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# Pesticide Fate in the Environment: A Guide for Field Inspectors

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## Abstract

The high cost of laboratory analysis often limits the number of samples that can be collected as part of a site investigation. Field inspectors must determine if collecting soil and plant tissue samples for analysis is justified. This document serves as a quick reference on the environmental fate of 35 common herbicides that field inspectors are likely to encounter. The use for each herbicide is described along with estimated herbicide persistence in the soil, water, and plant tissues. Understanding herbicide behavior in plants should help improve the information obtained from site investigations.

## Acknowledgements

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## Introduction

This guide was prepared as a resource to help field inspectors determine when soil and plant tissue samples should be collected and analyzed as part of a site investigation. The high cost of laboratory analysis often limits the number of samples that can be analyzed, but the decision to collect samples can be made easier by answering these questions: How long is this herbicide likely to persist in the soil? Does the applied herbicide translocate to plant tissues and persist? Does the applied herbicide have the potential to leach below the shallow soil layers or move away in runoff?

Only chemical names are included in this guide, but a list of trade names and more detailed information are available in the *Herbicide Handbook* (WSSA, 2007). Another resource is *The Bulletin*, a newsletter published weekly throughout the crop-growing season by the University of Illinois Crop Sciences Department, http://bulletin.ipm.illinois.edu. New trade names, herbicide premixes, and updates are normally included in the first issues of *The Bulletin* each year. In addition, a searchable list of trade names is available at the Illinois Department of Agriculture website: http://www.agr.state.il.us/Environment/Pesticide/productsearch.php.

## Background

Herbicide decomposition begins immediately after application. The rate of decomposition depends on the chemical and physical properties of the herbicide, site characteristics, and environmental conditions. Herbicide loss occurs through volatilization, photodegradation, microbial degradation, plant metabolism, hydrolysis, leaching, and herbicide transport with runoff.

As a result, collecting a plant or soil sample may or may not confirm that an herbicide was the cause of damage. When collecting plant samples, it is best to include the leaves, shoots, or roots where the herbicide is most active or likely to accumulate. When collecting soil for analysis, a sample taken near the soil surface may be more useful for identifying pesticide drift than one taken 6 to 8 inches deep.

Persistence is the length of time an herbicide remains in the field. In certain situations, long persistence is desirable for residual weed control, but in other situations, extended soil persistence can have negative effects including carryover that damages subsequent crops.

The rate of herbicide decomposition in the field is dependent upon soil chemistry, temperature, moisture, microbial population, herbicide properties, and application rate. The average field half-life ($T_{1/2}$) provides a generalized number of days required for the initial applied concentration of herbicide to decay to half the initial concentration. Figure **1** illustrates soil concentrations of an herbicide over days following the original application as an example of the idealized decay process.

