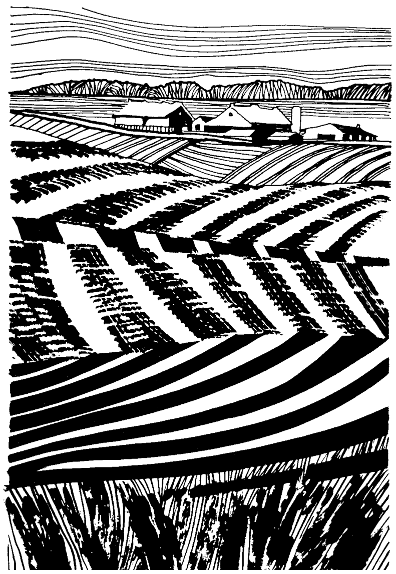
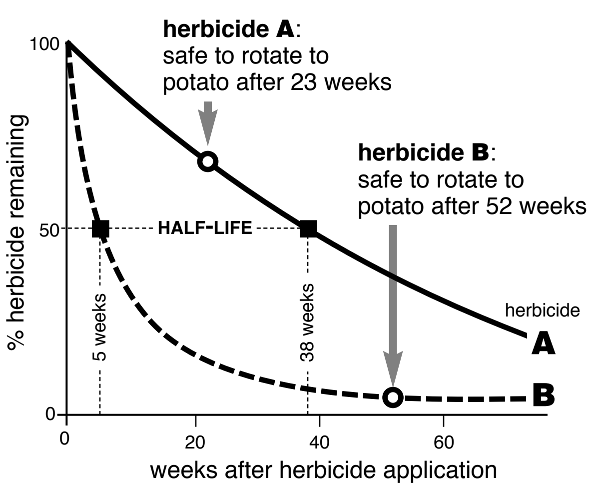


Herbicide persistence and carryover

Jed Colquhoun

Residual herbicides are those that continue to control weeds for some time after application. The use of residual herbicides such as Pursuit, Spartan, and Sinbar, is fairly common in some horticultural crops. Residual herbicides extend the period of weed control, increasing the efficiency of weed management efforts. However, they may persist longer than desired and injure or kill subsequent rotational crops. Most herbicide labels include crop rotation guidelines, but rotational restrictions are often not listed for many horticultural crops. Herbicide persistence, or the length of time a herbicide remains in the soil, varies greatly with climatic conditions, soil type, and cultural practices. It is important to distinguish between *herbicide persistence* and *herbicide activity*. Some herbicides persist for a long time in soil but are not available for plant uptake and therefore are not active as herbicides. Given the difficulty in predicting herbicide persistence, it is important to know the factors that lead to persistence. Incorporating these factors into crop planning can reduce herbicide injury risk.

Figure 1. Comparison of persistence and carryover of two herbicides



The life of a herbicide

Residual herbicide activity is often described in terms of the "half-life," or the amount of time required for dissipation of one half of the original amount of applied herbicide. The half-life varies by herbicide but can range from a few days to a few years. The herbicide half-life does not coincide very well with crop rotational restrictions for several reasons:

- **Rotational crop response varies greatly by herbicide and species susceptibility.** Some crops tolerate a particular herbicide residue and can be replanted soon after that herbicide is applied, while other crops remain sensitive to the herbicide for a longer time after application. Some herbicides can dissipate for many half-lives and still be injurious to certain crop species, while other herbicides persist longer but are less injurious to some crops. In the example in figure 1, herbicide "A" (with a half-life of 38 weeks) persists longer in the soil than herbicide "B" (with a half-life of 5 weeks). However, potatoes are much more sensitive to injury from herbicide "B" than herbicide "A," even after 10 half-lives.

