# 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. 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 108-109.**

**- 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, 7):** kochia.
**- 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

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

**- ALS inhibitor (2):** Yellow foxtail, giant foxtail, lambsquarters, sunflower, P Amaranth, cocklebur, 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, R. Thistle, horseweed, ragweed, Palmer Amaranth, waterhemp, and lambsquarters (suspected)
- **Glutamine synthetase (10) (glufosinate):** Italian ryegrass.
- **PPO inhibitor (14):** Palmer amaranth, ragweed and waterhemp.
- **Very Long Chain Fatty Acid Inhibitor (15)**: waterhemp and Palmer amaranth
- **HPPD inhibitor (27):** P amaranth and waterhemp.

**Multiple Resistance:**

Waterhemp - Group 2 + 4 + 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.
Palmer amaranth: Group 2 + 3 + 5 + 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 areas.** 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, waterways, 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/

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

| Site of Action | Common Name | Herbicide Trade name | Premix or Co-pack Trade names |
|---|---|---|---|
| **ACCase Inhibitor (1)** | clodinafop-P | Discover NG. | - |
| | fenoxaprop-P | Puma = Tacoma = Parity. | Wolverine Advanced. |
| Aryloxyphenoxy | fluazifop-P | Fusilade DX. | - |
| propionic acid "Fop" | quizalofop | Assure II = Targa. | - |
| | clethodim | Select/Max = Volunteer = Intensity. Arrow, Clethodim, Section, Select Max, Shadow, Tapout, Vaquero. | - |
| Cyclohexanedione "Dim" | sethoxydim | Poast. | - |
| Phenylpyrazolin "Den" | pinoxaden | Axial XL. | Axial Star, Axial Bold |
| **ALS Inhibitor (2)** | imazamethabenz | Assert. | - |
| | imazamox | Beyond = Clearcast = Raptor. | Varisto |
| Imidazolinone | imazapic | Cadre = Impose = Plateau. | Journey. |
| "Imi" | imazapyr | Arsenal = Habitat. | Sahara. |
| | imazethapyr | Pursuit = Thunder. | Authority Assist, Extreme=Thunder Master, Lightning, Matador, Pummel, Torment, Zidua Pro. |
| Sulfonylurea | chlorimuron | Classic. | Enlite, Valor XLT. |
| "SU" | chlorsulfuron | Glean = Telar. | Cimarron Max/X-tra, Perspective, Report Extra. |
| | halosulfuron | Halomax = Herbivore = Permit = Sandea. | - |
| | mesosulfuron | Osprey. | Rimfire Max. |
| | metsulfuron | Ally=Escort=Patriot=Plotter=Rometsol. | Accurate Extra, Ally Extra, Chaparral, Cimarron Max, Cimarron X-tra, Finesse, Report Extra, Travallas. |
| | nicosulfuron | Accent | Revulin Q |
| | rimsulfuron | Matrix = Resolve. | Alluvex, Instigate, Prequel, Realm Q, Require Q, Resolve Q, Steadfast Q. |
| | sulfometuron | Oust. | - |
| | sulfosulfuron | Certainty (turf), Outrider. | - |
| | thifensulfuron | Harmony = Treaty = Volta. | Accurate Extra, Agility, Affinity BS/TM, Afforia, Alluvex, Ally Extra, Basis, Harmony Extra, Nimble, Rapport BS/TM, Resolve Q, Sentrallas, Travallas, Treaty Extra. |
| | tribenuron | Express = Nuance = Victory. | Accurate Extra, Afforia, Affinity/Rapport BS/TM, Agility, Ally Extra, Harmony Extra, Nimble, Supremacy. |
| | triflusulfuron | UpBeet. | - |
| Triazolopyrimidine | cloransulam | FirstRate. | Authority First=Sonic, Surveil. |
| "TPS" | florasulam | - | GoldSky, Orion, Starane Flex, Quelex. |
| | flumetsulam | Python. | Hornet, SureStart II, TripleFlex II. |
| | pyroxsulam | PowerFlex HL, Teammate. | GoldSky, OpenSky, PerfectMatch. |
| Sulfonylamino-carbonyltriazolinone "SACT" | flucarbazone | Everest 3.0, Pre-Pare, Sierra. | |
| | propoxycarbazone | Olympus. | Rimfire Max. |
| | thiencarbazone | Varro | Autumn Super, Capreno, Corvus, Huskie Complete. |
| **Mitotic Inhibitor (3)** | ethalfluralin | Sonalan. | - |
| Dinitroaniline (DNA) | pendimethalin | Prowl/H20 = Acumen. | - |
| | trifluralin | Trifluralin = Treflan = Triflurex = Trust/others. | Buckle. |
| **Growth Regulators (4)** | 2,4-D amine/ester | 2,4-D, others. | See bromoxynil. Crossbow, Curtail, Grazon P+D = Gun Slinger, Landmaster BW, Weedmaster. |
| Phenoxy | 2,4-D-choline | - | Enlist Duo |
| | MCPA amine | MCPA Amine, Rhomene, others. | - |
| | MCPA ester | MCPA E, Rhonox, Sword, Wildcard. | CurtailM, Hat Trick, Orion, Weld |
| Benzoic acid | dicamba acid | Vision | Latigo |
| | -bapma salt | Engenia | - |
| | -dma salt | Banvel = Dicamba = 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 Star. |
| | -dea salt | - | Weedmaster = Banvel + 2,4-D = Brash = Outlaw = Range Star = Rifle D. |
| Pyridine | aminopyralid | Milestone. | Capstone, Chaparral, CleanWave. |
| | clopyralid | Clean Slate, Spur = Stinger = Reclaim = Transline. | Curtail/M , WideMatch = Colt, Hat Trick, Hornet, PerfectMatch, Resicore, SureStart, TripleFlex. |
| | fluroxypyr | Starane = Comet. Starane Ultra = Vista XRT. | Axial Star, Colt+Salvo/Sword, Gold/OpenSky, Hat Trick, PerfectMatch, Supremacy, Starane Flex/ NXT, Colt, Sentrallas, Travallas, Trump Card = WideMatch = Weld. |
| | picloram | Tordon 22K = Triumph 22K. | Grazon P+D = GunSlinger, Surmount, Trooper Extra/Pro. |
| | triclopyr | Garlon = Remedy. Pathfinder II. | PastureGard, Vengeance Plus. |
| Arylpicolinate | halauxifen | Elevore | Quelex |
| Pyrimidine | aminocyclopyrachlor | Method | Perspective, Streamline, Viewpoint. |
| Quinoline | quinclorac (dicots) | Facet=Quinstar=Quinclorac | - |

