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 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 mechanism of action may give resistance to other herbicides with the same mechanism of action. However, weed specificity for resistance is known for different herbicides within a mechanism 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 mechanism 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 mechanism 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). Mechanisms 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 - Nearly all plants with this type of resistance are injured shortly after the herbicide application because the movement of herbicide is either impeded, moved away from the target site, or moved to a location where it is ineffective. This may be at the whole-plant or cellular level. Herbicide sequestration is considered low-level resistance because increasing rates applied to smaller plants increases mortality. Examples of herbicide sequestration include biotypes of glyphosate-resistant horseweed, ryegrass, common and giant ragweed, and weed biotypes resistant to paraquat. Variable lambsquarters control may result from limited glyphosate translocation.

Target-site amplification - Some glyphosate-resistant kochia, Palmer amaranth, and waterhemp express increased levels of herbicide-susceptible EPSPS target-site protein. These plants can have up to 100 copies or more of the EPSPS gene, and produce more target-site enzyme than glyphosate can fully inhibit.

Cross and Multiple Resistance

A plant with a single resistance mechanism that survives treatment with chemicals within the same mechanism 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 a different mechanism of action has multiple resistance, example: a kochia plant that survives SU and atrazine has multiple resistance.

Herbicide-resistant weed species in ND:

(#) = Herbicide mode of action, see pages 98-99.

- ACCase inhibitor herbicides (1): wild oat and green foxtail.
- ALS inhibitor herbicides (2): green foxtail, kochia, marshelder, mustard, ragweed, redroot/powell pigweed, waterhemp, and wild oat.
E. black nightshade and redroot pigweed - Imi herbicides.
- Mitotic inhibitor (3): green foxtail - Treflan, Sonalan, Prowl.
- Growth regulator (4): kochia - 2,4-D and dicamba, Starane
- Photosystem II inhibitor (5): kochia - atrazine.
- EPSP synthase inhibitor (9): Horseweed (marestail), kochia, common ragweed, waterhemp, and lambsquarters = unconfirmed.
- PPO inhibitor (14): ragweed and waterhemp (suspected).

Multiple Resistance:

Green foxtail - Group 1 + 2
Ragweed - Group 2 + 9 + 14
Wild oat - Group 1 + 2 + 8 + 26
Kochia - Group 2 + 4 + 9
Waterhemp - Group 2 + 9 + 14

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, common ragweed, and waterhemp.
- **EPSP Synthase Inhibitor (9) (glyphosate):** Kochia, horseweed (marestail), common and giant ragweed, waterhemp, and lambsquarters = unconfirmed.
- **Glutamine synthetase (10) (glufosinate):** Italian ryegrass.
- **PPO inhibitor (14):** Common and giant ragweed and waterhemp.
- **HPPD inhibitor (27):** Waterhemp.

Multiple Resistance:

Waterhemp - Group 2 + 5 + 9 + 14 + 27.
Horseweed (marestail) and kochia - Group 2 + 9.
Waterhemp, common ragweed, and giant ragweed:
Group 2 + 9 or Group 2 + 14 or Group 2 + 9 + 14.

Weeds expressing some natural tolerance to glyphosate: Cinquefoil, clover, lambsquarters, common mallow, dandelion, galinsoga, horseweed (marestail), kochia, nightshade, nutsedge, pennsylvania pellitory, prickly lettuce, purslane speedwell, smartweed, velvetleaf, waterhemp, wild buckwheat.

Weeds expressing some natural tolerance to glufosinate (Liberty): grasses, lambsquarters, yellow nutsedge.

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

GENERAL WEED MANAGEMENT STRATEGIES:
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 in weeds **cannot** be prevented, but can be delayed. Herbicide rotations, management, 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 may occur first in fields where repeated use of a single mode of action herbicide is used in a growing season or across several growing seasons. 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.

Integrated weed management uses multiple strategies to manage weed populations including the following:
- Scouting, proper weed identification, and weed mapping.
- Use crop canopy/competition to improve weed control.
- Use weaknesses in the biology of weed species which include traits, life cycles, and ecology.
- Judicious use of and multiple approaches with herbicides.
- Use mechanical weed control as appropriate.
- Regular evaluation and adjustments of weed management strategies.

1. Scout fields before and soon after herbicide application. Correctly identify weeds. Use effective herbicides, handweeding, cultivation/tillage, and other methods of weed control to kill weeds that escape or germinate after chemical application. Scout fields at the end of the season and draw field maps to denote locations of weed species, weed density, and weed escapes. Save maps as a field record.

