

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 gene. 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 - if a wild oat population is resistant to one ACCase herbicide, other ACCase inhibitor herbicides may or may not provide control.

Weed plants with a wide genetic diversity develop resistance rapidly, especially for herbicides with one mode of action. Kochia developed resistance rapidly in North Dakota to ALS herbicides because of diversity and the SU single mode of action. Kochia plants vary in resistance to various SUs, but in general kochia plants rapidly develop resistance to individual SU herbicides. Imidazolinone (Imi) herbicides are in the same action group (ALS inhibitors) as SUs, but weeds may not have cross resistance. For example, nightshade species exhibit natural tolerance to most SU herbicides, but only recently developed resistance to Imi herbicides. Table X1 lists herbicides within various mode of action groups as a guide for possible cross resistance.

Types of Resistance

Altered target site - ALS inhibitors and other herbicides act on one specific site in a plant selecting for resistant plants in diverse plant species. Herbicides that affect one enzyme in a plant usually are prone to altered site-of-action resistance.

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.

Herbicide sequestration / Altered herbicide localization - Movement of herbicide is impeded, is moved away from its target site, or is moved to a location where it is ineffective. This may be at the whole-plant or cellular level. This resistance mechanism appears to be important in Roundup and paraquat resistance.

Plants having altered site-of-action resistance often are not affected by herbicide concentration (rate), but plants having altered metabolism or herbicide localization resistance are affected by herbicide rate. As rate increases, the plant eventually reaches a point where it cannot degrade the herbicide or alter its location faster than the herbicide is absorbed or moved.

Cross and Multiple Resistance

A plant with a single resistance mechanism that enables survival when treated with different chemicals within the same mode of action is cross resistant to those chemicals. Resistance that develops to one ALS herbicide often confers cross resistance to other ALS herbicides. 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. Kochia may be resistant to SUs and atrazine. Different resistance mechanisms are involved;

therefore, a kochia plant that withstands treatment with SUs and atrazine has multiple resistance. Plants with altered herbicide localization are also likely to exhibit this rate effect.

Herbicide resistant weed species in ND:

(#) = Herbicide mode of action, see pages 82-83.

ACCcase inhibitor herbicides (1):

Wild oat (ACCcase herbicides except Select*)
Green foxtail (All ACCcase herbicides except Select*)
Yellow foxtail (All ACCcase herbicides except Select)
Wild oat resistance has been documented in nearly every ND county.

ALS inhibitor herbicides (2):

Wild oat (Assert, Everest, Olympus, Rimfire, and Silverado)
Kochia (All ALS herbicides)
E. black nightshade (Imi herbicides: Raptor and Pursuit)
Redroot pigweed (Imi herbicides: Pursuit and Raptor)
Waterhemp (All ALS herbicides)
Wild mustard (All ALS herbicides)
Common ragweed (ALS herbicides)
Marshelder (Imi - Pursuit and Raptor, and SU - Express*)

Mitotic inhibitor (3):

Green foxtail (Treflan*, Sonalan, Prowl)

Growth regulator (4):

Kochia (2,4-D* and Banvel*)

Photosystem II inhibitor (5):

Kochia (atrazine*)

Lipid synthesis inhibitor (8):

Wild oat (Far-Go)
Resistant wild oat biotypes were also found to be resistant to Avenge.

EPSP synthase inhibitor (9) (glyphosate):

Lambsquarters (unconfirmed), Common ragweed

Unknown mode of action (26):

Wild oat (Avenge)
Resistant wild oat biotypes were also resistant to Far-Go.

Multiple Resistance:

Wild oat - ACCcase (1) + ALS (2)
Kochia - Growth Regulator (4) + ALS (2)

Herbicide resistant weed species in the U.S. - not in ND:

Other weeds present in ND that have developed resistance to herbicides in other areas of the nation are listed below.

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.

EPSP Synthase Inhibitor (9) (glyphosate):

Kochia (unconfirmed), horseweed (marestail), giant ragweed, lambsquarters (unconfirmed), waterhemp.

PPO inhibitor (14):

Common and giant ragweed and waterhemp.

*Or generic equivalent.

Multiple Resistance:

Wild oat - ACCase (1) + ALS (2)

Kochia - Growth regulator (4) + ALS (2)

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.

General Guidelines:

1. Scout fields regularly and identify weeds that escape herbicide treatment. Monitor changes in weed populations early (a few plants in the field) and restrict spread of potentially resistant weeds that match the field history and herbicide pattern. If there are dead plants, unaffected plants, and plants showing intermediate responses then resistance should be strongly considered. Use full rates of all products and use the most effective adjuvants when tank-mixing with glyphosate.

2. Rotate herbicides with different modes of action in consecutive years. New and novel sites of action are not likely to be discovered.

3. 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. Most commercial premixes do not contain herbicides that target the same weed species. Antagonism among tank-mix partners should be avoided.

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.

Weed resistance to herbicides **cannot** be prevented, but can be delayed. Herbicide and tillage rotations will only delay resistance by the length of time that the selection pressure for a given herbicide is removed by an alternative control method. Resistance should occur in no-tillage fields before conventional tillage 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.

Two options for resistance management are: 1. Use the desired herbicide until resistance occurs and then change to an alternative; and 2. Rotate control methods to delay the on-set of resistance.

5. Use high labeled rates of POST herbicides. Reduced rates may allow hybridization among plants with low-level resistance to produce plants with high-level resistance.

Method 1. Continued Herbicide Use - This approach allows for the use of the preferred treatment but will require 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 uncontrolled plants are obvious for early eradication. Elimination of the resistant plants will allow for continuous use of the herbicide.