| Site of Action | Common Name | Herbicide Trade name | Premix or Co-pack Trade names |
|---|---|---|---|
| **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. | |
| Triazinone | metribuzin | Dimetric = Glory = Metribuzin = Sencor = TriCor | Authority MTZ, Boundary=Tailwind, Matador. |
| Phenyl-carbamate | des/phenmedphm | | Betamix |
| **Photosystem II Inhibitor (6) - Site B** | bentazon | Basagran. | Storm, Varisto. |
| | bromoxynil | BroClean = Brox = Buctril = Moxy. | Huskie/Complete, Talinor, Wolverine Advanced, Carnivore. |
| **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. | - |
| Thiocarbamate | EPTC | Eptam. | Imperium. |
| | triallate | Far-Go. | Buckle. |
| Benzofuran | ethofumesate | Nortron = Ethofumesate 4SC = Ethotron. | |
| **EPSP Synthase Inhibitor (9)** | glyphosate-ipa, K, dma, mea, $(NH_4)_2$ | Roundup, several generics - see page 71. | Enlist Duo, Extreme, Landmaster BW, Roundup Xtend, others. |
| **Glutamine Synthet-ase Inhibitor (10)** | glufosinate | Finale, Liberty, Rely. | - |
| **Bleaching: DOXP Synthase Inhib. (13)** | clomazone | Command | |
| **PPO (Protox) Inhibitor (14)** | acifluorfen | Ultra Blazer. | Storm. |
| Diphenylether | fomesafen | Fomesafen, Flexstar=Rumble, Reflex=TopGun. | Flexstar GT 3.5, Marvel, Prefix=Vice. |
| | 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 = Tuscany. | Afforia, Fierce, Surveil, Enlite. - |
| Oxadiazole | oxadiargyl | Raft, Topstar. | - |
| Phenylpyrazole | pyraflufen | ET, Vida. | - |
| Pyrimidinedione | saflufenacil | Sharpen. | Verdict, Zidua Pro. |
| Triazolinone | carfentrazone | Aim = Quicksilver. | Spartan Charge, Anthem Flex |
| | sulfentrazone | Spartan = Blanket = Portfolio. | Authority Assist/Elite/MTZ/First/Supreme, BroadAxe XC, Spartan Charge |
| **Very Long Chain Fatty Acid Inhibitor (15)** | acetochlor | Harness = Confidence. | Imperium, Breakfree ATZ Lite=Keystn LA=Volley ATZ Lite, Resicore, SureStart=TripleFlex. |
| | | Surpass = Breakfree = Volley. | - |
| | | Degree, TopNotch, Warrant. | - |
| | alachlor | Alachlor, Lasso, others. | |
| Acetamide | dimethenamid-P | Outlook = Commit = Establish. | Armezon Pro, Commit, Establish, Verdict. |
| | metolachlor | 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, BroadAxe XC, 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/Flex, Fierce, Zidua Pro |
| **Auxin Inhibitor (19)** | diflufenzopyr | - | Distinct, Overdrive, Status. |
| **Photosystem I Inhibitor (22)** | diquat | Reglone = Diquat. | - |
| | 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, ImpactZ |
| - | tolpyralate | - | - |
| **Cellulose Inhib. (29)** | indaziflam | Alion | - |
| **Fatty Acid Thioesterase. (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. | | | |

# HERBICIDE CARRYOVER

**Y1.** Herbicide persistence into the next growing season may restrict rotational crops. The following information discusses herbicide degradation for some chemistries known to carryover.

General Rules For Herbicide Breakdown

1. Many herbicides are broken down in soil by microbial decomposition. In addition, SUs and triazines are broken down by chemical reactions like acid hydrolysis.
2. Herbicide molecules must be free from binding to soil particles or organic matter for soil microorganisms to degrade.
3. Most herbicide molecules are more tightly adsorbed to soil particles in dry soils than moist soils.
4. Chemical degradation of herbicides in soil is affected by soil pH. Acid hydrolysis nearly ceases at soil pH above 6.8.

**Effect of pH on Herbicide Activity and Persistence**

Negative charges (-) on soil particles and organic matter adsorb positive-charged (+) compounds or substances. Soil pH influences adsorption and availability of the following herbicides by determining the electrical charge of the herbicide molecules: Imidazolinones, SUs, Triazines, and Triazolopyrimidines (TPS).

Molecules become (-) charged when a proton is removed or become (+) charged when a proton is added. Most herbicides become (+) charged in acid (H+) pH conditions. Positively charged herbicide molecules are adsorbed to the (-) charges on soil particles soil particles.

**Y2. Breakdown of Imidazolinone (Imi), TPS Herbicides, and some HPPD herbicides (Callisto).**

In general, breakdown occurs by soil microbes and **breakdown occurs more rapidly and herbicide activity increases as soil pH increases.** Rate of breakdown decreases in dry conditions. Imi and TPS herbicides are:

1. Broken down by microbes - not broken down by hydrolysis.
2. Not degraded in anaerobic (waterlogged soil) conditions.
3. Not volatile, not photodegraded, not leached beyond 12 inches.
5. Weakly bound to soil but strongly bound to OM.
6. Adsorbed more strongly as soil dries and through time.

Imi herbicides molecules adsorb to OM in dry soil but can desorb and go into soil solution in wet/moist soil allowing molecules to become free for plant uptake and microbial breakdown. For sensitive crops like sugarbeet, the adsorption and desorption process may occur over several years causing crop injury from herbicide residues that become available after moisture events.

7. Negatively (-) charged, not adsorbed, and free for plant uptake and microbial degradation at soil pH >6.5 for Imi herbicides and pH >7 for TPS herbicides.
8. Strongly bound to OM at pH <6.5 for Imi herbicides and pH <7 for TPS herbicides. For Imi herbicides: Amount adsorbed changes little from 6.5 to 8. At soil pH <6.5, pH reduction as small as 0.2 pH units can **DOUBLE** the amount adsorbed.

Large variation in pH can exist in the same field. In low pH, residues of Imi herbicides can injure sensitive plants for many years.

In summary, activity and degradation of Imi and TPS herbicides increase as soil pH increases. Herbicide adsorption increases as OM matter increases and as soil pH decreases. All factors increasing microbial activity also increase herbicide degradation (warm, moist soils). Degradation increases in soils with pH above 6.5 (Imi) or 7 (TPS) because herbicide molecules are not adsorbed and are in soil solution for plant uptake and microbial breakdown.

**Y3. Breakdown of SU Herbicides (with exceptions):**

In general, most SU herbicides are broken down by acid hydrolysis and can leave a residue in soil for more than one year. The chemical reaction ceases at soil pH above 6.8.

**Exceptions:** Express*, Harmony*, Option, and UpBeet are rapidly broken down by soil mirobes. Pemit and Resolve*/Matrix* are broken down faster by hydrolysis as pH moves above and below pH of 7.0. Herbicide breakdown is slowest in neutral soil pH of 7.0.

Most SU herbicides are:

1. Not leached, nor volatile, nor broken down by photodegradation.
2. Affected by pH. Water solubility increases as pH increases.
3. Broken down primarily by acid hydrolysis. Microbial degradation is very slow.
4. Non-microbial hydrolysis for most residual SU herbicides ceases at soil pH above 6.8.
5. SU herbicides are undissociated (neutral charge) at pH less than 7.0 and are adsorbed to soil and OM. As soil pH increases above 7.0 molecules are (-) charged, are in a free form, do not bind with (-) charged soil particles, and are are available for plant uptake. **Even at low pH ranges, SU herbicides are so biologically active at low concentrations that plant response may still occur.**

SU herbicides carryover more in high pH soils (above 6.8) because acid hydrolysis ceases above that level. Hydrolysis is minimally affected by soil moisture, organic matter, soil texture, soil microbes, and soil compaction or aeration. Hydrolysis is affected by soil temperature and soil pH. As temperature increases and pH decreases below 6.8, hydrolysis increases.

**Y4. Breakdown of Triazine Herbicides**

Triazines are degraded by hydrolysis similar to SU herbicides. Therefore, the same factors affecting SU breakdown also affect breakdown of triazine herbicides - See Y3. Some slight differences are noted below. Triazine herbicides are:

1. More active in high pH soils.
2. Broken down by photodegradation only when herbicide remains on soil surface for extended periods.

Triazine molecules are (+) charged at soil pH < 7.5. Positive charged triazine molecules bind to (-) charges on soil and OM making them unavailable for plant uptake and microbial breakdown. This is why pH sensitive herbicides like atrazine and Sencor* can be used with less risk of crop injury in low pH soils. However, as pH fluctuates across the field, herbicide availability may be radically altered ranging from complete crop safety and erratic weed control at low pH to crop injury and adequate weed control at high pH.