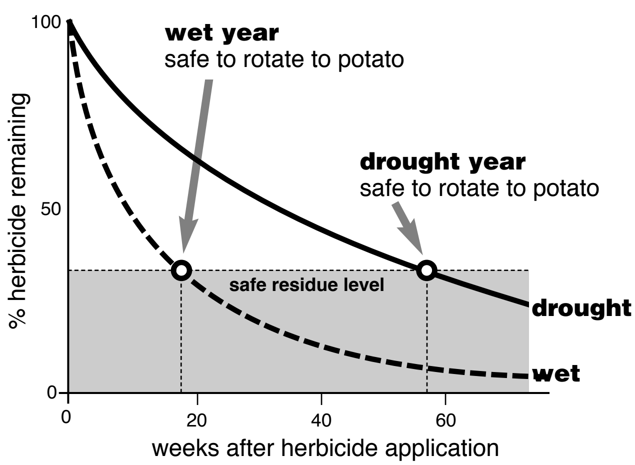
- **Herbicide half-life varies greatly with soil type, soil pH, climatic conditions, and cropping systems.** Half-lives are often determined in laboratory research and may not reflect all field conditions. Herbicide persistence is difficult to predict with climatic variation from year to year. In the example in figure 2, the same herbicide is applied in a wet year and a drought year. The herbicide half-life is 40 weeks longer in the drought year than in the wet year, delaying the earliest potential planting date without herbicide injury for potato.

Where do herbicides go after they leave the sprayer?

Herbicide fate plays an important role in persistence and potential carryover. Herbicides are ultimately subjected to one of three potential fates:

- **Herbicides are removed from the soil system.** Herbicides can leave the area where they were applied through any of several channels. Routes include being carried away in surface water runoff, leaching out of the area in soil water, volatilization from a solid or liquid to a gas that dissipates in the atmosphere, and uptake by plant roots or foliage.
- **Herbicides are adsorbed to soil particles.** Adsorption is the binding of chemicals to the surface of solids.
- **Herbicides are degraded into compounds that are inactive as herbicides.** Degradation is the breakdown of a herbicide by microbes, sunlight, or chemical reaction.

Figure 2. The effect of soil moisture on herbicide persistence. Herbicides persist much longer during dry years than during wet years.



Herbicides in the soil environment

Herbicides in soil typically exist in one of three phases:

- **Adsorbed to soil particles.** Adsorbed herbicides are "banked." They are not available for plant uptake, degradation, or movement from the soil environment (other than when the soil particle itself is moved, such as in surface water runoff).
- **In soil water solution.** Herbicides in soil solution are the most active: they are available for plant uptake, degradation, and movement.
- **In soil air spaces.** Herbicides in soil air are not common once a herbicide is incorporated in the soil.

Factors that affect herbicide persistence

Herbicide persistence is directly related to how quickly the product decomposes and its availability for plant uptake. Microbes, chemical reactions, and exposure to light affect decomposition, while soil adsorption and leaching in soil water determine availability. All of these factors vary greatly by soil type and pH, by climatic conditions between the time of herbicide application and re-cropping, and by cropping practices. Understanding the variables that determine persistence can reduce crop injury risk from herbicide carryover. Table 1 provides information about the relative persistence and important factors in persistence for common herbicides.

Factors that affect herbicide availability:

- **Soil adsorption.** Herbicides that are chemically bound, or adsorbed, to solids are not available for leaching, plant uptake, or microbial degradation. Such herbicides persist until they are released from the soil surface. Some herbicides, such as Gramoxone and Diquat, bind to soil so tightly that they persist nearly indefinitely and are not typically available for plant uptake.

  + Soil type is very important in determining potential adsorption. Soil organic matter and clay increase soil adsorption because of their chemical reactivity and high number of binding sites.

  + Soil water competes with herbicides for binding sites. As a result, wet soils adsorb less herbicide than dry soils.

  + Soil adsorption is greater in low pH soils as there are fewer positively charged particles to compete for the negatively charged binding sites.