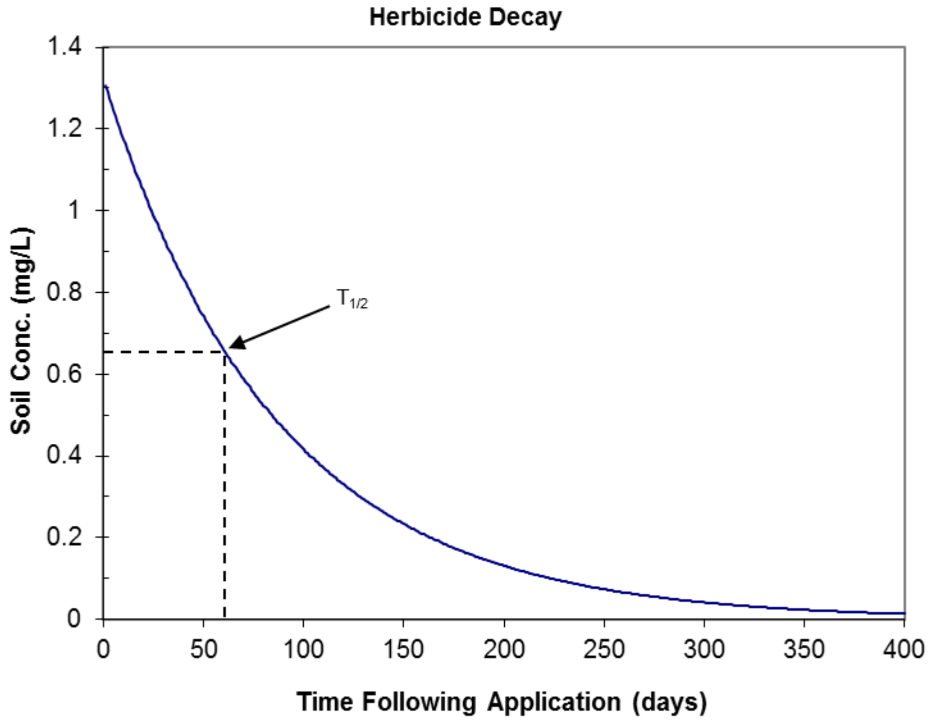


Figure 1. Idealized herbicide decay with the half-life indicated

In addition to persistence, soil adsorption and water solubility are two other important properties that influence herbicide behavior in the field. $K_{oc}$ is a binding coefficient commonly used to describe a pesticide's tendency to sorb to organic carbon. A high $K_{oc}$ value (greater than 1000) indicates the pesticide sorbs strongly to organic carbon and is not likely to be transported, except with eroding soil particles. Pesticides with low $K_{oc}$ values (less than 300 to 500) are less strongly adsorbed and tend to be transported more readily with runoff water.

Similarly, the higher an herbicide's water solubility, the greater the likelihood of the herbicide dissolving in water and moving in the aqueous phase. Water solubility is typically measured in milligrams per liter (mg/L), which is equivalent to parts per million (ppm) in most near-surface environments. In general, pesticides having a water solubility of 1 mg/L (1 ppm) or less tend to remain attached to the soil surface, while pesticides with water solubilities greater than 30 ppm are more likely to be transported in water (Czapar, 2000). In the following sections, each herbicide description is followed by an explanation of the herbicide's persistence in soil, water, and plant tissues.

## 2,4-D

*(Numerous formulations and trade names are available)*

Detailed information on formulations, chemical structures, and combination products is available in the Herbicide Handbook (WSSA, 2007). This herbicide is used to control many broadleaf weeds and has limited activity on grasses. It is used in corn production, pasture management, small grains, turfgrass, and non-crop areas. Certain formulations are also used in lakes and ponds to control Eurasian watermilfoil and other undesirable aquatic plants.

***In soil:*** Considered non-persistent in the soil, the average field half-life is 10 days, with residual effects on susceptible plants lasting 1 to 4 weeks. 2,4-D is degraded primarily by microbes.

***In water:*** 2,4-D degradation and plant uptake significantly reduce leaching potential. Table 1 provides a summary of 2,4-D mobility potential based on the solubility and the soil organic carbon sorption coefficient.

***In plant tissues:*** 2,4-D is a synthetic auxin that accumulates at the shoots and root tips. Metabolism occurs slowly.

**Table 1. Solubility and the Soil Organic Carbon Sorption Coefficient for 2,4-D Forms**

| 2,4-D Formulation | Solubility (mg/L) | $K_{oc}$ (mL/g) | Mobility Potential |
|---|---|---|---|
| Acid | 900 | 20 | Moderate |
| Butoxyethyl ester | 100 | 100 | Low |
| Dimethylamine salt | 797,000 | 20 | Moderate |
| Isooctyl ester | 0.03 | 100 | Low |

## 2,4-DB

Included are the acid, butoxyethyl ester, and dimethylamine salt formulations. This herbicide has some broadleaf selectivity. Sensitive plants quickly convert 2,4-DB into 2,4-D acid, while less-sensitive legumes such as soybeans convert 2,4-DB to 2,4-D acid at a much slower rate.

***In soil:*** The soil persistence of 2,4-DB is slightly different for each form: Acid $T_{1/2}$ = 5 days, butoxyethyl ester $T_{1/2}$ = 7 days, dimethylamine salt $T_{1/2}$ = 10 days.

***In water:*** The solubility and soil organic carbon sorption coefficients for 2,4-DB forms are shown in Table 2.

***In plant tissues:*** A synthetic auxin herbicide, 2,4-DB is absorbed by plant roots and foliage, and tends to accumulate in meristematic tissues in the leaves and roots (WSSA, 2007).

