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) ----------															
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.															
Acuron/Flexi	18/10	4	18	0	18	18	18	18	10	18	10	18	10	18	18	4
Ally Extra (e) (0.2 oz/A)	22	10	22	22	6	22	22	22	10	22	22	22	22	22b	22	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	10	11	18	0	18	11	6	18	11	6	4	18	0	12	4	1
Armezon/Pro (0.5 fl oz)	9	3	9	0	18	18n	18n	9	3	18	9	18	9	18	9	3
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
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
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

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/ Durm
	---------- (months after application) ----------															
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
Raze	NCS	9	9	NCS	NCS	9	11	9	18	24	9	9	9	9	9	0/4
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.

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 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.

k See label - 0.2 oz/A has less restrictive rotation restrictions than at higher rates. Requires 24 inches of accumulated precipitation.

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 Dry bean can be planted after 9 months at Armezon/Impact rates of 0.5 fl oz/A or less.
Dry pea can be planted after 9 months at Armezon/Impact rates of 0.75 fl oz/A or less.

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.

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 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 100 to 104 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.

'Managing risk when using herbicides and cover crops in corn and soybean'
http://www.extension.umn.edu/agriculture/weeds/herbicides/docs/cover-crops-and-herbicides.pdf
by University of Minnesota Extension, Spring, 2016.

'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
3505 Conestoga Drive, Fort Wayne, IN 46808
219-483-4759, http://www.algreatlakes.com

AgSource Harris Laboratories
300 Speedway Circle, Lincoln, NE 68502
402-476-0300, http://www.agsource.com

Agvise Laboratories
PO Box 510, 604 Hwy 15, Northwood, ND 58267
701-587-6010, www.agviselabs.com
902 13th St N, Benson, MN 56215, 320-843-4109

APT Labs Inc.
1050 Spring St., Reading, PA 19610
610 375-3888, www.aptlabsinc.com

Carbon Dynamics Institute, LLC
2835 Via Verde Dr, Springfield, IL 62703-4325
217-585-8340 Specialize Group 4 residue analysis

Columbia Food Laboratories, Inc.
12423 NE Whitaker Way
Portland, OR 97230
503-695-2287, www.columbiafoodlab.com/
info@columbiafoodlab.com (Can test plant tissue).

Hazelton Environmental Services
525 Science Drive, Madison, WI 53711
608-232-3300

Midwest Laboratories
13611 B Street, Omaha, NE 68144
402-334-7770, www.midwestlabs.com

Minnesota Valley Testing Laboratories, Inc.
Iowa, Minnesota, North Dakota
800-782-3557, www.mvtl.com

Montana State Analytical Laboratory
McCall Hall, PO Box 173620
Montana State University, Bozeman, MT 59717
406 994-3383, Heidi Hickes

SGS Brookings
Rose Neal, Agricultural Services, Analytical Scientist
241 34th Ave, Brookings, SD 57006
605-692-7611 x294
rose.neal@ sgs.com www.sgs.com/agriculture

South Dakota Agriculture Laboratories, Brookings Biospace
Dr. Regina Wixon, regina.wixon@sdaglabs.com
1006 32nd Ave #103 / #105, Brookings, SD 57006-4728
605-692-7325, www.sdaglabs.com

Collecting tissue samples and interpreting residue test results.

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.

Herbicide residue levels in soil to cause injury.

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

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

Glyphosate residue levels in plant tissue to cause injury.

Herbicide	Crop	ppm	ppb
Glyphosate	Dry bean	0.02-0.1	20-100

*Glyphosate exposure was at beginning bloom and measurements were taken 10 and 20 days after exposure. Residue levels do not predict dry bean yield loss because of environmental factors and stage of growth at time of exposure. 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. Residue levels will tend to be higher the closer plant foliage is sampled to the exposure event. Damage to reproductive tissue will determine degree of yield loss.

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