tolerance to plants. Clomazone has a relatively high vapor pressure and may volatilize off the soil surface resulting in off-target injury. *Mode of action: bleacher.*

<b>Product</b>	<b>Active ingredients</b>
----------------	---------------------------

Command \_\_\_\_\_ clomazone

Command Xtra \_\_\_ clomazone +  
sulfentrazone

## **Auxin Transport Inhibitors**

Diflufenzopyr (Distinct) has a unique mode of action in that it inhibits the transport of auxin, a naturally occurring growth regulator. Diflufenzopyr is primarily active on broadleaf species, but it may suppress certain grasses under favorable conditions. Diflufenzopyr is primarily active through foliar uptake, but it can be absorbed through the soil for some residual activity. Injury symptoms are similar to growth regulator herbicides. *Mode of action: auxin transport.*

<b>Product</b>	<b>Active ingredients</b>
----------------	---------------------------

Distinct \_\_\_\_\_ diflufenzopyr +  
dicamba

## **Lipid Synthesis Inhibitors**

Although the specific target site for the thiocarbamate herbicides has not been identified, it is believed the primary site of action is lipid synthesis. In grasses, thiocarbamate herbicides inhibit meristem activity and cause abnormal emergence of leaves from the coleoptile. The growth of susceptible broadleaf weeds is inhibited, and plants exhibit cupped or crinkled

leaves. Uptake may occur through seeds, shoots, and roots; shoots are more affected than roots. These herbicides are soil-applied and most must be physically incorporated into the soil due to volatility characteristics. Corn injury from thiocarbamate herbicides is demonstrated by leaves not properly unrolling from the coleoptile. Leaves are stunted and twisted, often appearing knotted. In recent years, antidotes or safeners have been developed that help to prevent thiocarbamate injury to corn. These are formulated directly with the herbicide. The protective mechanism of these antidotes is not known, but they may enable corn to more rapidly degrade the herbicides. The antidotes are formulated directly with the herbicides; Sutan+ contains R-25788, and Eradicane contains R-29148. Soybean injury from thiocarbamate herbicides occurs as slowed emergence and crinkling of leaves on seedling plants. The antidotes or safeners do not protect soybeans from thiocarbamate herbicides. *Mode of action: lipid.*

<b>Product</b>	<b>Active ingredients</b>
Eradicane _____	EPTC + R- 29148
Eradicane Extra _	EPTC + R- 29148 + R- 33865
Sutan + _____	butylate + R- 29148
Sutazine* _____	butylate + R- 29148 + atrazine

### Unknown Site of Action

Herbicides in the amide family (also referred to as acetanilides or acetamides) inhibit root and shoot growth causing stunted, malformed seedlings. The specific site of action and mode of action of this herbicide family is unknown. Normal cell division, cell elongation, and protein synthesis are potentially inhibited. The herbicides

must be present in early stages of germination and growth of weeds for effective control. These herbicides are most effective on annual grass weeds, although some small-seeded annual broadleaf weeds are also sensitive. Injury symptoms to corn from these herbicides include leafing out underground and failure of leaves to properly unfurl. Soybean injury from these herbicides occurs in the form of a shortened mid-vein in the leaflets resulting in crinkling and a heart-shaped appearance. Dimethenamid (Frontier) and flufenacet (Axiom) have slightly different chemical structures than the amide herbicides, but it is believed they kill plants in the same manner as the amides. *Mode of action: unknown.*

### Product Active ingredients

Axiom, Domain _	flufenacet + metribuzin
Axiom AT _____	flufenacet + metribuzin + atrazine
Bicep II* MAGNUM* /Cinch _____	s-metolachlor + atrazine + safener
Bicep Lite II MAGNUM* _____	s-metolachlor + atrazine + safener
Boundary _____	s-metolachlor + metribuzin
Bullet* _____	alachlor + atrazine
Define _____	flufenacet
Degree* _____	acetochlor + safener
Degree Xtra* _____	acetochlor + atrazine + safener
Dual II MAGNUM/Cinch_	s-metolachlor + safener
Epic* _____	flufenacet + isoxaflutole

Expert _____	s-metolachlor + atrazine + glyphosate
FieldMaster* _____	acetochlor + atrazine + glyphosate + safener
Frontier _____	dimethenamid
FulTime* _____	acetochlor + atrazine + safener
Guardsman Max* _____	dimethenamid + atrazine
Harness*/ Confidence* _____	acetochlor + MON 13900
Harness Xtra*/ Confidence Xtra* _	acetochlor + atrazine + safener
Harness Xtra 5.6L*/ Confidence Xtra 5.6L* _____	acetochlor + atrazine + safener
Keystone*/ Keystone LA _____	acetochlor + atrazine + safener
Lariat* _____	alachlor + atrazine
Lasso*, Intro*, MicroTech* _____	alachlor
Outlook _____	dimethenamid-P
Parallel _____	metolachlor
Parallel PCS _____	metolachlor
Stalwart _____	metolachlor
Stalwart C _____	metolachlor + safener
Stalwart Xtra* _____	metolachlor + atrazine + safener
Surpass* _____	acetochlor + safener
Surpass 100* _____	acetochlor + atrazine + safener
TopNotch* _____	acetochlor + safener

\* Restricted use pesticides