2. Diversified crop sequences with different life cycles e.g. winter annual crops (winter wheat), perennial crops (alfalfa) and summer annual crops (spring wheat, corn or beans) results in different planting and harvest times, more herbicide options, and decreased risk of herbicide resistant weeds.

3. Consider weed biology and ecology. Use tillage, crop sequence, soil fertility, planting date, crop competition, weed seed longevity, and response to herbicides to increase successful weed management.

4. "Don't forget the PRE". Apply effective PRE herbicides at full rates and include multiple mechanisms of action. PRE herbicides will reduce weed emergence and allow flexibility in POST herbicide timing. Residual PRE herbicides applied to soil and early POST (if labeled) will suppress weed emergence through canopy closure, particularly those with a long germination pattern (waterhemp). Use PRE herbicides that will effectively control problem weeds.

5. Apply effective POST herbicides. Apply herbicides that include multiple mechanisms of action in tank-mix or in sequential applications. Two or more herbicides in mixture must have activity against potentially resistant weeds to be effective. Herbicides in most commercial mixtures do not target the same weed species. Effective tank-mixtures on weeds will reduce 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.

6. Use high herbicide rates and effective adjuvants. Full rates kill weeds with low-level resistance and dead plants cannot produce resistant progeny. Reduced rates allow plants with low-level resistance to survive, hybridize, and produce progeny with elevated resistance. Hybrid plants (>1 resistance gene) express a higher level of resistance and require even higher herbicide rates to kill the plant. Dead weeds means zero tolerance (no seed production, zero resistant progeny) and is effective resistance weed management.

7. Spray small annual weeds. Generally, small weeds (<3 inches) are more susceptible to herbicides than large weeds. Even weeds with low level herbicide resistance are more susceptible at 1 inch than at larger growth stages.

8. Practice Zero Tolerance. Scout fields after row closure and kill uncontrolled weeds. Seed from escaped weeds will contribute to the weed seedbank and will require diversified weed management strategies of mowing, cultivation/tillage, and hand weeding to achieve near 100% weed control. Timely cultivation can improve weed control and handpulling is effective for single plants or small patches.

9. Control weeds in field perimeters, drown out, and non-crop area. Weeds surviving a partial herbicide dose on field borders can be a repository for the introduction of resistant weeds into a field. Control weeds in all areas of the field where crop is not growing including field edges, fence lines, water-ways, ditch banks, and areas where crop has either not been planted or has been destroyed.

10. Rotate herbicides with different mechanisms of action in consecutive years. Diverse crop rotations can introduce herbicides with different mechanisms of action to delay herbicide resistance. A mix of dead plants, unaffected plants, and plants showing intermediate responses indicate herbicide resistance has occurred.

11. Clean tillage and harvest equipment to ensure weed seed will not be transported between fields. This is particularly important in crops that are harvested with a platform header equipped combine.

12. Evaluate weed management at the end of each season and revise to improve weed control the next year.

For more information:
1. Documented herbicide resistant weeds, herbicide resistance education, and herbicide mode of action see:
http://wssa.net/weed/resistance/

2. Take Action web site is an industry-wide partnership between university weed scientists, major herbicide providers and corn, cotton, sorghum, soybean, and wheat commodity organizations for effective weed management information and tools.
http://takeactiononweeds.com/

Take Action app for choosing herbicides with different sites of action:
http://takeactiononweeds.com/understanding-herbicides/site-of-action-lookup/mobile/