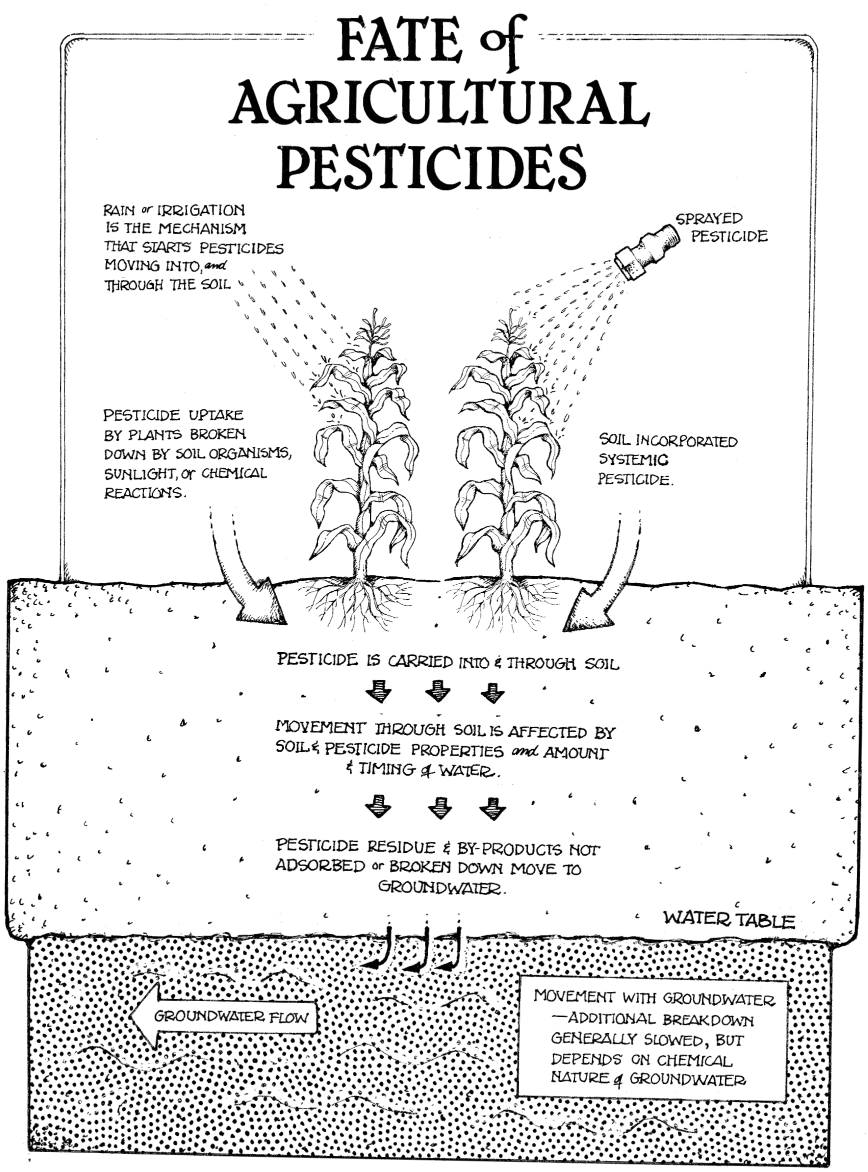
  + Herbicides that are highly soluble in water do not adsorb well to soil.

- **Herbicide leaching.** Herbicide leaching in soil water can move herbicides out of the tillage and root zone of subsequent crops. Herbicide leaching is greatest in coarse-textured soils with low levels of organic matter. Highly soluble herbicides are prone to leaching.

Factors that affect herbicide degradation:

- **Microbial decomposition.** The breakdown of herbicides by soil organisms known as microbes accounts for a large portion of herbicide degradation in soil. Certain bacteria, fungi, and algae use herbicides as a food source. Microbes are herbicide-specific, and their population in the soil is related to the amount of herbicide available for consumption. Repeated use of a herbicide can lead to increased microbe populations and a shorter duration of effective weed control. Conditions that support high microbe populations favor rapid herbicide degradation.