At high soil pH, the opposite reaction occurs. At soil pH > 7.5, triazine herbicide molecules donate protons ($H^+$) resulting in ($H + OH = H_2O$) so the molecules have a net neutral charge, which do not bind to soil particles and OM, and are free for plant uptake and microbial decomposition.

**Y5.** Persistence of phytotoxic levels of a herbicide for more than 1 year can be a problem with some herbicides. Herbicide residues are most likely to occur following years with low rainfall because chemical and microbial activity needed to degrade herbicides are limited in dry soil. Crop damage from herbicide residues can be minimized by applying the lowest herbicide rate required for good weed control, by using band rather than broadcast applications, and by moldboard plowing before planting the next crop. Moldboard plowing reduces phytotoxicity of some herbicides by diluting the herbicide residue in a large volume of soil. Moldboard plowing is effective in reducing the residual effects of atrazine, Nortron, Prowl, Sencor*, Sonalan, and Treflan*.

*Or generic equivalent.

**Y6.** Herbicide residues often can be detected by bioassay. Representative soil samples of the whole field are obtained by sampling many places to the depth of the tillage layer. A soil sample free of herbicide residues can serve as the untreated check. The samples should be dried and the clods broken so that the largest particles are no larger than a wheat kernel. Prepare two or more samples of untreated check soil and the test soil in pots or other containers with holes in the bottom for water drainage.

The crop to be grown in the field should be used as one bioassay species. Alfalfa and canola also should be planted as an additional bioassay species because of their relative sensitivity to many residual herbicides. Plant seeds of large-seeded crops like corn or soybean at 1 seed per 1 to 2 square inches, or seeds of small-seeded crops like cereals or flax at about 1 seed/sq inch. Water as needed but do not over-water. Thin plant stands when seedlings are 2 to 3 inches tall to allow sufficient space for adequate growth. Position containers in direct sunlight and maintain temperature at 70 to 75 F. Observe the plants 2 to 3 weeks after emergence. Record visible and physical measurements such as plant height and leaf length for abnormalities.

Symptoms of some herbicides like atrazine and metribuzin do not develop until 2 to 3 weeks after emergence. Observe roots of plants grown in root inhibiting herbicides, such as dinitroanilines. Window bioassay does not provide accurate information for ALS herbicide carryover.

**Field Bioassay Instructions:** Plant several strips of desired crops across the field perpendicular to the direction the suspect herbicide was applied. Strips should be spaced to represent different field conditions (texture, pH, and drainage). If no visible signs of injury, stand reduction, or yield reduction occur, then the field can be seeded with the desired crop the next growing season. Do not plant if injury occurs and the bioassay must be repeated the next growing season to determine the safety of the crop to existing residues.

**Y7. Atrazine*** at rates over 0.38 lb ai/A generally has residue the year following application to corn in North Dakota. If soil moisture is deficient, atrazine may cause injury to susceptible crops the following year. Corn and millet are tolerant to atrazine while other crops vary in susceptibility. The approximate ranking of crops from most to least tolerant is corn, sorghum, millet, flax, soybean, barley, wheat, oat, sunflower, canola/mustard, alfalfa, and sugarbeet.

**Y8. Balance Flexx** (isoxaflutole) may have a residue the following year. Breakdown is primarily by microbial activity. Risk of Balance carryover increases as precipitation occurring during the growing season decreases. Balance becomes more active as soil texture becomes more coarse and organic matter decreases.

**Y9. Dicamba** at rates greater than 1.5 pt/A may remain as a residue in soil. Most grass and broadleaf crops can be planted 4 months or more after application at 1 pt/A. Refer to specific dicamba label for crop rotation restrictions . The approximate ranking of crops from most to least tolerant is corn, barley, wheat, oat, flax, potato, buckwheat, soybean, dry edible bean, sunflower, and sugarbeet.

*Or generic equivalent.

**Y10. Flexstar/Reflex** (fomesafen) at 0.75 to 1 pt/A may have a residue the year following application to soybean, dry bean, or potato. Most crops can be planted the next growing season except canola, crambe, flax, safflower, sugarbeet, and sunflower. Fomesafen is weakly adsorbed by OM but mobility and amount available for plant uptake increases as soil pH increases above 6.5. Degradation is through soil microbes and under anaerobic conditions. Conditions that inhibit microbial activity also reduce fomesafen breakdown. Cold or dry conditions after application reduce rate of breakdown. Northern production areas, like ND, have a shorter growing season and the soil temperature is colder for longer periods of time, which limits breakdown. Late applications in beans decreases the amount of time that breakdown can occur.

Ways to reduce risk of fomesafen carryover include lower application rates, banded herbicide applications, and tillage to dilute herbicide residues. The approximate ranking of non-labeled crops from most to least tolerant is cereals, potato, oil-seed rape/canola, field corn, sunflower, sugarbeet, sorghum, and alfalfa.

**Y11.** Metribuzin* may not have residue the following year at 0.25 lb ai/A, but rates over 0.5 lb ai/A may damage susceptible crops the next year. The approximate ranking of crops from most to least tolerant is potato, soybean, dry edible bean, corn, barley, wheat, oat, sunflower, flax, and sugarbeet.

**Y12. Nortron*** (ethofumesate) often has a residue the year following use on sugarbeet. The approximate ranking of crops from most to least tolerant is sunflower, dry beans, soybean, corn, barley, and wheat. Moldboard plowing usually will eliminate crop injury. Nortron should be applied in a band to reduce cost and reduce potential crop injury from residues the following year.

**Y13. Sonalan** (ethalfluralin), **Prowl/Prowl $H_20$** (pendimethalin), and **Treflan*** (trifluralin) are similar herbicides called dinitroanilines. Under dry soil conditions these herbicides can persist in soil for more than 1 year. Sonalan has less soil residue than Treflan* and Prowl. Land treated with Sonalan in the spring may be planted to any crop the next year except sugarbeet. Sunflower, soybean, potato, and dry edible bean are quite tolerant of dinitroaniline herbicides. The approximate ranking of other crops from most to least tolerant is soybean, flax, alfalfa, barley, wheat, corn, oat, and sugarbeet.

**Y14. Spartan** (sulfentrazone) residue may remain in soil the following season. Most grass and broadleaf crops can be planted the following year except canola, crambe, lentil, and sugarbeet. Spartan is degraded by soil microbes, is not affected by sunlight, and is not volatile. Precipitation after PRE application activates the herbicide by moving it into the soil where microbial degradation can oocur. Spartan solubility increases as soil pH increases above 6.5, as soil texture changes from fine to coarse, and as OM decreases. As Spartan solubility increases availability for plant uptake increases, weed control increases, and risk of crop injury increases. The approximate ranking of crops from most to least tolerant is soybean, flax, chickpea, mint, sunflower, potato, field pea, dry edible beans, safflower, crambe, canola, lentil, and sugarbeet.

*Or generic equivalent.