**Table 2. Solubility and Soil Organic Carbon Sorption Coefficient for 2,4-DB Forms**

| 2,4-DB Formulation | Solubility (mg/L) | $K_{oc}$ (mL/g) | Mobility Potential |
|---|---|---|---|
| Acid | 46 | 440 | Low |
| Butoxyethyl ester | 8 | 500 | Low |
| Dimethylamine salt | 709,000 | 20 | Moderate |

## Acetochlor

Acetochlor is typically applied pre-emergence or pre-plant incorporated to provide residual control of annual grasses, nutsedge, and some broadleaf weeds in corn and soybean fields.

***In soil:*** Acetochlor provides 8 to 12 weeks of residual weed control under normal conditions. In warm and moist conditions favorable for rapid herbicide degradation, acetochlor has been shown to have a half-life of 6.3 days (Mueller et al., 1999). More recent studies have found that under anaerobic conditions the half-life was between 10 and 16 days (Loor-Vela et al., 2003).

***In water:*** Loam soils with high organic matter content have the highest sorption capacity for acetochlor. Acetochlor has a solubility of 223 mg/L.

***In plant tissues:*** Acetochlor is absorbed in the shoots of emerging seedlings. The herbicide does not control established weeds.

## Acifluorfen

Acifluorfen is applied post-emergence for control of broadleaf plants in soybeans. Certain grasses can also be controlled with acifluorfen if it is applied post-emergence early at a higher rate. Acifluorfen is a fast-acting herbicide, and injury normally occurs 1 to 2 days after application.

***In soil:*** Acifluorfen has a half-life of 14 to 60 days with microbial degradation in the soil as the primary loss mechanism. Warm and moist conditions favorable to microbial activity can cause an accelerated decay of acifluorfen.

***In water:*** The solubility of acifluorfen is dependent upon the formulation: for acifluorfen acid, 120 mg/L; for acifluorfen sodium salt, 250,000 mg/L. The herbicide has a moderate soil $K_{oc}$ of 113 milliliters per gram (mL/g). The potential for leaching and runoff is moderate to low. In surface water exposed to sunlight, acifluorfen photodegrades with a half-life of 2.5 days.

***In plant tissues:*** Tolerant plants quickly metabolize acifluorfen into non-phytotoxic metabolites. Susceptible plants do not readily metabolize the herbicide and die within a few days.

## Alachlor

Alachlor is used to control annual grasses, nutsedge, and some broadleaf weeds in row crops and can also be applied for control of pre-emergent weeds around ornamental trees and shrubs.

***In soil:*** Alachlor provides weed control for 6 to 10 weeks and has an average soil half-life of 21 days. Microbes are responsible for nearly all of the degradation of alachlor.

***In water:*** This herbicide tends to have a variable $K_{oc}$ of 43 to 209 mL/g and a moderately low solubility of 242 mg/L at 25°C. Alachlor has a low to moderate potential for leaching and runoff (WSSA, 2007).

***In plant tissues:*** Emerging plants tend to accumulate alachor in the shoots, while previously emerged weeds are unaffected.

## Atrazine

A commonly used agricultural herbicide for corn production, atrazine has many trade names and can be found in several premixes.

***In soil:*** Atrazine has an average soil half-life of 60 days and can persist longer under cool, dry conditions or in soils with pH values greater than 7.2. Both microbial activity and hydrolysis degrade atrazine. Degradation due to hydrolysis is typically greater in lower pH soils of 5.5 to 6.5 (WSSA, 2007). In a lab study, the photodegradation $T_{1/2}$ of atrazine exposed on a sandy loam soil was 45 days (WSSA, 2007). In situations with little or no rainfall, photodegradation can become an important component of atrazine degradation.

***In water:*** The solubility of atrazine is 33 mg/L, and the $K_{oc}$ varies from 39 to 155 mL/g.

***In plant tissues:*** Atrazine is mostly absorbed by plant roots and moves in the xylem or water conducting tissues in the plant. Foliar absorption is increased with tank mixes of oils or surfactants. Tolerant crop species quickly convert the phytotoxic herbicide into inactive metabolites.

## Bentazon

Bentazon is applied post-emergence for control of broadleaf weeds in soybeans, corn, sorghum, and other crops.

