

HERBICIDE RESISTANT WEEDS

X1. Herbicide resistance occurs with repeated use of a specific herbicide or a combination of herbicides for control of weed species that contain some plants in the population with a resistant genes. The resistant type will increase with each use of the herbicide(s) because the gene pool in the field will shift from susceptible to resistant. This shift may be permanent, assuming that the resistant type plants are equally “fit” in the cropping environment. Use of one herbicide from a group with one mode of action may give resistance to other herbicides with the same mode of action. However, weed specificity for resistance is known for different herbicides within a mode of action group. For example, if a wild oat population is resistant to one ACCase inhibitor herbicide, other ACCase inhibitor herbicides may or may not provide control.

Weed populations with wide genetic diversity may develop resistance rapidly, especially for herbicides with a single mode of action. Large plant numbers, prolific seed production, high rates of weed migration/spread, and diverse environmental conditions may contribute to high genetic diversity. For example, kochia developed resistance rapidly in North Dakota to SU herbicides because of genetic diversity and the single mode of action (ALS inhibition). Weeds may vary in resistance to herbicides of the same mode of action group, especially if the herbicides are from different chemical classes. For example, weeds resistant to SU herbicides may or may not be cross-resistant to the Imi class of ALS inhibitors. Weeds may also vary in resistance to herbicides of the same chemical class, depending on their specific resistance mutation(s). Table X1 lists herbicides within various mode of action groups as a guide for possible cross resistance.

Types of Resistance

Altered target site - Genetic mutations within a herbicide site of action can prevent complete herbicide interaction with binding sites, allowing the target-site protein to remain functional. The incomplete inhibition of the altered site of action may result in little to no observed plant injury. Where the herbicide has such little inhibitory effect on the site of action, plants may survive greater than 10 times the normal herbicide rate (considered high-level resistance). Modes of action where high-level resistance is most often seen include ACCase, ALS, and photosystem II inhibitors. However, target-site alterations may only partially reduce a herbicide's inhibitory effect. Such are considered low-level resistance because plants are unlikely to survive greater than 10 times the normal use rate. Plants with low-level target-site resistance may sometimes be controlled when the herbicide is applied to small plants at high-end label rates. Examples of low-level resistance due to target-site alterations include common ragweed resistant to PPO inhibitors, and goosegrass and some ryegrass resistant to glyphosate.

Altered herbicide metabolic processes - Plants prevent herbicide toxicity by rapid degradation. Corn degrades atrazine by this mechanism. This type of resistance is more complex than altered site-of-action type resistance because it involves several plant processes. Plants with altered metabolism resistance can degrade several unrelated herbicides of different modes of action through multiple genes controlling metabolic processes.

Plant injury may occur because plants can not rapidly degrade absorbed herbicide, causing this mechanism to be considered low-level resistance. Therefore increasing the herbicide rate to smaller plants may control more plants. Examples of altered herbicide metabolism include some ryegrass resistant to ACCase, ALS, and photosystem II inhibitors, and velvetleaf resistant to atrazine. Metabolic resistance is believed to be present in many other weed species.

Herbicide sequestration / Altered herbicide localization - Movement of herbicide is impeded, moved away from its target site, or moved to a location where it is ineffective. This may be at the whole-plant or cellular level. Nearly all plants with this type of resistance are injured shortly after the herbicide application because the herbicide can not be moved away from the site of action fast enough and for a long enough time. Herbicide sequestration is considered low-level resistance because increasing rates applied to smaller plants increases mortality. Examples of herbicide sequestration include glyphosate-resistant horseweed and some ryegrass, likely glyphosate-resistant common and giant ragweed, and weed biotypes resistant to paraquat.

Target-site amplification - Some glyphosate-resistant Palmer amaranth has been shown to express increased levels of herbicide-susceptible EPSPS target-site protein. Many of these plants have up to 100 copies or more of the EPSPS gene, and likely produce more target-site enzyme than glyphosate can fully inhibit. This case is the only known example of this type of mechanism.

Cross and Multiple Resistance

A plant with a single resistance mechanism that survives treatment with chemicals within the same mode of action is cross resistant to those chemicals. Resistance that develops to one ALS herbicide chemistry often confers cross resistance to other ALS herbicide chemistries. The same is generally true with imidazolinones. In some cases, resistance that develops to a SU confers cross resistance to imidazolinones.

A plant with two or more resistance mechanisms that survives treatment with different chemicals within different modes of action has multiple resistance. Different resistance mechanisms are involved; therefore, a kochia plant that survives SU and atrazine has multiple resistance.