  + Soil type is important for microbe populations: soil organic matter provides excellent habitat for microbes.



+ The effect of soil pH on microbial degradation varies by microbe, but the extremes in pH are typically less favorable for high microbe populations.

+ Climatic conditions that favor optimum plant growth also favor microbial activity. Microbes are most active when soil moisture ranges from 50 to 100% of field capacity; when fields are flooded, microbial activity drops due to lack of oxygen. Similarly, microbes are most active in warm soils (with adequate moisture); when soil temperatures fall below about 40°F, microbial activity becomes negligible.

- **Chemical decomposition.** Chemical decomposition is important for some herbicides such as those in the sulfonylurea family (examples include Matrix, Sandea, and Accent). Most chemical decomposition occurs when herbicides react with soil water (a process called hydrolysis). The rate increases in soils with lower pH values and at warmer temperatures.
- **Photodecomposition.** Photodecomposition occurs when energy from the sun breaks down a herbicide. Only a limited number of herbicides, such as Treflan and Goal, are sensitive to sunlight. To prevent photodecomposition, soil applications of these herbicides are often incorporated.

Strategies to avoid herbicide carryover

- **Apply labeled rates and follow rotational restrictions.** Exceeding the rates listed on the label is illegal and can result in herbicide persistence. Crop rotational restrictions for a particular herbicide can vary by application rate and timing, geography, and soil type and pH, so be sure to read the label thoroughly. The rotational restrictions listed on the label are based on extensive field research. Some labels do not allow rotation to crops not listed on the label; others include many horticultural crops in the "all other crops" category. Be aware that persistent herbicides can lead to illegal residue levels in rotational crops even when the risk for visible crop injury is minimal. When tank-mixing herbicides, follow the crop rotation guidelines for the more restrictive label unless otherwise noted.
- **Keep future cropping plans in mind when planning herbicide programs.** Avoid the use of long-residual herbicides when including sensitive crops in the rotation.
- **Note climatic conditions from the time between herbicide application and the next crop.** Low moisture and temperature, in particular, can slow herbicide degradation and increase the risk for carryover.
- **Rotate herbicide mode of action to avoid buildup in soil.** Although rare, repeated use of the same herbicide, or even the same herbicide family, can lead to herbicide buildup in the soil.
- **Maintain healthy soil.** Soil conditions that are favorable for plant growth are also favorable for herbicide degradation. Maintain a moderate soil pH and organic matter for optimum herbicide degradation.

Strategies to reduce crop injury risk from herbicide carryover

These methods are not intended to supersede rotational restrictions on the pesticide label, but to reduce the risk of carryover.

- **Work the soil.** Thorough tillage will distribute residual herbicide evenly and dilute concentration, thus allowing maximum exposure to microorganisms and clay and organic matter that adsorb herbicides. Tillage can also reduce compaction and increase aerobic microorganism activity. Tillage will not solve all potential carryover issues, and in rare cases, can make the situation worse. For example, deep plowing can invert residual herbicides, concentrating the residue at soil depths that remain lower in temperature. The herbicide residue can then be brought back to the plant root zone with subsequent deep plowing, exposing future crops to potential carryover. It is essential to thoroughly distribute any herbicide residue in the soil.

- **Plant more tolerant crops.** If crop choice is flexible, consider planting a crop with a shorter rotational restriction in fields where environmental conditions may have extended the length of herbicide carryover.
- **Conduct a herbicide bioassay.** With a herbicide bioassay, crop seeds are grown in pots using soil from the field. This simple and economical test allows growers to screen for potential herbicide carryover. (A laboratory analysis, by contrast, is often very costly and the results are difficult to interpret in terms of rotational crop safety.) Bioassays are not fail-proof: climatic conditions in the field, such as available moisture, often differ from plants grown indoors in pots. Consider the following "recipe" when conducting herbicide bioassays.