X1. Herbicide Site of Action and Chemical Family for Resistant Weed Management

Site 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.	Wolverine Advanced.
	fluazifop-P	Fusilade DX.	-
	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.
ALS Enzyme Inhibitor (2) Imidazolinone "Imi"	imazamethabenz	Assert.	-
	imazamox	Beyond = Clearcast = Raptor.	Varisto
	imazapic	Cadre = Impose = Plateau.	Journey.
	imazapyr	Arsenal = Habitat.	Sahara.
	imazethapyr	Pursuit = Thunder.	Authority Assist, Extreme=Thunder Master, Lightning, Matador, Militia, Pummel, Op-Till, Torment, Zidua Pro.
Sulfonylurea "SU"	chlorimuron	Classic.	Enlite, Valor XLT.
	chlorsulfuron	Glean = Report = Telar.	Chism, Cimarron Max/X-tra, Perspective, Report Extra.
	halosulfuron	Halomax = Herbivore = Permit = Sandea.	-
	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, Travallas.
	nicosulfuron	Accent	Revulin Q
	rimsulfuron	Matrix = Resolve = Rule.	Alluvex, Instigate, Prequel, Realm Q, Require Q, Resolve Q, Steadfast Q.
	sulfometuron	Oust.	-
	sulfosulfuron	Certainty (turf), Maverick.	-
	thifensulfuron	Harass = Harmony = Treaty = Volta.	Accurate Extra, Agility, Affinity BS/TM, Afforia, Alluvex, Ally Extra, Basis, Harmony Extra, Nimble, Rapport BS/TM, Resolve Q, Semprallas, Travallas, Treaty Extra.
	tribenuron	Express = Nuance = Victory.	Accurate Extra, Afforia, Affinity/Edition/Rapport BS/TM, Agility, Ally Extra, Harmony Extra, Nimble, Supremacy.
	triflusulfuron	UpBeet.	-
Triazolopyrimidine "TPS"	cloransulam	FirstRate.	Authority First=Sonic, FrontRow, Gangster=Surveil.
	florasulam	-	GoldSky, Orion, Starane Flex, Quelex.
	flumetsulam	Python.	Hornet, SureStart II, TripleFlex II.
	pyroxsulam	PowerFlex HL, Teammate.	GoldSky. PerfectMatch.
Sulfonylamino-carbonyltriazolinone "SACT"	flucarbazone	Everest 2.0, Pre-Pare, Sierra.	Raze.
	propoxycarbazone	Olympus.	Rimfire Max.
	thiencarbazone	Varro	Autumn Super, 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 amine/ester	2,4-D, others.	See bromoxynil. Crossbow, Curtail, Grazone P+D = Gun Slinger, Landmaster BW = Campaign = Credit Master, Starane+Salvo, Weedmaster.
	2,4-D-choline	-	Enlist Duo
	MCPA amine	MCPA Amine, Rhomene, others.	-
	MCPA ester	Daggar, MCPA E, Rhonox, Sword, Wildcard.	ClearMax, CurtailM, HatTrick, Orion, Starane+Sword, Weld
Benzoic acids	dicamba acid	Vision	Latigo
	-bapma salt	Engenia	-
	-dma salt	Banvel = Dicamba = Oracle = Rifle.	-
	-dga salt	Clarity = Sterling Blue, DiFlexx, XtendiMax.	DiFlexx Duo, Roundup Xtend
	-Na salt	Banvel SGF.	Agility, Distinct=Overdrive, Require Q, Status, Yukon.
	-ipa salt	Vision.	Fallow Master = Fallow Star.
	-dea salt	-	Weedmaster = Banvel + 2,4-D = Brash = Outlaw = Range Star = Rifle D.
Pyridine	aminopyralid	Milestone.	Capstone, Chaparral, CleanWave.
	clopyralid	Clean Slate, Clopyr Ag = Garrison = Spur = Stinger = Reclaim = Transline.	Curtail/M = Redeem. WideMatch = Colt, Hat Trick, Hornet, PerfectMatch, Resicore, SureStart, TripleFlex.
	fluroxypyr	Starane = Comet = Trump Card = Vista. Starane Ultra = Obtain = Vista XRT.	Axial Star, Colt+Salvo/Sword, GoldSky, Hat Trick, PerfectMatch, Raze, Supremacy, Starane Flex/ NXT, Semprallas, Travallas, WideMatch = Colt, Weld.
	picloram	Tordon 22K = Triumph 22K.	Grazone P+D = Gun Slinger, Surmount, Trooper Extra/Pro.
	triclopyr	Garlon = Remedy. Pathfinder II, Tricera.	PastureGard, Redeem, Vengence Plus.
Arylpicolinate	halauxifen	Elevore	Quelex
Pyrimidine	aminocyclopyrachlor	Method	Perspective, Steamline, Viewpoint.
Quinoline	quinclorac (dicots)	Facet=Quinstar=Quinclorac=.	-