Herbicide resistant weed species in ND:

(#) = Herbicide mode of action, see pages 104-105.

ACCcase inhibitor herbicides (1): Wild oat, green foxtail, and yellow foxtail - All ACCcase herbicides except Select*.

ALS inhibitor herbicides (2):

Wild oat - Assert, Everest, Olympus, Rimfire, and Silverado.
Kochia, waterhemp, c. ragweed, and wild mustard - All ALS herb.
E. black nightshade and redroot pigweed - Imi herbicides.
Marshelder - Imi herbicides and Express* (SU).

Mitotic inhibitor (3):

Green foxtail - Treflan*, Sonalan, Prowl.

Growth regulator (4): Kochia - 2,4-D and Banvel*.

Photosystem II inhibitor (5): Kochia - atrazine.

EPSP synthase inhibitor (9) (glyphosate): C. ragweed.

Kochia, waterhemp, and lambsquarters = unconfirmed.

Multiple Resistance:

Wild oat - ACCcase (1) + ALS (2), Lipid synthesis (8) + Unknown (26).
Kochia - Growth Regulator (4) + ALS (2).

Herbicide resistant weed species in other U.S. states:

ALS inhibitor (2): Yellow foxtail, giant foxtail, lambsquarters, sunflower, common cocklebur, giant ragweed, and Russian thistle.

Growth regulator (4): Wild mustard and field bindweed.

Photosystem II Inhibitor (5): Yellow foxtail, redroot pigweed, Powell amaranth, lambsquarters, and common ragweed.

*Or generic equivalent.

EPSP Synthase Inhibitor (9) (glyphosate): Kochia, horseweed (marestail), common and giant ragweed, waterhemp, lambsquarters (unconfirmed).

PPO inhibitor (14): Common and giant ragweed and waterhemp.

Multiple Resistance:

Powell amaranth - ALS (2) + triazine* (5) - Canada

Horseweed/Marestail - ALS (2) + Roundup* (9)

Multiple resistance (shown below) has been documented in biotypes of waterhemp, common ragweed, and giant ragweed:

ALS (2) + PPO (14)

ALS (2) + Roundup* (9)

ALS (2) + Roundup* (9) + PPO (14)

Weeds expressing some natural tolerance to Roundup*:

Cinquefoil, clover, lambsquarters, common mallow, dandelion, horseweed (marestail), kochia, nightshade, nutsedge, prickly lettuce, smartweed, velvetleaf, waterhemp, wild buckwheat.

Weeds expressing some natural tolerance to glufosinate

(Ignite/Liberty): grasses, lambsquarters, yellow nutsedge.

Genetically engineered crops resistant to glyphosate and glufosinate may be used to control weeds resistant to other herbicides. However, heavy selection pressure from these herbicides may cause selection of multiple resistant biotypes.

For a comprehensive list of resistant weeds in North Dakota, U.S., and world see web site: www.weedscience.com

STRATEGIES TO MINIMIZE HERBICIDE RESISTANT WEEDS

The following strategies should be effective in reducing problems with herbicide tolerant and resistant weed biotypes, but no single strategy is likely to be totally effective.

Weed resistance to herbicides **cannot** be prevented, but can be delayed. Herbicide rotations and tillage will only delay resistance by the length of time the selection pressure for a given herbicide is removed by an alternative control method. Resistance should occur in no-till fields before conventional-till fields. The gene pool does not revert back in absence of the original selection, except when the resistant plants are poorly fit. Fitness has not been greatly different for resistant and susceptible biotypes and should not be relied upon for resistance management.

General Guidelines:

1. Scout fields regularly and identify weeds that escape herbicide treatment. Monitor changes in weed populations early (single plants or small patches) and restrict spread of escaped weeds that match the herbicide use pattern. If there are dead plants, unaffected plants, and plants showing intermediate responses then resistance should be strongly considered.

2. Apply herbicides in tank-mix, prepackage, or sequential mixtures that include multiple modes of action. Two or more herbicides in the tank-mix must have substantial activity against potentially resistant weeds to be most effective. Many commercial premixes do not contain herbicides that target the same weed species. Effective tank-mixtures likely reduce the selection of herbicide-resistant biotypes more successfully than rotating herbicide modes of action. Antagonism should be reduced as much as possible.

3. Rotate herbicides with different modes of action in consecutive years. Few novel modes of action are likely to be released in the foreseeable future, therefore proper management of all currently available modes of action is necessary.