Literature sources

Devlin, D., D. Peterson, and D. Regehr. 1992. *Residual Herbicides, Degradation, and Recropping Intervals*. Kansas State University Extension (Pub. C-707). Summary: Technical details of herbicide persistence and rotational information for agronomic crops.

Gunsolus, J.L. and W.S. Curran. 1999. *Herbicide Mode of Action and Injury Symptoms*. University of Minnesota (Pub. NCR377). Summary: Describes and shows damage from common herbicides.

Hanson, B., T. Rauch, and D. Thill. 2004. *Plantback Restrictions for Herbicides Used in the Dryland Wheat Production Areas of the Pacific Northwest*. Pacific Northwest Extension (Pub. 571). Summary: Crop rotation information for agronomic crops.

Miller, P. and P. Westra. 2004. *Herbicide Behavior in Soils*. Colorado State University Cooperative Extension Service (Pub. 0.562). Summary: Chemical characteristics of herbicide families.

Radosevich, S.R., J.S. Holt, and C. Ghersa. 1997. *Weed Ecology: Implications for Management*. New York, New York: J. Wiley. 589 p. Summary: General herbicide characteristics and behavior.

Vencill, W.K., ed. 2002. *Herbicide Handbook: Eighth Edition*. Lawrence, Kansas: Weed Science Society of America. 493 p. Summary: Reference for herbicide characteristics.

How to conduct a bioassay

1. Collect soil from the top 2 to 3 inches in several areas of the field and thoroughly mix samples. Sample from areas that may have high residual herbicide, such as in head-row turnarounds and field corners, and analyze these soils separately as a worst-case scenario. Representative, thorough sampling is critical to an accurate bioassay.
2. Fill several flower pots or similar containers with sample soil.
3. Plant the crop species that is planned for the field, or a crop that has a long rotational restriction listed on the herbicide label. Thin plants to one per container after emergence.
4. Place pots indoors and provide uniform light and water. Uniform natural light is better than artificial light, if possible.
5. About 2 to 3 weeks after emergence, evaluate the plants for symptoms of damage from the suspected herbicide. For descriptions and pictures of herbicide damage, see *Herbicide Mode of Action and Injury Symptoms* (NCR377) by J.L. Gunsolus and W.S. Curran.

Table 1. Relative persistence and importance of persistence factors for each herbicide group. Consult the label for rotational restrictions before any application.

Herbicide group	**ACCase inhibitors (acetyl CoA carboxylase)**	
Herbicide families	Arloxyphenoxypropionates, cyclohexanediones (Group 1)	
Examples	Assure II, Fusilade, Poast, Select	
Relative persistence	Short to moderate	
General rotational risk	Risk greatest for rotation to monocot (grass) crops; overall, rotational concerns are relatively low and restrictions are often 120 days or less	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Low to moderate	
Leaching	Low	
Microbial decomposition	High	
Chemical decomposition	Low to moderate	
Photodecomposition	Low to high	Poast decomposes on soil surface

Herbicide group	**ALS inhibitors (acetolactate synthase)**	
Herbicide families	Imidazolinones (Group 2)	
Examples	Pursuit, Raptor	
Relative persistence	Moderate to long	
General rotational risk	Risk increases as soil pH decreases; persistence very dependent on environmental conditions after application; several vegetable crops are sensitive to low levels of imidazolinone herbicides	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Low	Organic matter and clay content important
Leaching	Low	Dependent on soil pH
Microbial decomposition	Very high	Poor anaerobic decomposition
Chemical decomposition	Low	
Photodecomposition	Low	

Herbicide group	**ALS inhibitors (acetolactate synthase)**	
Herbicide families	Sulfonylureas (Group 2)	
Examples	Accent, Matrix, Sandea	
Relative persistence	Short to long, depending on herbicide, soil environment, and climate	
General rotational risk	Risk increases as soil pH increases; several vegetable crops are sensitive to low levels of residual sulfonylurea herbicides	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Low	
Leaching	Low to moderate	
Microbial decomposition	Moderate to high	Important when chemical decomposition is slow
Chemical decomposition	Very high	Decreases as soil pH increases
Photodecomposition	Low	

