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.

- ACCase inhibitor herbicides (1): Wild oat, green foxtail, and yellow foxtail - All ACCase 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):
Kochia, common ragweed and waterhemp.
Horseweed (maretail) and lambsquarters = unconfirmed.

Multiple Resistance:

Wild oat - ACCase (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, field bindweed, waterhemp.
- **Photosystem II Inhibitor (5):** Yellow foxtail, redroot pigweed, Powell amaranth, lambsquarters, and common ragweed.
- **EPSP Synthase Inhibitor (9) (glyphosate):** Kochia, horseweed (marestail), common and giant ragweed, waterhemp, and lambsquarters (unconfirmed).
-**PPO inhibitor (14):** Common and giant ragweed and waterhemp.
-**HPPD inhibitor (27):** Waterhemp.

*Or generic equivalent.

Multiple Resistance:
Waterhemp - ALS (2) + Roundup*(9) + PPO (14) + HPPD (27) + triazine (5).
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. Zero seed rain may be difficult but should be the ultimate goal of weed management by using all management strategies. Preventing weed seed production from plants surviving herbicide phytotoxicity is required to delay future weed problems.

3. Apply effective herbicides in tank-mix, prepackage, or sequential mixtures that include multiple modes of action. Two or more herbicides in mixture must have activity against potentially resistant weeds to be effective. Most commercial mixtures 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 may occur with some mixtures, especially between contact and systemic herbicides.

4. Rotate herbicides with different modes of action in consecutive years. Few novel modes of action are being registered, therefore strategic management of all currently available modes of action is necessary.

5. 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.

6. Use high herbicide rates and effective adjuvants. Some think reducing herbicide rates will decrease selection pressure for resistance - the opposite is often true. Full rates kill weeds with low-level resistance and dead plants cannot produce seed to pass their genes on to the next generation. Reduced rates allow plants with low-level resistance to survive, hybridize, and produce progeny with elevated resistance. Hybrid plants with more than one resistance gene will express a higher level of resistance and will require a higher herbicide rate to kill the plant. Even in susceptible weed populations, uncontrolled weeds due to sub-optimum weed control means more surviving plants which means a greater chance that rare resistant mutants will arise within the field. Summary points: Dead weeds is good resistance management. Dead weeds means zero seed rain.

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 listed methods can be used for eradication. Identification can be best accomplished with 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 of this system allows use of preferred herbicides and may save costs as a herbicide with a second mode of action may not be needed for the weeds present before resistance develops. Disadvantages include more rapid expression of resistance which will require earlier monitoring for resistance, does not save the herbicide for use in crops without alternatives, and may require hand-labor.

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

Advantages of this system include less monitoring and herbicide mixtures may control more weed species and reduce the need for scouting to choose appropriate herbicides for the weed spectrum. Disadvantages include use of herbicides other than those most desired, selection for multiple resistance, and fewer herbicide options saved for future use.

Testing weeds for herbicide resistance:
Ag-Quest, Inc., Dr. Haisheng Xie (Dr. Z), Minto, Manitoba, Canada. 204-776-5565, haisheng.xie@agquest.com, www.agquest.com

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

On-line herbicide resistance education and training course at: http://wssa.net/LessonModules/herbicide-resistant-weeds/

*Or generic equivalent.