## Y15. Crop Rotation Restrictions for North Dakota

| Herbicide | Alf-alfa | Bar-ley | Can-ola | Corn | CRP grss | Dry bean | Field pea | Flax | Oat | Edibl Leg.[1] | Pot-ato | Saff lowr | Soy-bean | Sgr-beet | Sun-flwr | HRS/ Drm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | months after application (d = days) | | | | | | | | | | | | | | | |
| **Acuron/Flexi** | 18/10 | 4 | 18 | 0 | 18 | 18 | 18 | 18 | 10 | 18 | 10 | 18 | 10 | 18 | 18 | 4 |
| **Ally Extra** (e) (0.3 oz/A) | 22e | 10 | 22 | 22 | 6 | 22e | 22e | 22 | 10 | 22e | 22 | 10 | 22 | 22b | 10 | 1/10 |
| **Anthem/Max** | 10 | 11 | 18 | 0 | 18 | 11 | 6-8 | 18 | 11 | 6-8[1] | 4 | 18 | 0 | 15 | 4 | 4 |
| **Anthem Flex** (r) | 10 | 11 | 18 | 0 | 18 | 11 | 6 | 18 | 11 | 6 | 4 | 18 | 0 | 12 | 4 | 1 |
| **Armezon/Pro** | 9 | 3/4n | 9 | 0 | 18 | 9n | 9 | 18 | 3/4n | 18 | 9 | 18 | 9 | 18 | 9 | 3/4n |
| Atrazine* (0.38 lb ai) | NCS | NCS | NCS | 0 | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | 10 | NCSb | NCS | NCS |
| (0.38-0.5 lb ai) | 2CS | NCS | 2CS | 0 | 2CS | 2CS | 2CS | NCS | 2CS | 2CS | NCS | 2CS | 10 | 2CSb | 2CS | 2CS |
| (0.5-1 lb ai) | 2CS | 2CS | 2CS | 0 | 2CS | 2CS | 2CS | 2CS | 2CS | 2CS | 2CS | 2CS | 10 | 2CSb | 2CS | 2CS |
| **Authority Assist** | 12 | 9.5 | 40b | 10 | 12 | 4 | 4 | 26 | 18 | 4/12[1] | 26 | 18 | 0 | 40b | 18 | 4 |
| **Authority Elite** | 12 | 4.5 | 12 | 10 | 12 | 0 | 0 | 12 | 12 | 0/12[1] | 4 | 12 | 0 | 36b | 0 | 4.5 |
| **Authority First/Sonic** | 12 | 12 | 24 | 10 | 30b | 12 | 12 | 30b | 12 | 30b | 18 | 30b | 0 | 30b | 30b | 4 |
| **Authority MTZ** | 12 | 4 | 24 | 10 | 12 | 12 | 18 | 18 | 18 | 18 | 12 | 18 | 0 | 24b | 12 | 4 |
| **Authority Supreme** (r) | 12 | 11 | 24 | 10 | 18 | 9 | 0 | 0 | 12 | 9 | 4 | 18 | 0 | 24 | 0 | 4 |
| **Autumn Super** (i) | 18 | 9j | 18 | 1 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 2 | 24 | 18 | 3 |
| **Balance Flexx** (j) | 10 | 6 | 18 | 0 | 18 | 18 | 18 | 18 | 6 | 18 | 6 | 6 | 6 | 18 | 10 | 6 |
| **Banvel*** (0.5 lb ai) | NCS | 3d/oz | NCS | NCS | 0h | NCS | NCS | NCS | 3d/oz | NCS | NCS | NCS | 45 d | NCS | NCS | 3d/oz |
| (>0.5 lb ai) | NCS | NCS | NCS | NCS | 0h | NCS | NCS | NCS | NCS | NCS | NCS | NCS | 90 d | NCS | NCS | 3d/oz |
| **Beyond** | 9 | 18t | 18 | 8.5 | 9 | 0 | 0 | 18 | 9 | 9 | 18t | 18 | 0 | 18t | 9 | 3 |
| **Boundary** | 4.5 | 8 | 12 | 4 | 12 | 12 | 8 | 12 | 12 | 12 | 0 | 12 | 0 | 18 | 12 | 8 |
| **BroadAxe XC** | 12 | 4.5 | 12 | 10 | 12 | 12 | 0 | 12 | 12 | 0/12[1] | 4 | 12 | 0 | 36b | 0 | 4.5 |
| **Capreno** (i) | 18 | 10 | 18 | 0 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 10 | 18 | 18 | 4 |
| **Callisto/GT** | 10 | 4 | 10 | 0 | 18 | 18 | 10g | 0 | 0 | 18 | 10 | 18 | 10 | 18 | 10 | 4 |
| **Callisto Xtra** | NCS | NCS | NCS | 0 | 18 | 18 | 18g | NCS | 18 | 18 | NCS | 18 | NCS | 18 | NCS | NCS |
| **Clarity*** (0.5 lb ai) | 4 | 22 d | 4 | 4 | 0h | 4 | 4 | 4 | 22 d | 4 | 4 | 4 | 4 | 4 | 4 | 22 d |
| (>0.5 lb ai) | 6 | 44 d | 6 | 6 | 0h | 6 | 6 | 6 | 44 d | 6 | 6 | 6 | 6 | 6 | 6 | 44 d |
| **Corvus** (i) | 17 | 9 | 17 | 0 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 9 | 17 | 17 | 4 |
| **Curtail*/M*** | 10.5m | 1 | 5 | 1 | 1 | 10.5m | 18 | 5 | 1 | 18 | 18 | 10.5m | 10.5m | 5 | 10.5m | 1 |
| **DiFlexx Duo** | 10 | 4 | 10 | 0 | 4 | 10 | 10 | 18 | 18 | 18 | 10 | 18 | 6 | 10 | 10 | 4 |
| **Everest*** soil pH: <8/>8 | 11/18 | 9 | 9 | 11 | NCS | 9 | 11/18 | 9 | 18/24 | 11/24a | 9 | 9 | 9 | 9 | 4 | 0 |
| **Extreme** | 4 | 18 | 40b | 8.5 | 4 | 4 | 4 | 26 | 18 | 4 | 26 | 18 | 0 | 40b | 18 | 0/4 |
| **Facet L** | 24b | 10 | 10 | 10 | 10 | 24b | 24b | 24b | 10 | 24b | 24b | 24b | 10 | 24b | 10 | 0 |
| **Far-Go** | NCS | 0 | NCS | NCS | NCS | NCS | NCS | NCS | 18 | NCS | NCS | NCS | NCS | NCS | NCS | 0 |
| **Fierce** | 10 | 11 | 18 | 7d/1 | 18 | 11 | 6 | 18 | 11 | 11 | 4 | 18 | 0 | 15 | 4 | 1 |
| **FirstRate** | 9 | 12 | 18 | 9 | 18 | 9 | 9 | 18 | 9 | 18 | 18 | 18 | 0 | 30b | 30b | 4 |
| **Flexstar/GT 3.5** | 18 | 4/9a | 18 | 10/18a | 18 | 0 | 12 | 18 | 4/9a | 12 | 0 | 18 | 0 | 18 | 18 | 4/9a |
| **Halex GT** | 10 | 4.5 | 12 | 0 | 18 | 18 | 10g | 12 | 4.5 | 18 | 10 | 18 | 10 | 18 | 10 | 4.5 |
| **Harness*** | 9 | NCS | NCS | 0 | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | 4 |
| **Huskie** | 4c | 0.25 | 9 | 9 | B | 9 | 9 | 9 | 0.25 | 9/18[1] | 9 | 9 | 4 | 9 | 9 | 0.25 |
| **Huskie Complete** | 9c | 9 | 9 | 9 | 18b | 9 | 9 | 9 | 9 | 9/18[1] | 18b | 18b | 9 | 9 | 9 | 3 |
| **Impact** | 9 | 3 | 9 | 0 | 18 | 18n | 18n | 9 | 3 | 18 | 9 | 18 | 9 | 18 | 9 | 3 |
| **Instigate** | 18 | 18 | 18 | 0 | 18 | 18 | 18 | 10 | 18 | 18 | 10 | 18 | 10 | 18 | 10 | 9 |
| **Laudis** | 10 | 4 | 10 | 0 | 18 | 10g | 10 | 18 | 4 | 18 | 10 | 18 | 8 | 10g | 10 | 4 |
| **Liberty 280** | 6 | 2.33 | 0 | 0 | 2.33 | 6 | 6 | 6 | 2.33 | 6 | 2.33 | 6 | 0 | 0 | 6 | 2.33 |
| **Lumax EZ (<3 pt/A)** | 18 | 4.5 | 18 | 0 | 18 | 18 | 18 | 18 | NCS | 18 | 18 | 18 | NCS | 18 | 18 | NCS |
| **Marvel** | 18 | 4 | 18 | 10 | 18 | 0 | 10 | 18 | 4 | 18 | 0 | 18 | 0 | 18 | 18 | 4 |
| **Matrix*** | 12 | 9/18p | 18 | 0 | 18 | 10 | 18 | 18 | 9 | 18 | 0 | 18 | 4 | 18 | 10 | 9 |
| Metribuzin* (u) | 4 | 8u | 12 | 4 | 4 | 12 | 8 | 12 | 12 | 8 | 12 | 12 | 4 | 18 | 12 | 8u |
| **Milestone** (b) | 36b | B | 24b | 12b | B | B | B | B | B | B | B | B | B | B | B | B |