4. Rotate crops, particularly those with different life cycles, e.g. winter annual crops (winter wheat), perennial crops (alfalfa), and summer annual crops (spring wheat, corn or beans). Do not use herbicides with the same mode of action in the different crops unless other effective control practices are also included.

5. Use high rates of herbicides. Use full herbicide rates and use the most effective adjuvants with herbicides applied alone and in tank-mixtures. Reduced rates will allow plants with low-level resistance to hybridization and produce plants with high-level resistance.

Methods for Resistance Management

Method 1. Continued Herbicide Use - This approach allows for the use of the preferred herbicide until resistance occurs and then change to an alternative herbicide. This method requires more intense monitoring for resistance. The best resistance management strategy is early identification of resistant plants and then complete control (eradication) of the resistant plants while the infestation is small. Hand weeding, non-selective herbicides, cultivation, or combinations of methods can be used for eradication. Identification can be best accomplished with highly effective herbicide rates so that resistant plants are obvious for early eradication. Elimination of all resistant plants prior to reproduction on an annual basis should allow for continuous use of the herbicide.

Advantages:

1. Allow use of preferred herbicide.
2. Allow use of the herbicide best suited for weeds in a given field.
3. The above may save costs as a herbicide with a second mode of action may not be needed for the weeds present before resistance develops.

Disadvantages:

1. Resistance will occur sooner and require earlier monitoring for resistance.
2. Does not save the herbicide for use in crops without alternatives.
3. Requires hand-labor for greatest effect.

Method 2. Rotate Herbicides - This system will delay resistance, but may use unnecessary or less desirable herbicides in rotation or in mixture. Delaying resistance by alternative herbicides in the crop rotation is a means of keeping a herbicide for use in a crop that does not have an effective alternative.

Advantages:

1. Monitoring for resistance is less essential but still very important.
2. Herbicide mixtures may control more weed species and reduce the need for scouting to choose the appropriate herbicide for the field.

Disadvantages:

1. Will use herbicides other than the most desired.
2. Will select for multiple resistance.
3. Fewer herbicide options saved for future use.

Testing weeds for herbicide resistance:

Plant samples can be sent to Ag-Quest to test for weed resistance. Contact before sending to determine cost and packaging instructions. Ag-Quest, Inc.

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ACCASE or ALS (Group 1) herbicides = \$80 CAN/sample

Dinitroaniline (Group 3) herbicides = \$45 CAN/sample

On-line study course on herbicide mode of action can be found at: <http://www.wsweedscience.org/Lessons/lessons.asp>

*Or generic equivalent.