***In soil:*** Bentazon has an average soil half-life of 20 days and is often undetectable after 42 days. Soil microbes are responsible for rapid degradation of bentazon.

***In water:*** The soil organic carbon sorption coefficient, $K_{oc}$, is 34 mL/g, indicating a weak sorption to soil particles, and the solubility is 500 mg/L. Due to rapid microbial degradation and photodegradation, bentazon has a low leaching potential despite having a low $K_{oc}$ and a high solubility. In surface water bentazon photodegrades with a half-life of 63 hours (USEPA 1994).

***In plant tissues:*** Bentazon is foliar-applied most often with adjuvants to aid adsorption of herbicide into the plant leaves. Tolerant crops metabolize bentazon quickly while susceptible weeds exhibit chlorosis 3 to 5 days after herbicide application (WSSA, 2007).

## Bromacil

Bromacil is primarily used as a pre-emergence herbicide in non-crop areas to control grasses and broadleaf weeds.

***In soil:*** Bromacil provides residual weed control and has an average field half-life of 60 days. When higher rates are applied to control brush, bromacil residues may persist to kill or injure sensitive plants longer than 1 year following application. The application of higher rates can increase half-lives to 6 months.

***In water:*** The $K_{oc}$ for bromacil is 32 mL/g, indicating weak sorption to soil particles. Bromacil acid has a solubility of 815 mg/L, and the lithium salt formulation has a solubility of 700 mg/L. Bromacil has a moderate leaching potential due to the weak soil sorption, high solubility, and long persistence.

***In plant tissues:*** Bromacil is absorbed by plant roots and translocated to the leaves where the herbicide disrupts photosynthesis.

## Bromoxynil

Bromoxynil is a foliar-applied contact herbicide that controls broadleaf weeds in tolerant crops, including corn, wheat, barley, oats, rye, and others.

***In soil:*** The average field half-life of bromoxynil is 7 days. A study in Mississippi found that bromoxynil applied to a silt loam soil had a half-life of less than 1 day due to rapid formation of metabolites and incorporation into the soil organic matter by microbes (Zablotowicz et al., 2009).

***In water:*** The octanoate ester form of bromoxynil is not susceptible to water transport due to a high $K_{oc}$ of 10,000 mL/g and a low solubility of 0.08 mg/L. The acid form of bromoxynil has low potential for water transport due to its low $K_{oc}$ of 190 mL/g and a solubility of 130 mg/L at 25°C.

***In plant tissues:*** Bromoxynil is quickly absorbed into plant leaves where it disrupts photosynthesis. Symptoms occur within 1 or 2 days after application.

## Carfentrazone

Carfentrazone is a foliar-applied herbicide for post-emergence control of broadleaf weeds in corn, soybeans, and cereals. The herbicide is also applied to control aquatic floating and emergent weeds. Carfentrazone causes plant death quickly, with the first symptoms appearing in a few hours following application.

***In soil:*** Carfentrazone is degraded to a free acid by microbes within hours of application. The resulting free acid has a half-life of 2.5 to 4 days; thus, carfentrazone is not considered persistent.

***In water:*** The solubility of carfentrazone is 12,000 mg/L at 20°C, 22,000 mg/L at 25°C, and 23,000 mg/L at 30°C. The $K_{oc}$ for carfentrazone-ethyl and carfentrazone acid is 750 mL/g and 20 mL/g, respectively. With a high solubility and a low $K_{oc}$ of the carfentrazone acid, one would expect significant leaching potential; however, microbial action and hydrolysis degrade carfentrazone quite rapidly and the herbicide is not considered mobile (WSSA, 2007). In pond water carfentrazone is reported to have a half-life of 83 hours with no residues detectable after 7 days (Koschnick et al., 2004).

***In plant tissues:*** Carfentrazone is absorbed through the foliage and is rapidly converted to metabolites including carfentrazone acid. Plants exhibit symptoms of herbicide application within hours and death within a few days (WSSA, 2007).

## Chlorimuron Ethyl

Chorimuron ethyl can be applied pre-emergence, pre-planting incorporated, or post-emergence to control broadleaf weeds in soybeans and non-crop areas.