Advantages:

1. Allow use of preferred herbicide.
2. Allow for 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.

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. Fusilade DX. Assure II = Targa.	- Fusion, Wolverine. Fusion. -
	Cyclohexanedione "Dim"	clethodim sethoxydim tralkoxydim	Select = Trigger = Volunteer = Intensity. Arrow, Clethodim, Envoy, Section, Select Max, Shadow. Poast. Achieve.
Phenylpyrazolin "Den"	pinoxaden	Axial XL.	Axial TBC.
ALS Enzyme Inhibitor (2) Imidazolinone "Imi"	imazamethabenz imazamox imazapic imazapyr imazaquin imazethapyr	Assert. Beyond = Clearcast = Raptor. Cadre = Impose = Plateau. Arsenal = Habitat. Scepter. Pursuit.	- ClearMax. Journey. Lightning, OneStep, Sahara. Squadron. Authority Assist, Extreme, Lightning, Pursuit Plus.
	Sulfonylurea "SU"	chlorimuron chlorsulfuron foramsulfuron halosulfuron mesosulfuron metsulfuron nicosulfuron prosulfuron rimsulfuron sulfometuron sulfosulfuron thifensulfuron triasulfuron tribenuron triflurosulfuron	Classic. Glean = Report = Telar. Option. Permit = Sandea. Silverado. Accurate=Ally=Cimarron=Escort=Metgard = Metsulfuron=Plotter=Romet=Valuron. Accent/Q, Nic-It, Nico. Peak. Matrix = Resolve DF. 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, GoldSky, Orion. FrontRow, Hornet, SureStart. GoldSky.
Sulfonylamino-carbonyltriazolinone "SACT"	flucarbazone propoxycarbazone thiencarbazone	Everest = Pre-Pare. Olympus. -	Finesse Grass and Broadleaf. Olympus Flex, Rimfire, Rimfire Max. Corvus.
Mitotic Inhibitor (3) Dinitroaniline (DNA)	ethalfluralin pendimethalin trifluralin	Sonalan. Prowl/H20 = Acumen = Pendimax=Pendant. Trifluralin = Treflan = Triflurex = Trust/others.	- Pursuit Plus. Buckle, Freedom.
Growth Regulators (4) Phenoxy	2,4-D	2,4-D, others.	See bromoxynil. Crossbow, Curtail = Commando, ForeFront, Grazzone P+D = Gun Slinger, Landmaster BW = Campaign = Credit Master, Rage D-Tech, Recoil, 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=Commando 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 = GlyKamba. Weedmaster = Banvel + 2,4-D = Brash = Kamba Master = Outlaw = Range Star = Rifle D.
Pyridine	aminopyralid clopyralid fluroxypyr picloram triclopyr	Milestone. Clopyr Ag = Garrison = Spur = Stinger = Reclaim = Transline. Starane = Vista. Starane Ultra = Obtain = Vista XRT. Tordon 22K = Triumph 22K. Garlon = Remedy. Pathfinder II.	CleanWave, ForeFront Commando/M = Curtail/M, = Cutback/M = Redeem, WideMatch = Colt, Hat Trick, Hornet, SureStart. CleanWave, Colt+Salvo/Sword, GoldSky, HatTrick, Pulsar, Surmount, Starane NXT, WideMatch = Colt. Grazzone P+D = Gun Slinger, Surmount. PastureGard, Redeem, Vengeance Plus
Pyrimidine	aminocyclopyrachlor	- (DPX-KJM44 / DPX-MAT44)	-
Quinoline	quinclorac (dicots)	Drive = Facet = 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
	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 = Commit.	Command Xtra, Commence.
PPO (Protox) Inhibitor (14) Diphenylether Imine N-phenylphthalimide Oxadiazole Phenylpyrazole Pyrimidinedione Triazolinone	acifluorfen	Ultra Blazer.	Galaxy, Storm.
	fomesafen	Flexstar, Reflex.	Prefix.
	lactofen	Cobra, Phoenix.	Stellar.
	oxyfluorfen	Goal.	-
	fluthiacet	Cadet.	-
	flumiclorac	Resource.	Stellar.
	flumioxazin	Valor = Broadstar = Chateau = Encompass = Payload = Suregard.	Gangster, Diligent, Enlite, Valor XLT. -
	oxadiargyl	Raft, Topstar.	-
	pyraflufen	ET, Vida.	-
	saflufenacil	Sharpen.	Integrity
Very Long Chain Fatty Acid Inhibitor (15) Acetamide Oxyacetamide Pyrazole/Oxazole	acetochlor	Harness = Confidence. Surpass = Breakfree = Volley. Degree, TopNotch.	Harness Xtra/5.6L=Confidence Xtra/5.6L. Imperium. Breakfree ATZ Lite=Keystn LA=Volley ATZ Lite. SureStart. Powerplay.
	alachlor dimethenamid-P metolachlor meto + safener S-metolachlor S-meto + safener	Alachlor, Intrro, Lasso, others. Establish, Outlook, 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.	- Integrity, Establish Lite=G-Max Lite=Propel ATZ Lite. - 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.
	flufenacet	Define.	Domain, Epic, Radius
	pyroxasulfone	KIH-485.	-
Unknown (16)	ethofumesate	Nortron = Ethofumesate = Ethotron.	BNB Plus = Progress.
Auxin Inhibitor (19)	diflufenzopyr	-	Celebrity Plus, Distinct, Status
Photosystem I Inhibitor (22)	diquat	Reglone.	-
	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.	Camix, Halex GT, Instigate, Lumax, Trigate.
	tembotrione	Laudis.	-
	isoxaflutole	Balance Pro, Balance Flexx.	Corvus, Epic, Prequel, Radius
	pyrasulfatole	-	Huskie, Wolverine
	topramezone	Impact.	-

Cold, Hard STEEL (28): Plow, cultivator, rotary-hoe, etc.

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