X1. Herbicide Classification and Mode of Action for Resistant Weed Management

Mode of Action	Common Name	Herbicide Tradename	Premix or Co-pack Tradenames
ACC-ase Inhibitor (1) Aryloxyphenoxy propionic acid "Fop"	clodinafop-P fenoxaprop-P fluazifop-P quizalofop	Discover NG. Puma = Tacoma. Fusilade DX. Assure II = Targa.	- Fusion, Wolverine. Fusion. -
	Cyclohexanedione "Dim"	clethodim sethoxydim tralkoxydim	Select = Trigger = Volunteer = Intensity. Arrow, Clethodim, Envoy, Section, Select Max, Shadow, Tap Out. Poast. Achieve.
Phenylpyrazolin "Den"	pinoxaden	Axial XL.	Axial TBC.
ALS Enzyme Inhibitor (2) Imidazolinone "Imi"	imazamethabenz imazamox imazapic imazapyr imazethapyr	Assert. Beyond = Clearcast = Raptor. Cadre = Impose = Plateau. Arsenal = Habitat. Pursuit = Thunder.	- ClearMax. Journey. Lightning, OneStep, Sahara. Authority Assist, Extreme=Thunder Master, Lightning, Matador, Pursuit Plus.
	Sulfonylurea "SU"	chlorimuron chlorsulfuron foramsulfuron halosulfuron metsulfuron nicosulfuron pro sulfuron rimsulfuron sulfometuron sulfosulfuron thifensulfuron triasulfuron tribenuron triflusaluron	Classic. Glean = Report = Telar. Option. Permit = Sandea. Accurate=Ally=Cimarron=Escort=Metgard = Metsulfuron=Patriot=Plotter=Romet=Valuron. Accent/Q, Adapt, Nic-It, Nico. Peak. Matrix = Resolve DF=Rule. Resolve SG. Oust. Certainty (turf), Maverick. Harass = Harmony DF = Treaty = Unity = Volta. Amber. Express = Nuance = Victory.
Triazolopyrimidine "TPS"	cloransulam florasulam flumetsulam pyroxulam	FirstRate. - Python. PowerFlex.	Authority First=Sonic, FrontRow, Gangster. Axial TBC, FirstStep, GoldSky, Orion, Starane Flex. FrontRow, Hornet, SureStart, TripleFlex. GoldSky.
Sulfonylamino-carbonyltriazolinone "SACT"	flucarbazone propoxycarbazone thiencarbazone	Everest 2.0 = Pre-Pare. Olympus. -	Raze. Olympus Flex, Rimfire Max. Corvus.
Mitotic Inhibitor (3) Dinitroaniline (DNA)	ethalfuralin pendimethalin trifluralin	Sonalan. Prowl/H20 = Acumen = Pendimax=Pendant. Trifluralin = Treflan = Triflurex = Trust/others.	- Pursuit Plus, Spartan Guard. Buckle, Freedom.
Growth Regulators (4) Phenoxy	2,4-D	2,4-D, others.	See bromoxynil. Crossbow, Curtail = Commando, ForeFront, Grazone P+D = Gun Slinger, Landmaster BW = Campaign = Credit Master, Rage D-Tech, Shotgun, Starane+Salvo, Weedmaster = see dicamba.
	MCPA amine MCPA ester	MCPA Amine, Rhomene, others. Daggar, MCPA E, Rhonox, Sword, Wildcard.	- See bromoxynil. ClearMax, Curtail M, Hat Trick, Orion, Starane+Sword.
Benzoic acids	dicamba-dma salt dicamba-dga salt dicamba-Na salt dicamba acid dicamba-ipa salt dicamba-dea salt	Banvel = Dicamba = Oracle = Rifle. Clarity = Sterling Blue. Banvel SGF. Vision. - -	- Pulsar Agility, Distinct=Overdrive, Require Q, Status, Yukon. Latigo. Fallow Master = Fallow Star. Weedmaster = Banvel + 2,4-D = Brash = Outlaw = Range Star = Rifle D.
Pyridine	aminopyralid clopyralid fluroxypyr picloram triclopyr	Milestone. Clean Slate, Clopyr Ag = Garrison = Spur = Stinger = Reclaim = Transline. Starane = Comet = Trump Card = Vista. Starane Ultra = Obtain = Vista XRT. Tordon 22K = Triumph 22K. Garlon = Remedy. Pathfinder II.	CleanWave, ForeFront. Curtail/M, = Redeem, WideMatch = Colt, Hat Trick, Hornet, SureStart, TripleFlex. CleanWave, Colt+Salvo/Sword, GoldSky, Hat Trick, Pulsar, Raze, Supremacy, Starane Flex/NXT, Trooper Pro, WideMatch = Colt. Grazone P+D = Gun Slinger, Surmount, Trooper Extra/Pro. PastureGard, Redeem, Vengeance Plus.
Pyrimidine	aminocyclopyrachlor	- (DPX-KJM44 / DPX-MAT44)	Plainview, Perspective, Steamline, Viewpoint.
Quinoline	quinclorac (dicots)	Drive=Quinstar=Quinclorac. Paramount.	-