| Herbicide | Alf-alfa | Bar-ley | Can-ola | Corn | CRP grss | Dry bean | Field pea | Flax | Oat | Edibl Leg.[1] | Pot-ato | Saff lowr | Soy-bean | Sgr-beet | Sun-flwr | HRS/ Drm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ---------- months after application (d = days) ---------- | | | | | | | | | | | | | | | |
| **Nortron*** | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 0 | 12 | 12 |
| **Olympus** (0.2-0.4 oz) | B | 10 | 10 | 10 | 10 | 10 | 10 | B | 24 | 10 | B | B | 10 | 10 | 10 | 0/9 |
| **Osprey** | 10 | 1 | 10 | 12 | 10 | 3 | 3 | 10 | 10 | 10/3[1] | 10 | 10 | 3 | 10 | 1 | 0.25 |
| **PerfectMatch** | 10.5 | 9 | 9 | 9 | 9 | 10.5 | 10.5 | 9 | 9 | 18 | 18 | 10.5 | 10.5 | 9 | 10.5 | 1 |
| **Permit*** | 9 | 2 | 15 | 1 | 2 | 9 | 9 | B | 2 | 9 | 9 | B | 9 | 36 | 18 | 2 |
| **Plateau** | 36 | 24 | 48b | 36 | 0 | 36 | 36 | 36 | 24 | 36 | 48b | 36 | 18 | 48b | 36 | 12 |
| **PowerFlex HL** | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 5 | 9 | 9 | 1 |
| **PrePare** | NCS | 9 | 9 | NCS | NCS | 9 | 11 | 9 | 18 | 24 | 9 | 9 | 9 | 9 | 9 | 0/4 |
| **Prequel** | 10j | 9 | 18 | 0 | 18 | 18j | 18 | 18 | 9 | 18 | 6 | 18 | 10 | 18j | 18 | 9 |
| **Prowl EC / H2O** | NCS | NCS | NCS | 0s | NCS | 0 | 0 | NCS | NCS | 0 | 0 | NCS | 0 | 2CS | 0 | NCS |
| **Pursuit** | 4 | 18 | 40b | 8.5 | 4 | 4 | 4 | 26 | 18 | 4 | 26 | 18 | 0 | 40b | 18 | 4 |
| **Quelex** | 9 | 0 | 9 | 3 | 3 | 9 | 9 | 9 | 3 | 9/15 | 15 | 9 | 3 | 15 | 3 | 0 |
| **Raptor** | 9 | 18t | 18 | 8.5 | 9 | 0 | 0 | 18 | 9 | 9 | 18t | 18 | 0 | 18t | 9 | 3 |
| **Realm Q** | 18 | 9 | 18 | 0 | 18 | 18 | 18 | 10 | 9 | 18 | 10 | 18 | 10 | 18 | 10 | 9 |
| **Reflex** | 18 | 4 | 18 | 10 | 18 | 0 | 12 | 18 | 4 | 12 | 0 | 18 | 0 | 18 | 18 | 4 |
| **Require Q/Resolve Q** | 18 | 9 | 18 | 0 | 18 | 10 | 10 | 10 | 9 | 18 | 0 | 18 | 10 | 18 | 10 | 9 |
| **Resicore** | 10.5 | 10.5 | 18 | 0 | 18 | 18 | 18 | 18 | 10.5 | 18 | 18 | 18 | 10.5 | 18 | 10.5 | 4 |
| **Revulin Q** | 18 | 10 | 10 | 0 | 18 | 18 | 18 | 10 | 10 | 18 | 10 | 18 | 10 | 18 | 10 | 10 |
| Rimsulfuron*(1ozDF/A) | 10j | 9 | 10j | 0 | 18 | 10 | 18 | 18 | 9 | 18 | 0 | 18 | 10 | 10j | 10 | 9 |
| **Sharpen** (1 fl oz) (v) | 4 | 0 | 4 | 0 | 4 | 4 | 0 | 4 | 0 | 0/1[1] | 4 | 4 | 0-1 | 4 | 4 | 0 |
| (2 fl oz) (v) | 5 | 0 | 5 | 0 | 5 | 5 | 0 | 5 | 0 | 0/2[1] | 5 | 5 | 1-2 | 5 | 5 | 0 |
| (3 fl oz) (v) | 6 | 0 | 6 | 0 | 6 | 6 | 2 | 6 | 0 | 2/3[1] | 6 | 6 | 2-3 | 6 | 6 | 0 |
| **Solstice** | 10 | 4 | 10 | 0 | 18 | 18 | 10g | 0 | 0 | 18 | 10 | 18 | 10 | 18 | 10 | 4 |
| **Sonalan** | NCS | NCS | 0 | NCS | 13w | 0 | 0 | NCS | NCS | 0 | NCS | NCS | 0 | 2CS | 0 | NCS |
| **Spartan Charge** | 12 | 4 | 24 | 4 | 12 | 0 | 0 | 0 | 12 | 0/12[1] | 4 | 12 | 0 | 24b | 0 | 4 |
| **Spartan Elite** | 12 | 4.5 | 12 | 10 | 12 | 0 | 0 | 12 | 12 | 0/12[1] | 4 | 12 | 0 | 36b | 0 | 4.5 |
| **Starane Flex** | 9 | 0 | 9 | 3 | 0 | 9 | 9 | 9 | 0 | 9 | 9 | 9 | 9 | 9 | 9 | 0 |
| **Status** (h) | 4 | 4 | 4 | 0.25 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 1 |
| **Stinger*** | 10.5 | 0 | 0 | 0 | 0 | 10.5m | 18 | 0 | 0 | 18 | 18 | 10.5m | 10.5m | 0 | 10.5m | 0 |
| **SureStart II** | 18 | NCS | 26b | 0 | 26b | 12/18 | NCS | 26b | NCS | NCS | 18 | 26b | NCSj | 26b | 18 | 4 |
| Surpass* | 9 | NCS | NCS | 0 | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | NCS | 4 |
| **Surveil** | 12 | B | B | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 18 | B | 0 | 30b | 30b | 3 |
| **Talinor** (a) | 9 | 1 | 9 | 0 | 18 | 9/15a | 10 | 9 | 3 | 15 | 9 | 18 | 10 | 15 | 9 | 1 |
| **Tordon** (1.5 oz) | 2CS | NCS | 2CS | 2CSx | 1 | 2CS | 2CS | NCS | NCS | 2CS | 2CS | 2CS | 2CS | 2CS | 2CS | NCS |
| **Travallas** (e) | 22 | 1day | 12 | 12 | B | 22 | 12 | 12 | B | 22 | B | B | 12 | B | 12 | 1day |
| **Treflan*** (y) | 0 | NCS | 0 | NCS | 18/21 | 0 | 0 | 0 | 18 | 0 | 0 | 0 | 0 | 2CS | 0 | NCS |
| **TripleFlex II** | 18 | NCS | 26b | 0 | 26b | 12/18 | NCS | 26b | NCS | NCS | 18 | 26b | NCSj | 26b | 18 | 4 |
| **Valor / Chateau** | | | | | | | See page 6 | | | | | | | | | |
| **Varisto** | 9 | 18t | 18 | 8.5 | 9 | 0 | 9 | 18 | 9 | 9 | 18t | 18 | 0 | 18t | 9 | 3 |
| **Varro** | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 18b | 9 | 3 | 9 | 9 | 3 |
| **WideMatch*** | 10.5 | 0 | 4 | 0 | 0 | 10.5 | 10.5z | 4 | 0 | 18 | 18 | 10.5 | 10.5 | 0 | 10.5 | 0 |
| **Wolverine Advanced** | 4c | 1 | 9 | 9 | B | 9 | 9 | 9 | 1 | 9/18[1] | 9 | 9 | 4 | 9 | 9 | 1 |
| **Zidua** | | | | | | | See page 6 | | | | | | | | | |
| **Zidua Pro** | 10 | 18 | 40b | 8.5 | 40 | 11 | 6 | 26 | 18 | 6 | 26 | 18 | 0 | 40b | 18 | 4 |