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

Mechanism of Action	Common Name	Herbicide Tradename	Premix or Co-pack Tradenames
ACC-ase Inhibitor (1) Aryloxyphenoxy propionic acid "Fop"	clodinafop-P	Discover NG.	-
	fenoxaprop-P	Puma = Tacoma = Parity.	Fusion, Wolverine.
	fluazifop-P	Fusilade DX.	Fusion.
	quizalofop	Assure II = Targa.	-
Cyclohexanedione "Dim"	clethodim	Select = Trigger = Volunteer = Intensity. Arrow, Clethodim, Envoy, Section, Select Max, Shadow, Tapout.	-
	sethoxydim	Poast.	Rezult.
Phenylpyrazolin "Den"	pinoxaden	Axial XL.	Axial Star, Axial TBC.
ALS Enzyme Inhibitor (2) Imidazolinone "Imi"	imazamethabenz	Assert.	-
	imazamox	Beyond = Clearcast = Raptor.	ClearMax.
	imazapic	Cadre = Impose = Plateau.	Journey.
	imazapyr	Arsenal = Habitat.	Lightning, OneStep, Sahara.
	imazethapyr	Pursuit = Thunder.	Authority Assist, Extreme=Thunder Master, Lightning, Matador, Op-Till.
Sulfonylurea "SU"	chlorimuron	Classic.	Enlite, Freestyle, Instigate, Traverse, Valor XLT.
	chlorsulfuron	Glean = Report = Telar.	Chism, Cimarron Max/X-tra, Finesse/G&B, Report Extra.
	foramsulfuron	Option.	Equip.
	halosulfuron	Permit = Sandea.	Priority.
	mesosulfuron	Osprey.	Rimfire Max.
	metsulfuron	Accurate=Ally=Cimarron=Escort=Metgard = Metsulfuron=Patriot=Plotter=Romet=Valuron.	Accurate Extra, Ally Extra, Chaparral, Chisum, Cimarron Max, Cimarron X-tra, Finesse, Report Extra.
	nicosulfuron	Accent/Q, Adapt, Nic-It, Nico.	Celebrity Plus, Clarion, Ironclad, Steadfast/Q, Stout.
	prosulfuron	Peak.	Exceed, Spirit.
	rimsulfuron	Matrix = Resolve = Rule.	Diligent, Instigate, Ironclad, Prequel, Realm Q, Require Q, Resolve/ Q, Steadfast/Q, Traverse, Trigate.
	sulfometuron	Oust.	-
	sulfosulfuron	Certainty (turf), Maverick.	-
	thifensulfuron	Harass = Harmony = Treaty = Unity = Volta.	Accurate Extra, Agility, Affinity BS/TM, Ally Extra, Basis, Enlite, Freestyle, Harmony Extra, Nimble, Rapport BS/TM, Resolve Q, TNT, Treaty Extra.
	triasulfuron	Amber.	Fuego, Rave.
	tribenuron	Express = Nuance = Victory.	Accurate Extra, Agility, Affinity/Edition/Rapport Broadspec /Tankmix, Ally Extra, Freestyle, Harmony Extra, Nimble, Supremacy, Trigate, TNT.
	triflusulfuron	UpBeet.	-
Triazolopyrimidine "TPS"	cloransulam	FirstRate.	Authority First=Sonic, FrontRow, Gangster.
	florasulam	-	Axial TBC, FirstStep, GoldSky, Orion, Starane Flex.
	flumetsulam	Python.	FrontRow, Hornet, SureStart, TripleFlex.
	pyroxulam	PowerFlex.	GoldSky.
Sulfonylamino-carbonyltriazolinone "SACT"	flucarbazone	Everest 2.0, Pre-Pare, Sierra.	Raze.
	propoxycarbazone	Olympus.	Olympus Flex, Rimfire Max.
	thiencarbazone	-	Capreno, Corvus, Huskie Complete.
Mitotic Inhibitor (3) Dinitroaniline (DNA)	ethalfluralin	Sonalan.	-
	pendimethalin	Prowl/H20 = Acumen = Pendimax=Pendant.	-
	trifluralin	Trifluralin = Treflan = Triflurex = Trust/others.	Buckle, Freedom.
Growth Regulators (4) Phenoxy	2,4-D	2,4-D, others.	See bromoxynil. Crossbow, Curtail, ForeFront, Grazone P+D = Gun Slinger, Landmaster BW = Campaign = Credit Master, Starane+Salvo, Weedmaster.
	MCPA amine	MCPA Amine, Rhomene, others.	-
	MCPA ester	Daggar, MCPA E, Rhonox, Sword, Wildcard.	ClearMax, Curtail M, Hat Trick, Orion, Starane+Sword.
Benzoic acids	dicamba-dma salt	Banvel = Dicamba = Oracle = Rifle.	-
	dicamba-dga salt	Clarity = Sterling Blue.	Pulsar
	dicamba-Na salt	Banvel SGF.	Agility, Distinct=Overdrive, Require Q, Status, Yukon.
	dicamba acid	Vision.	Latigo.
	dicamba-ipa salt	-	Fallow Master = Fallow Star.
	dicamba-dea salt	-	Weedmaster = Banvel + 2,4-D = Brash = Outlaw = Range Star = Rifle D.
Pyridine	aminopyralid	Milestone.	Chaparral, CleanWave, ForeFront.
	clopyralid	Clean Slate, Clopyr Ag = Garrison = Spur = Stinger = Reclaim = Transline.	Curtail/M, = Redeem, WideMatch = Colt, Hat Trick, Hornet, SureStart, TripleFlex.
	fluroxypyr	Starane = Comet = Trump Card = Vista. Starane Ultra = Obtain = Vista XRT.	Axial Star, CleanWave, Colt+Salvo/Sword, GoldSky, Hat Trick, Pulsar, Raze, Supremacy, Starane Flex/NXT, Trooper Pro, WideMatch = Colt.
	picloram	Tordon 22K = Triumph 22K.	Grazone P+D = Gun Slinger, Surmount, Trooper Extra/Pro.
	triclopyr	Garlon = Remedy. Pathfinder II, Tricera.	PastureGard, Redeem, Vengence Plus.
Pyrimidine	aminocyclopyrachlor	MAT-28	Plainview, Perspective, Steamline, Viewpoint.
Quinoline	quinclorac (dicots)	Drive=Quinstar=Quinclorac. Paramount.	-