Table 1. Relative persistence and importance of persistence factors for each herbicide group *(continued).*

Herbicide group	**Bleaching**	
Herbicide families	Isoxazolidinone (Group 11), triketone (Group 28)	
Examples	Callisto, Command	
Relative persistence	Moderate to long	
General rotational risk	Selected crops quite sensitive to low levels of persistent bleaching herbicides and therefore have long rotational restrictions.	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Low	
Leaching	Low	
Microbial decomposition	High	Primary degradation mechanism
Chemical decomposition	Low	
Photodecomposition	Low	

Herbicide group	**Cell wall synthesis inhibitors**	
Herbicide families	Nitriles (Group 20)	
Examples	Casoron	
Relative persistence	Moderate to long	
General rotational risk	Rotational restrictions often 1 year after application	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Moderate	
Leaching	Moderate	
Microbial decomposition	High	Primary decomposition mechanism
Chemical decomposition	Low	
Photodecomposition	Low	

Herbicide group	**EPSP synthase inhibitors (Group 9)**	
Herbicide families	Not applicable	
Examples	Roundup and other glyphosate herbicides	
Relative persistence	Moderate	
General rotational risk	While persistence is moderate, herbicide activity is minimal after contact with soil; minimal rotation risk	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Very high	Not particularly dependent on soil type or pH
Leaching	Low	
Microbial decomposition	High	
Chemical decomposition	Low	
Photodecomposition	Low	

Table 1. Relative persistence and importance of persistence factors for each herbicide group *(continued).*

Herbicide group	**Lipid synthesis inhibitors**	
Herbicide families	Thiocarbamates (Group 8)	
Examples	Eptam, Ro-Neet	
Relative persistence	Short	
General rotational risk	Relatively low rotation risk; residual weed control often less than 30 days	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Low to moderate	Organic matter greatly increases adsorption
Leaching	Moderate	
Microbial decomposition	High	Primary degradation mechanism
Chemical decomposition	Low	
Photodecomposition	Low	

Herbicide group	**Microtubule assembly inhibitors**	
Herbicide families	Dinitroanilines (Group 3)	
Examples	Prowl, Sonalan, Treflan	
Relative persistence	Moderate	
General rotational risk	Monocot (grass) crops typically at greater risk; some crops very sensitive to low residue levels, such as beets, and thus have fairly long rotational restrictions	
Persistence factor	**Relative importance**	**Notes**
Adsorption	High	Increases greatly with increased organic matter
Leaching	Low	Low water solubility
Microbial decomposition	Moderate to high	Accounts for majority of degradation
Chemical decomposition	Low	
Photodecomposition	Moderate to high	

Herbicide group	**Photosystem I inhibitors**	
Herbicide families	Bipyridyliums (Group 22)	
Examples	Gramoxone, Diquat	
Relative persistence	Very long	
General rotational risk	While persistence is very long, these herbicides are bound so tightly to soil that they are not biologically active; minimal rotational risk	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Very high	Extremely rapid and strong adsorption to clay
Leaching	Low	
Microbial decomposition	Low	
Chemical decomposition	Low	
Photodecomposition	Moderate	

Table 1. Relative persistence and importance of persistence factors for each herbicide group *(continued).*

Herbicide group	**Photosystem II inhibitors**	
Herbicide families	Triazines, uracils (Group 5)	
Examples	Atrazine, Sencor, Sinbar	
Relative persistence	Moderate to long	
General rotational risk	Rotational restrictions can be more than 2 years in some cases; rotational risk often increases at higher soil pH	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Low to high	Highest at low pH (triazines)
Leaching	Moderate to high	Greater risk at higher pH (due to less adsorption)
Microbial decomposition	Moderate to high	
Chemical decomposition	Low to moderate	Fastest at low pH
Photodecomposition	Low	