*Or generic equivalent.

[1] Edible legumes = chickpea (garbanzo bean)/lentil.

**NCS** = Next cropping season after herbicide application.

**2CS** = Second cropping season after herbicide application.

**MAA** = months after application.

**Herbicides that allow most crops to be planted the year following application:**
2,4-D, 2,4-DB, acetochlor, Affinity, Afforia, Aim, Alluvex, Axial, Basagran, Betamix, Buctril, Cadet, Cobra, Discover, diquat, Dual, DiFlexx, Engenia, Enlist Duo, Eptam, Express, glyphosate, GoldSky, Harmony, LeadOff, Liberty, Linuron*, MCPA, OpenSky, Orion, Outlook, paraquat, POST grass herbicides, PowerFlex, Resource, Ro-Neet, Sentrallas, Sharpen, Starane/NXT, Status, Storm, Supremacy, Teammate, Ultra Blazer, UpBeet, Verdict (v), Vida, Warrant, Xtendimax.

**Field Bioassay Instructions** - Refer to label or paragraph Y6 in the narrative section.

**a** Refer to label - restrictions may be adjusted based on herbicide rate, rainfall, tillage, soil type, soil pH, bioassay, and ND 24(c) labels.

**B or b** = Bioassay. Do not plant until field bioassay indicates it is safe. Crop rotation after atrazine* is rate and soil pH dependent.
Python, Hornet, and SureStart/TripleFlex = 26 month rotation + successful field bioassay.
FirstRate = 30 month rotation + successful field bioassay. Pursuit = 40 month rotation + successful field bioassay.

**c** Requires thorough tillage and 12 inches of rain.

**d** days

**e** These rotation intervals apply only to 0.3 oz/A. Dry pea, dry bean, lentil, and alfalfa can be planted after 10 months if soil pH is 6.8 or lower, or 22 months if soil pH is 6.9 to 7.9. Canola, corn, flax, soybean, and potato require 22 months and 18 inches precipitation. Above soil pH 7.9, soil bioassay must be performed.

**g** Cumulative precipitation between application and planting of rotational crops is 20 inches. Soil pH >6. No HPPD herbicide applied the previous year. For Laudis only: Cumulative precipitation of 20 inches. 10 MAA rotation interval applies to all dry bean types except red kidney and cranberry (18 MAA). Thorough tillage must precede planting of sugarbeet.

**h** Any rotational crop may be planted 120 days following application of dicamba at 1.5 pt/A or less, excluding days when ground is frozen. For all crops and rates greater than 1.5 pt/A allow 45 days per 1 pt/A of dicamba used excluding days when ground is frozen.

**i** Crops with a 9 or 10 month rotation restriction require 15 inches of cumulative precipitation after application. Crops with an 17 or 18 month rotation restriction require 30 inches of cumulative precipitation after application. Soil at 7.5 pH or above require crop rotation to be extended from 9 or 10 months to 17 or 18 months and from 17 or 18 months to 24 months.

**j** Requires 15 inches of cumulative precipitation during the growing season following application. An 18 month restriction applies to Prequel and rimsulfuron* applied above rates indicated or if drought follows application. Refer to label if higher rates are used.

**m** Do not plant dry bean, dry pea, soybean or sunflower for 18 months on soil with less than 2% OM and rainfall less than 15 inches during the 12 MAA OR may be planted 12 MAA if risk of injury is acceptable. Perform a field bioassay prior to planting for areas that receive less than 15 inches of rainfall and have less than 2% OM. Do not plant lentil, potato or any other broadleaf crop grown for seed for 18 months unless risk of injury is acceptable.

**n** Alfalfa, canola, dry pea, dry bean, potato, soybean, and sunflower can be planted 9 months after applying Armezon Pro at 20 fl oz/A or less or Armezon at 0.74 fl oz or less. Small grains can be planted 3 months after applying Armezon and 4 months after Armezon Pro.

**p** Barley can be planted 9 months after application in Cass, Grand Forks, Pembina, Towner, Traill, and Walsh counties of ND.
In all other counties of ND allow an 18 month rotation restriction before planting barley.

**r** Rotation interval is dependent on rate.

**s** Corn can be planted only if Prowl*/H20 are applied PRE. DO NOT APPLY PPI.

**t** Rotation to barley is: 9 months if (>18 inches water + >6.2 soil pH) or (moldboard plow with <18 inches water or <6.2 soil pH) or 18 months if (<18 inches water or soil pH <6.2).
Rotation to potato is: 9 months: soil pH >6.2 and rainfall is >18 inches/year or 18 months: soil pH <6.2 and rainfall is <18 inches/year
Rotation to sugarbeet: 18 months: soil pH >6.2 or 26 months if soil pH is <6.2.

**u** Must add 2 months if soil pH is 7.5 or above. Wheat and barley can be planted 4 MAA following dry pea, lentil or soybean.

**v** Do not include time when soil is frozen. Sunflower and safflower are the most sensitive crops.
For Verdict: Fall seeded cereals can be planted 4 months after application. All crops can be planted the spring following application.

**w** CRP grasses may be planted 13 MAA but a field bioassay must be performed prior to planting CRP grasses. The manufacturer assumes no liability for injury. Fall is recommended as the best time to plant CRP grasses.

**x** Do not plant corn or sorghum until soil samples analyzed for Tordon residue indicates no detectable levels present.
Restriction is based on non-legal herbicide residue that may be found in corn and sorghum and not on crop safety.

**y** Oats, sorghum, and annual or perennial grass crops may be planted at least 12 MAA in areas that received 20 inches or more of precipitation during the growing season. CRP grasses may be planted 18 MAA if Treflan* is spring-applied or 21 MAA if fall-applied.

**z** For rotation to field pea in 10.5 months, precipitation must be greater than 7 inches during the 10.5 months following application and greater than 5.5 inches of precipitation from June 1 to August 31 following application. Otherwise allow 18 months.

*Or generic equivalent.

**Y16. Herbicide residue and fall cover crop establishment.**

Late summer/ fall-seeded cover crops promote soil health, protect water quality, and enhance wildlife habitat. Cover crop response to spring-applied herbicides is limited but crop tolerance research is ongoing at several academic institutions. Herbicides labels may be expanded to consider soil residue effects on establishment of cover crops. Refer to pages 108 to 112 for current data base. Use rotational restrictions of common crops or herbicide effectiveness on common weeds with close relatives of fall seeded cover-crops:
- Use alfalfa for other legumes/pulse species.
- Use canola/mustard for Cruciferae species: radishes and turnips.
- Use small grains and wild oat for other grass species.