Mechanism of Action	Common Name	Herbicide Tradename	Premix or Co-pack Tradenames
Photosystem II Inhibitor (5) - Site A	atrazine	Atrazine, others.	See 2,4-D, dicamba, bentazon, bromoxynil, glyphosate, acetochlor, dimethenamid-P, s-metolachlor + or - safener.
Triazine	simazine	Princep.	Derby.
Triazinone	metribuzin	Glory = Metribuzin = Sencor = TriCor.	Authority MTZ, Boundary, Canopy, Domain, Matador.
Phenyl-carbamate	des/phenmedphm	Alphanex = Betanex.	Betamix = Phen-Des 8+8.
Photosystem II Inhibitor (6) - Site B	bentazon	Basagran.	Galaxy, Laddok S-12, Rezult, Storm.
	bromoxynil	BroClean = Bromox = Brox = Buctril = Moxy.	Bronate = Bison = Bromac = Bromox MCPA = Maestro MA = Wild Card Xtra, Brox M, Huskie/Complete, 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)	cycloate	Ro-Neet.	-
	EPTC	Eptam = Eptek = Eradicane = Razencane.	Powerplay, Imperium.
Thiocarbamate	triallate	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 Synthet-ase Inhibitor (10)	glufosinate	Finale, Ignite, Rely.	-
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)	acifluorfen	Ultra Blazer.	Galaxy, Storm.
	fomesafen	Fomesafen, Flexstar, Reflex = Top Gun.	Flexstar GT 3.5, Prefix.
Diphenylether	lactofen	Cobra, Phoenix.	Stellar.
	oxyfluorfen	Goal.	-
Imine	fluthiacet	Cadet.	-
N-phenylphthalimide	flumiclorac	Resource.	-
	flumioxazin	Valor = Broadstar = Chateau = Encompass = Payload = Suregard.	Fierce, Gangster, Diligent, Enlite.
			-
Oxadiazole	oxadiargyl	Raft, Topstar.	-
Phenylpyrazole	pyraflufen	ET, Vida.	-
Pyrimidinedione	saflufenacil	Sharpen.	Op-Till, Verdict
Triazolinone	carfentrazone	Aim = Quicksilver.	Priority, Spartan Charge.
	sulfentrazone	Spartan = Blanket = Crossing = Portfolio.	Authority Assist/First=Sonic/MTZ, BroadAxe, Spartan Chrg
Very Long Chain Fatty Acid Inhibitor (15)	acetochlor	Harness = Confidence.	Imperium, Breakfree ATZ Lite=Keystn LA=Volley ATZ Lite, SureStart=TripleFlex.
		Surpass = Breakfree = Volley.	
		Degree, TopNotch. Warrant.	Powerplay.
	alachlor	Alachlor, Intrro, Lasso, others.	-
Acetamide	dimethenamid-P	Outlook = Commit = Establish = Propel.	Verdict, Commit/Propel ATZ Lite=Establish/G-Max Lite.
	metolachlor	Dual 8E, Parallel PCS, Stalwart.	Matador.
	meto + safener	Dual II, Me-Too-Lachlor, Parallel, Stalwart C.	Parallel Plus, Stalwart Xtra.
	S-metolachlor	Dual Magnum, Brawl, Charger Max.	Boundary, BroadAxe, Prefix, Sequence.
	S-meto + safener	Dual II Magnum, Brawl II, Cinch.	Bicep Lite II Magnum, Brawl II ATZ, Camix, Charger Max ATZ Lite, Cinch ATZ Lite, Halex GT, Lumax.
Isoxaline	pyroxasulfone	Zidua (KIH-485).	Anthem, Fierce.
Unknown (16)	ethofumesate	Nortron = Ethofumesate = Ethotron.	BNB Plus = Progress.
Auxin Inhibitor (19)	diflufenzopyr	-	Status.
Photosystem I Inhibitor (22)	diquat	Reglone = Diquat E-Ag.	-
	paraquat	Firestorm, Gramoxone SL, Parazone.	-
Unknown (26)	quinclorac (grass)	Drive = Facet = Paramount.	-
Bleaching: HPPD Inhibition(27) triketone	mesotrione	Callisto = Tenacity.	Callisto Xtra, Camix, Halex GT, Lumax, Realm Q, Trigate.
	tembotrione	Laudis.	Capreno.
Isoxazole	isoxaflutole	Balance Flexx.	Corvus, Epic, Prequel, Radius.
Pyrazolone	pyrasulfatole	-	Huskie/Complete, Wolverine.
	topramezone	Impact.	-
Cellulose Inhib. (29)	indaziflam	Alion	-
Cold, Hard STEEL (30): Plow, cultivator, rotary-hoe, etc.			
Adapted from WSSA Herbicide Classification System For Resistant Weed Management. Weed Technol. 17:606-608.			