***In soil:*** The average field half-life for chlorimuron is 40 days; however, in soils with a higher pH the half-life tends to be longer as microbes degrade chlorimuron at a slower rate.

***In water:*** The herbicide has a $K_{oc}$ of 110 mL/g and a solubility of 1200 mg/L. In more acidic soils chlorimuron becomes neutrally charged and has less potential to leach. The moderate sorption and high solubility indicate that chlorimurion ethyl has the potential to leach in basic pH soils.

***In plant tissues:*** Leaves of affected plants show discoloration 3 to 5 days following herbicide application, and plant death occurs in 7 to 21 days. In susceptible weeds, chlorimuron has a metabolic half-life of 30 hours or greater.

## Clomazone

Clomazone is applied pre-emergence or pre-plant incorporated to control grasses and annual broadleaf weeds in soybeans, peppers, pumpkins, and peas. This herbicide causes susceptible weed seedlings to emerge and turn a distinctive white color.

***In soil:*** The average field half-life for clomazone is 24 days, but the half-life tends to be longer in silt loam soils. Microbial degradation of clomazone occurs readily in both aerobic and anerobic conditions; however, photodegradation occurs slowly.

***In water:*** The $K_{oc}$ is 300 mL/g, and the solubility of 1100 mg/L indicates that clomazone could have the potential for leaching.

***In plant tissues:*** Clomazone tends to be rapidly adsorbed by the roots and shoots of emerging seedlings. The herbicide is translocated to the emerging foliage.

## Clopyralid

Clopyralid is a post-emergence herbicide for control of broadleaf weeds in Christmas trees, seed grasses, and field corn. Clopyralid is also particularly effective against legumes and certain herbaceous weeds. The formulation trade named Transline is labeled for application on kudzu and can be applied to weeds in forested areas without injury to many hardwood tree species.

***In soil:*** The average field half-life for clopyralid is 40 days. However, herbicide residues may remain in the soil to harm crops planted 1 year after application (WSSA, 2007). Clopyralid is degraded primarily by microbes.

***In water:*** The Herbicide Handbook (WSSA, 2007) lists the $K_{oc}$ for clopyralid as ranging from 6 to 60 mL/g, and the solubility is 1000 mg/L at 25°C. This suggests a moderate to high potential for leaching.

***In plant tissues:*** Clopyralid is readily absorbed by foliage and roots and is translocated in the plant to the growth points. Susceptible plants exhibit stem twisting and leaf cupping, and succumb in a manner consistent with synthetic auxin herbicides.

## Cloransulam methyl

Cloransulam methyl can be applied pre-plant incorporated, pre-emergence, or post-emergence for control of many broadleaf weeds in soybean fields.

***In soil:*** In field studies, the half-life of cloransulam methyl varied from 8 to 10 days with microbial degradation as the primary mechanism for decomposition.

***In water:*** The Herbicide Handbook (WSSA, 2007) indicates a $K_{oc}$ ranging from 54.4 to 915 mL/g. The higher $K_{oc}$ values occur in more acidic soils with more rain-free time. The solubility of cloransulam methyl ranges from 3 mg/L for pH values between 3 and 5 to 184 mg/L at a pH of 7. The $K_{oc}$ and the solubility would suggest a low to moderate mobility; however, the EPA Pesticide Fact Sheet for cloransulam-methyl, dated October 29, 1997, lists the herbicide as being highly mobile.

***In plant tissues:*** In pre-emergence application of cloransulam methyl, most susceptible weeds fail to emerge. Susceptible seedlings that do emerge may exhibit a distinctive "purpling" discoloration in addition to stunting. The herbicide is absorbed by the roots and translocated to the shoots. Soybeans quickly metabolize cloransulam methyl with a $T_{1/2}$ of 5 hours, while susceptible velvetleaf and ivyleaf morning glory metabolize the herbicide with a $T_{1/2}$ of 62 and 165 days, respectively (WSSA, 2007).

## Dicamba

Dicamba is used for control of broadleaf weeds in corn, sorghum, small grains, and grass pastures. The herbicide can be applied pre-emergence and post-emergence in corn and post-emergence only for other specific crops. Dicamba is often used in tank mixes.