Greater flexibility is provided where the cover crops is only used for conservation practices. However, the grower assumes all risk if the herbicide interferes with the establishment of the cover crop. Consider soil type, soil pH, and precipitation patterns on herbicide degradation. In general, herbicides with crop rotation restrictions of 4 months or less should be safe to most cover crops as they have half-lives of 30 days or less. This information was adapted from information developed by Dr. Bill Curran and Dr. Dwight Lingenfelter, Pennsylvania State University.

Residues may accumulate in cover crops that may be fed to animals as forage and consumed by humans. Follow rotational restriction on labels when planting cover crops that may be grazed or harvested for forage to avoid illegal residues.

**Herbicide rate, half-life values, and comments.**

| Herbicide | Rate/A | Half-lives (days[1]) | Comments |
|---|---|---|---|
| 2,4-D | 0.5 to 1 pt | 7 | Allow 30 days prior to planting broadleaf crops. |
| Dicamba | 0.5 to 1 pt | 5 to 14 | Allow 45 days/pt as a general rule for dicamba degradation. |
| Dual II Magnum | 1 to 2 pt | 15 to 50 | Ryegrass may be more susceptible than other crops. |
| Flexstar | 0.75 to 1 pt | 100 | Small-seeded legume and brassica crops may be more susceptible than other crops. |
| Glyphosate | 32 to 48 fl oz | 47 | - |
| Liberty | 22 to 36 fl oz | 7 | - |
| Spartan | 4.5 to 12 fl oz | 36 | Small-seeded legume and brassica crops may be more susceptible than other crops. |
| Valor | 2 to 3 oz | 12-18 | Small-seeded legume and brassica crops may be more susceptible than other crops. |

[1] Note: In general, herbicides with half-lives of 30 days or less should allow planting of cover crops after 4 months. Estimates derived from the WSSA Herbicide Handbook, 2014.

Risk of cover crop injury based on highest damage recorded at 5 ND locations in 2016-2017.

| Herbicide* | Radish | Turnip | Field pea | Lentil | Flax | Oat | Barley | Dwarf Essex Rape |
|---|---|---|---|---|---|---|---|---|
| Dicamba | MR | ~~HR~~ | LR | MR | MR | LR | MR | MR |
| Everest | MR | MR | LR | MR | LR | LR | LR | MR |
| Goldsky | MR | MR | LR | LR | MR | LR | LR | LR |
| Huskie | LR | LR | LR | LR | MR | LR | LR | MR |
| PowerFlex | LR | LR | LR | MR | MR | LR | LR | MR |
| Quelex | MR | MR | LR | LR | LR | LR | LR | LR |
| Supremacy | LR | LR | LR | LR | LR | LR | LR | LR |
| Varro | MR | LR | LR | LR | LR | LR | MR | LR |
| WideMatch | MR | MR | HR | ~~HR~~ | LR | LR | LR | MR |
| 2,4-D | MR | LR | LR | LR | LR | LR | LR | MR |

* or generic herbicide.
Key: LR - low risk - 0 to 20% injury, MR - medium risk = 21 to 50% injury, HR - high risk = 51 to 100 injury, Strike through = severe injury. Products were chosen due to known residual activity. Other products may be safe for cover crops. This list is not all-inclusive. Most instances of medium or high risk were observed in only one environment. Most combinations were LR in most environments. High OM, high rainfall, tillage, low pH, and other factors will reduce the risk of herbicide carryover to cover crops. If cover crops will be grazed or harvested in some way (including haying), refer to label regarding grazing restrictions.

Reference for additional information include:
'Herbicide Rotation Restrictions in Forage and Cover Cropping Systems'
http://wcws.cals.wisc.edu/new-fact-sheet-herbicide-rotation-restrictions-in-forage-and-cover-cropping-systems/
by the University of Wisconsin, June, 2014. It contains tables summarizing rotation restriction intervals in months along with specific restrictions for forages grown after commonly used herbicide applications in small grains, soybean, and corn.

'Herbicide Use May Restrict Grazing Options for Cover Crops'
https://store.extension.iastate.edu/Product/Herbicide-use-may-restrict-grazing-options-for-cover-crops
by Iowa State University Extension, December, 2016.

**Y17. Herbicide residue analysis for soil, water, and plant tissue.**

| The following list shows laboratories that can analyze for herbicide residues: |
|---|
| A & L Great Lakes Lab<br>3505 Conestoga Drive, Fort Wayne, IN 46808<br>219-483-4759, http://www.algreatlakes.com |
| AgSource Harris Laboratories<br>300 Speedway Circle, Lincoln, NE 68502<br>402-476-0300, http://www.agsource.com |
| Agvise Laboratories<br>PO Box 510, 604 Hwy 15, Northwood, ND 58267<br>701-587-6010, www.agviselabs.com<br>902 13th St N, Benson, MN 56215, 320-843-4109 |
| APT Labs Inc.<br>1050 Spring St., Reading, PA 19610<br>610 375-3888, www.aptlabsinc.com |
| Carbon Dynamics Institute, LLC<br>2835 Via Verde Dr, Springfield, IL 62703-4325<br>217-585-8340 Specialize Group 4 residue analysis |
| Columbia Food Laboratories, Inc.<br>12423 NE Whitaker Way<br>Portland, OR 97230<br>503-695-2287, www.columbiafoodlab.com/<br>info@columbiafoodlab.com (Can test plant tissue). |
| Hazelton Environmental Services<br>525 Science Drive, Madison, WI 53711<br>608-232-3300 |
| Midwest Laboratories<br>13611 B Street, Omaha, NE 68144<br>402-334-7770, www.midwestlabs.com |
| Minnesota Valley Testing Laboratories, Inc.<br>Iowa, Minnesota, North Dakota<br>800-782-3557, www.mvtl.com |
| Montana State Analytical Laboratory<br>McCall Hall, PO Box 173620<br>Montana State University, Bozeman, MT 59717<br>406 994-3383, Heidi Hickes |
| SGS Brookings<br>Rose Neal, Agricultural Services, Analytical Scientist<br>241 34th Ave, Brookings, SD 57006<br>605-692-7611 x294<br>rose.neal@ sgs.com www.sgs.com/agriculture |
| South Dakota Agriculture Laboratories, Brookings Biospace<br>Dr. Regina Wixon, regina.wixon@sdaglabs.com<br>1006 32nd Ave #103 / #105, Brookings, SD 57006-4728<br>605-692-7325, www.sdaglabs.com |

1. Contact a lab from Y17
2. Contact the lab to determine:
 - quantity of plant material needed testing
 - plant tissue collection and packaging instructions
 - if the lab can test for the suspect herbicide
 - testing for more than one herbicide will cost additional money
3. Collect plant tissue samples <2 weeks after the drift event
4. Collect samples from actively growing parts of the plant (i.e. for soybeans, collect the top 2-3 nodes)
5. Collect plant samples from the field which has not been injured. It may be difficult to determine meaningful conclusions from a tissue test without a sample taken from non-injured plants.
To avoid contamination collect non-injured plant samples first followed by plant samples from damaged areas. Collecting additional samples from the field in areas between the injured and non-injured parts can be beneficial but cost prohibitive for residue analysis.
6. Send plant samples to the lab as quickly as possible for testing or freeze samples quickly after sampling to prevent plant tissue and herbicide degradation. Follow instructions from laboratory.
7. Herbicide residue analysis results will come back as a concentration in leaf tissue, either ppm or ppb. The number have little meaning without a check to compare to (see #5).
8. The residue analysis results only support evidence of chemical injury. Tissue tests alone are not strong evidence of causality.
9. Grain can also be sent for herbicide analysis. Similar procedures should be used including the use of a 'untreated/check' sample that is herbicide free.
10. Significantly higher concentrations of herbicide than uninjured plant samples indicates damage. If similar concentrations may mean no herbicide damage but visual symptoms (and yield damage) may still indicate otherwise.