Site 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	Dimetric = Glory = Metribuzin = Sencor = TriCor	Authority MTZ, Boundary=Tailwind, Matador, Ransom.
Phenyl-carbamate	des/phenmedphm	Alphanex = Betanex.	Betamix
Photosystem II Inhibitor (6) - Site B	bentazon	Basagran.	Galaxy, Laddok S-12, Rezult, Storm, Varisto.
	bromoxynil	BroClean = Bromox = Brox = Buctril = Moxy.	Huskie/Complete, Talinor, Wolverine Advanced.
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 SB.	-
	EPTC	Eptam = Eptek = Eradicane = Razencane.	Imperium.
Thiocarbamate	triallate	Far-Go.	Buckle.
Benzofuran	ethofumesate	Nortron = Ethofumesate = Ethotron.	Progress.
EPSP Synthase Inhibitor (9)	glyphosate-ipa, K, dma, mea, $(NH_4)_2$	Roundup, several generics - see page 71.	Enlist, Extreme, Fallow Master, Landmaster BW, Roundup Extend, others.
Glutamine Synthetase Inhibitor (10)	glufosinate	Finale, Liberty, Rely.	-
Bleaching: DOXP Synthase Inhib. (13)	clomazone	Command	Command Xtra, Commence.
PPO (Protox) Inhibitor (14)	acifluorfen	Ultra Blazer.	Galaxy, Storm.
	fomesafen	Fomesafen, Flexstar=Rumble, Reflex=TopGun.	Flexstar GT 3.5, Marvel, Prefix=Vice.
Diphenylether	lactofen	Cobra, Phoenix.	Stellar.
	oxyfluorfen	Goal = Collide.	-
Imine	fluthiacet	Cadet.	Anthem/Max, Marvel.
N-phenylphthalimide	flumiclorac	Resource.	-
	flumioxazin	Valor=Brdstar=Chateau=Encompass=Outflank= Panther = Payload = Suregard = Tuscany.	Afforia, Fierce, Gangster=Surveil, , Enlite, Militia, Ransom. -
Oxadiazole	oxadiargyl	Raft, Topstar.	-
Phenylpyrazole	pyraflufen	ET, Vida.	-
Pyrimidinedione	saflufenacil	Sharpen.	Op-Till, Verdict, Zidua Pro.
Triazolinone	carfentrazone	Aim = Quicksilver.	Spartan Charge/Elite.
	sulfentrazone	Spartan = Blanket = Crossing = Portfolio.	Authority Assist/Elite/MTZ/First, BroadAxe, Spartan Charge
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, Resicore, SureStart=TripleFlex. -
	alachlor	Alachlor, Lasso, others.	-
Acetamide	dimethenamid-P	Outlook = Commit = Establish = Propel.	Armezon Pro, Commit, Establish, Verdict.
	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=Tailwind, BroadAxeXL, Prefix=Vice, Sequence.
	S-meto + safener	Dual II Magnum, Brawl II, Cinch.	Acuron/Flexi, Bicep, Brawl, Charger, Cinch, Halex GT, Lumax.
Isoxazoline	pyroxasulfone	Zidua.	Anthem/Max/ATZ, Fierce, Zidua Pro
Auxin Inhibitor (19)	diflufenzopyr	-	Status.
Photosystem I Inhibitor (22)	diquat	Reglone = Diquat E-Ag.	-
	paraquat	Firestorm, Gramoxone SL, Parazone.	-
Unknown (26)	quinclorac (grass)	Facet.	-
Bleaching: HPPD Inhibition(27)	mesotrione	Callisto = Tenacity.	Acuron/Flexi, Callisto/GT/Xtra, Halex GT, Instigate, Lumax EZ, Realm Q, Resicore, Revulin Q.
Triketone	tembotrione	Laudis.	Capreno, DiFlexx Duo.
-	bicyclopyrone	-	Acuron/Flexi, Talinor
Isoxazole	isoxaflutole	Balance Flexx.	Corvus, Prequel.
Pyrazolone	pyrasulfotole	-	Huskie/Complete, Wolverine Advanced.
	topramezone	Impact = Armezon.	Armezon Pro.
-	tolpyralate	-	-
Cellulose Inhib. (29)	indaziflam	Alion	-
Tyrosine Aminotransferase inhibition. (30)	cinmethylin	-	-
	methiozolin	-	-

Cold, Hard STEEL (31): Plow, cultivator, rotary-hoe, etc.

Adapted from WSSA Herbicide Classification System For Resistant Weed Management. Weed Technol. 17:606-608.
Contact herbicides = Groups 5, 6, 10, 14, and 22.