Herbicide group	**Photosystem II inhibitors**	
Herbicide families	Benzothiadiazines, nitriles (Group 6)	
Examples	Basagran, Buctril	
Relative persistence	Very short	
General rotational risk	Low rotational risk	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Low	
Leaching	Moderate	
Microbial decomposition	High	Majority of degradation
Chemical decomposition	Low	
Photodecomposition	Low	

Herbicide group	**Photosystem II inhibitors**	
Herbicide families	Ureas (Group 7)	
Examples	Diuron, Lorox	
Relative persistence	Moderate	
General rotational risk	Some crops quite sensitive to urea herbicide residues, even at low levels	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Moderate	Dependent on soil type and organic matter
Leaching	Moderate	Greatest in sandy soils
Microbial decomposition	High	Primary degradation mechanism
Chemical decomposition	Low	
Photodecomposition	Low	

Table 1. Relative persistence and importance of persistence factors for each herbicide group *(continued).*

Herbicide group	**PPO inhibitors (protoporphyrinogen oxidase)**	
Herbicide families	Diphenylethers, triazolinone (Group 14)	
Examples	Cobra, Goal, Spartan	
Relative persistence	Short to long (Spartan)	
General rotational risk	Spartan rotational restrictions long for selected crops; small grain crops have longer rotation restrictions after Goal application	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Moderate to high	Moderate adsorption for Spartan
Leaching	Low to moderate	Moderate for Spartan
Microbial decomposition	Moderate to high	
Chemical decomposition	Low	
Photodecomposition	Low to high	

Herbicide group	**Synthetic auxins**	
Herbicide families	Benzoic acids, phenoxyacetic acids, pyridines (Group 4)	
Examples	Banvel, MCPA, Stinger, Thistrol, Tordon, 2,4-D	
Relative persistence	Very short to short, moderate (Stinger), or long (Tordon)	
General rotational risk	Rotation restrictions fairly short, with the exception of Stinger and Tordon that can persist and remain active in soil; dicot (broadleaf) crops at greatest risk	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Low	Maximum adsorption at low pH
Leaching	Low to high	
Microbial decomposition	High	Soil moisture and temperature important
Chemical decomposition	Low	
Photodecomposition	Low	

Herbicide group	**Unknown mode of action**	
Herbicide families	Chloroacetamides (Group 15)	
Examples	Dual, Harness, Intrro, Outlook	
Relative persistence	Short to moderate	
General rotational risk	Some products, such as Harness or Intrro, are very restrictive in rotation to vegetable crops	
Persistence factor	**Relative importance**	**Notes**
Adsorption	Moderate	Adsorption increases greatly with organic matter
Leaching	Low to moderate	
Microbial decomposition	High	Primary decomposition mechanism
Chemical decomposition	Low	
Photodecomposition	Low	

References to chemicals in this publication are for your convenience and are not endorsements of particular products over other similar products. You are responsible for using pesticides according to the manufacturer's current label directions. Follow directions exactly to protect people and the environment from pesticide exposure. Failure to do so violates the law.

UW Extension

Author: Jed Colquhoun is assistant professor of horticulture, College of Agricultural and Life Sciences, University of Wisconsin-Madison and University of Wisconsin-Extension, Cooperative Extension. Produced by Cooperative Extension Publishing, University of Wisconsin-Extension.

University of Wisconsin-Extension, Cooperative Extension, in cooperation with the U.S. Department of Agriculture and Wisconsin counties, publishes this information to further the purpose of the May 8 and June 30, 1914 Acts of Congress; and provides equal opportunities and affirmative action in employment and programming. If you need this information in an alternative format, contact Cooperative Extension Publishing at 608-262-2655 or the UWEX Affirmative Action Office.

This publication is available from your Wisconsin county Extension office or from Cooperative Extension Publishing, To order, call toll free 877-WIS-PUBS (947-7827) or visit our web site at cecommerce.uwex.edu.