**Susceptibility of crops to soil residue - most to least tolerant:**
**Chlorimuron**: soybean > wheat > oat > corn > sorghum > sunflower > alfalfa > canola > sugarbeet.

**Clomazone**: soybean > corn > sorghum = sunflower > alfalfa = wheat = oat.

**Dinitroaniline:** soybean > alfalfa > wheat > corn > sorghum > oat > annual rye.

**Imazethapyr**: soybean > alfalfa > corn > wheat > oat > sunflower > sorghum > canola > sugarbeet.

**Atrazine**: corn > sorghum > millet > flax > soybean > barley > wheat > oat > sunflower > canola/mustard > alfalfa> sugarbeet.

**Amount of herbicide active ingredient from a postemergence application to cause injury:**
Glyphosate on soybean = 10% of x rate (0.75 lb ae/A)
Glyphosate on corn = 1% of x rate (0.75 lb ae/A)
Dicamba on soybean = 0.005% of x rate (0.5 lb ae/A)
Dicamba on soybean: Residue levels of dicamba in soybean tissue does not predict yield loss because of environmental factors, stage of growth at time of exposure, continued metabolism of dicamba in soybean plants, and exudation of dicamba from roots into soil. Soybean tissue may show no dicamba residue in plants tissue if not collected soon after exposure. Soybean plants exposed to dicamba and glyphosate at or near reproductive stages will cause more damage and risk of yield loss than exposure during the vegetative growth. Soybean injury and yield loss will be greater under drought stress conditions.

**Collecting tissue samples and interpreting residue test results.**

**Herbicide residue levels in soil to cause injury.**

| Herbicide | Crop | ppm | ppb |
|---|---|---|---|
| Atrazine | Alfalfa<br>Sugarbeet<br>Soybean<br>Oat<br>Wheat | 0.04-0.1<br><0.005<br>0.15-0.25<br>0.06-0.15<br>0.075-0.18 | 40-100<br><5<br>150-250<br>60-150<br>75-180 |
| | | 3 inch sample (No-till) | 6 inch sample (moldboard plow) |
| | Alfalfa/Oat<br>Corn<br>Soybean | <0.17 ppm<br>>0.35 ppm<br>0.17-0.35 ppm | <0.08 ppm<br>>0.17<br>0.08-0.17 ppm |
| Classic | Corn<br>Wheat | 0.001-0.002<br>0.002-0.005 | 1-2<br>2-5 |
| Command | Corn<br>Alfalfa/Wheat | 0.05-0.2<br>0.015-0.1 | 50-200<br>15-100 |
| Dinitroanil ine | Corn<br>Sugarbeet<br>Wheat | 0.1-0.2<br>0.05-0.1<br>0.2-0.3 | 100-200<br>50-100<br>200-300 |
| Pursuit | Corn<br>Sorghum<br>Sugarbeet | <0.01-0.03<br>0.004-0.015<br><0.001 | 10-30<br>4-15<br><1 |

1 ppm = 1,000 ppb.
*Safe values for herbicide residues differ by soil type and pH because of differences in availability in soil. Low-range values are for coarse textured soils with low levels of organic matter, higher values are for fine textured soils with high organic matter.

**Dicamba residue levels in plant tissue and visual injury symptoms to cause seed yield loss.**

| Herbicide | Crop | ppm | ppb | Injury | Yield loss |
|---|---|---|---|---|---|
| Dicamba | Dry bean<br>Field pea | 0.03-0.20<br>0.02-0.03 | 30-200<br>20-30 | 20-35%<br>10-25% | >=25%<br>>= 6% |

Data is from one herbicide exposure and is not representative of multiple exposures. The higher values of concentration and visible injury represent dicamba applied alone. Dicamba applied with glyphosate can cause visible injury and reduced yield at lower concentrations in the rate range listed. Residue levels will be greater the closer plant foliage is sampled to the exposure event. Residue levels do not predict yield loss because of environmental factors, stage of growth at time of exposure, continued metabolism of dicamba, and possible exudation of dicamba. Dry bean plants exposed to dicamba at or near reproductive stages will cause more damage and risk of yield loss than exposure during the vegetative growth. Dicamba injury as dead growing points, aborted flowers, and empty or mis-figured pods will determine amount of yield loss. Visual injury is more predictive of yield loss than a tissue test. A tissue test can confirm if a herbicide active ingredient is present in plants rather than predict the extent of damage.

**Pinto bean response to low doses of dicamba, Carrington, ND, 2015-18.**

| Treatment[a] | | Plant | | Seed | |
|---|---|---|---|---|---|
| Herbicide | Rate | Biomass reduction[b] | Physiological maturity | Yield | Germination[c] |
| | lb ae/A | % | day of year | lb/A | % |
| untreated check | x | **0** | **243** | **2,300** | **87** |
| dicamba | 0.00044 | 19 | 256 | **1,970** | **86** |
| | 0.0044 | 31 | 271 | 1,280 | **67** |
| | 0.044 | 48 | 280 | 150 | 26 |
| LSD (0.05) | | 10 | 12 | 790 | 32 |

[a]Application at bud- to early bloom-stage plants. Rate as Xtendimax: 0.00044=0.019 fl oz/A; 0.0044=0.19 fl oz/A; 0.044=1.9 fl oz/A.
[b]Visually evaluated 21 days after treatment.
[c]Data from three site-years.

Glyphosate residue levels in plant tissue is not an accurate method to predict crop yield loss.

Dry bean plants exposed to glyphosate at or near reproductive stages will cause more damage and risk of yield loss than exposure during the vegetative growth. Damage to reproductive tissue will determine degree of yield loss.

**Pinto bean response to low doses of glyphosate, Carrington, ND, 2015-18.**

| Treatment[a] | | Plant | | Seed | |
|---|---|---|---|---|---|
| Herbicide | Rate | Biomass reduction[b] | Physiological maturity | Yield | Germination[c] |
| | lb ae/A | % | day of year | lb/A | % |
| untreated check | x | **0** | **243** | **2,300** | 87 |
| glyphosate | 0.00088 | **6** | **242** | **2,160** | 86 |
| | 0.0088 | 11 | **253** | **1,790** | 89 |
| | 0.088 | 32 | 279 | 860 | 57 |
| LSD (0.05) | | 10 | 12 | 790 | NS |

[a]Application at bud- to early bloom-stage plants. Rate as Roundup Powermax: 0.00088=0.025 fl oz/A; 0.0088=0.25 fl oz/A; 0.088=2.5 fl oz/A.
[b]Visually evaluated 21 days after application.
[c]Data from three site-years.

**Publications on Herbicide Injury Symptoms:**
W-1141 Herbicide and Nonherbicide Injury Symptoms on Spring Wheat and Barley, NDSU Extension Service.

A-1085 Herbicide Mode of Action and Sugarbeet Injury Symptoms
NDSU Extension Service

PNW-498 Herbicide Drift and Carryover Injury in Potatoes
Ag Publications, U of ID, 208 885-7982, ckink@uidaho.edu

**Web sites:**
Google:
Herbicide Mode of Action and Injury Symptoms (U of MN):
z.umn.edu/cropinjury
Herbicide Mode of Action Symptoms, U of WI
Dicamba Injury to Soybean, U of WI
Recognizing Residue and Drift Injury in Canola, Alberta Res. Council