Mode of Action	Common Name	Herbicide Tradename	Premix or Co-pack Tradenames
Photosystem II Inhibitor (5) - Site A Triazine Triazinone Phenyl-carbamate	atrazine	Atrazine, others.	See 2,4-D, dicamba, bentazon, bromoxynil, glyphosate, acetochlor, dimethenamid-P, s-metolachlor + or - safener. Derby.
	simazine	Princep.	
	metribuzin	Metribuzin = Sencor = Tri-Cor.	Authority MTZ, Boundary, Canopy, Domain, Matador.
	desmedipham phenmedipham	Alphanex = Betanex. -	Betamix = Phen-Des 8+8, BNB Plus = Progress. Betamix = Phen-Des 8+8, BNB Plus = Progress.
Photosystem II Inhibitor (6) - Site B	bentazon	Basagran.	Galaxy, Laddok S-12, Rezult, Storm.
	bromoxynil	BroClean = Bromox = Brox = Bucril = Moxy.	Bronate = Bison = Bromac = Bromox MCPA = Maestro MA = Wild Card Xtra, Brox M, Huskie, Wolverine. Bronate Advanced = B-5 = Bison Advanced = Bromac Advanced = Brox M Ultra = Wolfpack Advanced. Bromoxynil + 2,4-D(2 lb+2 lb), B-4, Double Up, Maestro D. Bromoxynil + 2,4-D (2 lb+2.5 lb) = WECO Max.
Photosystem II Inhibitor (7) - Site A - different than 5	diuron	Diuron = Direx = Karmex.	Krovar, Sahara, WeedBlast.
	linuron	Lorox = Linex = Linuron.	-
	tebuthiuron	Spike.	-
Lipid Synthesis Inhibition (8) Thiocarbamate	cycloate	Ro-Neet.	-
	EPTC	Eptam = Eptek = Eradicane = Razencane.	Powerplay, Imperium.
	trallate	Far-Go.	Buckle.
EPSP Synthase Inhibitor (9)	glyphosate-ipa, K, dma, (NH ₄) ₂	Roundup, several generics - see page 71.	Extreme, Fallow Master, Landmaster BW, others.
Glutamine Synthetase Inhibitor (10)	glufosinate	Liberty = Finale. Ignite 280. Rely 200.	-
Bleaching: Phytoene Desaturase Inhibitor (PDS) (12)	beflubutamid	UBH-820.	-
	flurochloridone	Racer.	-
	flurtamone	-	Nikyl.
Bleaching: DOXP Synthase Inhib. (13)	clomazone	Command	Command Xtra, Commence.
PPO (Protox) Inhibitor (14) Diphenylether Imine N-phenylphthalimide Oxadiazole Phenylpyrazole Pyrimidinedione Triazolinone	acifluorfen	Ultra Blazer.	Galaxy, Storm.
	fomesafen	Flexstar, Reflex = Top Gun.	Flexstar GT, Prefix.
	lactofen	Cobra, Phoenix.	Stellar.
	oxyfluorfen	Goal.	-
	fluthiacet	Cadet.	-
	flumiclorac	Resource.	-
	flumioxazin	Valor = Broadstar = Chateau = Encompass = Payload = Suregard.	Fierce, Gangster, Diligent, Enlite. -
	oxadiargyl	Raft, Topstar.	-
	pyraflufen	ET, Vida.	-
	saflufenacil	Sharpen.	Verdict
Very Long Chain Fatty Acid Inhibitor (15)	acetochlor	Harness = Confidence. Surpass = Breakfree = Volley. Degree, TopNotch. Warrant.	Imperium, Breakfree ATZ Lite=Keystn LA=Volley ATZ Lite, SureStart=TripleFlex. Powerplay.
	alachlor dimethenamid-P metolachlor meto + safener S-metolachlor S-meto + safener	Alachlor, Intro, Lasso, others. Outlook = Commit = Establish = Propel= Sortie. Dual 8E, Parallel PCS, Stalwart. Dual II, Me-Too-Lachlor, Parallel, Stalwart C. Dual Magnum, Brawl, Charger Max. Dual II Magnum, Brawl II, Cinch.	- Verdict, Commit/Propel ATZ Lite=Establish/G-Max Lite. Matador. Parallel Plus, Stalwart Xtra. Boundary, Prefix, Sequence. Bicep Lite II Magnum, Brawl II ATZ, Camix, Charger Max ATZ Lite, Cinch ATZ Lite, Halex GT, Lumax.
Oxyacetamide	flufenacet	Define.	Domain, Epic, Radius.
Isoxaline	pyroxasulfone	Zidua (KIH-485).	Fierce. Pyrox + Cadet? (2011), Pyrox + Sharpen? (2011)
Unknown (16)	ethofumesate	Nortron = Ethofumesate = Ethotron.	BNB Plus = Progress.
Auxin Inhibitor (19)	diflufenzopyr	-	Celebrity Plus, Distinct, Status.
Photosystem I Inhibitor (22)	diquat	Reglone = Diquat E-Ag.	-
	paraquat	Firestorm, Gramoxone Inteon, Parazone, Rely.	-
Unknown (26)	difenzoquat	Avenge.	-
	quinclorac (grass)	Drive = Facet = Paramount.	-
Bleaching: HPPD Inhibition(27) triketone Isoxazole Pyrazolone	mesotrione	Callisto = Tenacity.	Callisto Xtra, Camix, Halex GT, Instigate, Lumax, Trigate.
	tembotrione	Laudis.	-
	isoxaflutole	Balance Flexx.	Corvus, Epic, Prequel, Radius.
	pyrasulfatole	-	Huskie, Wolverine.
	topramezone	Impact.	-

Cold, Hard STEEL (30): Plow, cultivator, rotary-hoe, etc.

Adapted from WSSA Herbicide Classification System For Resistant Weed Management. Weed Technol. 17:606-608.