***In soil:*** In a loam soil, dicamba has been found to have a half-life of 4 to 5 days; however, in situations with little rainfall and low soil moisture, dicamba may persist much longer. Degradation is mostly due to microbial action and occurs at a faster rate in aerobic conditions.

***In water:*** Dicamba has a weak sorption to soil, as the $K_{oc}$ is 2 mL/g with a high solubility of 4500 mg/L at 25°C. Although dicamba is very mobile due to these properties, the herbicide degrades quickly, which reduces the leaching and runoff potential to moderate.

***In plant tissues:*** Grasses and tolerant plants tend to quickly metabolize dicamba. Susceptible plants absorb the herbicide through the leaves, stems, and roots. Dicamba accumulates at the growing points of affected plants.

## Dimethenamid

Dimethenamid is a pre-emergence and early post-emergence herbicide for the control of annual grass and small-seeded broadleaf weeds in corn and soybeans. Dimethenamid has little or no affect on established weeds beyond the seedling stage.

***In soil:*** Dimethenamid has an aerobic soil half-life of 31 days and a much longer anaerobic soil half-life.

***In water:*** The $K_{oc}$ of dimethenamid varies from 105 to 396 mL/g and the solubility is 1174 mg/L. The high $K_{oc}$ indicates that dimethenamid is strongly sorbed to soil particles and is less likely to leach in loam or clay soils.

***In plant tissue:*** Dimethenamid is absorbed into the shoots and roots of emerging plants.

## Diuron

Diuron is used for pre-emergent weed control in established crops such as alfalfa, asparagus, and grapes or post-emergent weed control in corn, sorghum, oats, and winter wheat.

***In soil:*** Diuron has a 90-day average field half-life and may persist for more than 1 year when applied at high rates. Diuron is primarily degraded through microbial action.

***In water:*** The $K_{oc}$ for diuron is 480 mL/g and the solubility is 42 mg/L at 25°C. The high $K_{oc}$ and the low solubility are indicative of low leaching potential; however, since diuron is slow to degrade there exists a moderate potential for leaching in coarse-textured soils.

***In plant tissue:*** Used primarily as a pre-emergent herbicide, diuron is absorbed by the emerging plants roots and translocated to the shoots.

## Fomesafen

Fomesafen is a post-emergence selective herbicide for control of annual broadleaf weeds in soybeans.

***In soil:*** Fomesafen has an average field half-life of 100 days. However, in anaerobic conditions such as flooded soils, fomesafen will degrade at a much faster rate, and a field half-life of less than 3 weeks can be expected.

***In water:*** The $K_{oc}$ for fomesafen is 60 mL/g. The solubility depends upon the formulation: 50 mg/L for the acid formulation and 600,000 mg/L for the sodium salt. Studies suggest that fomesafen is moderately mobile (WSSA, 2007).

***In plant tissue:*** Fomesafen is foliar-applied and quickly enters the leaves of plants where it destroys cell membranes and leads to rapid tissue desiccation. Soybeans are tolerant to fomesafen by quickly converting the herbicide to inactive metabolites.

## Flumetsulam

Flumetsulam provides control of broadleaf weeds in corn and soybean fields. The herbicide can be applied pre-plant, pre-emergence, or post-emergence.

***In soil:*** Flumetsulam has a half-life of 30 to 90 days and tends to be less persistent in high pH soils. This herbicide is primarily degraded by microbes, but if exposed on the soil surface, flumetsulam will photodegrade with a half-life of 90 days.

***In water:*** With a $K_{oc}$ of 700 mL/g and solubility of 5600 mg/L, flumetsulam likely has a low to moderate potential for leaching and runoff.

***In plant tissues:*** Flumetsulam is absorbed by plant roots and emerging shoots. In tolerant corn and soybeans, flumetsulam is metabolized in less than 2 hours and 18 hours, respectively.

## Glyphosate

*(Numerous formulations and trade names are available)*

Glyphosate is widely used for weed control in glyphosate-tolerant crops, and is often applied in combination with other herbicides that provide residual weed control. Glyphosate by itself provides no residual weed control.

***In soil:*** Glyphosate has an average field half-life of 47 days and is primarily degraded by microbial action. Crops and weeds emerging after application of glyphosate are unaffected by residues in the soil.

***In water:*** Glyphosate has a $K_{oc}$ of 24,000 mL/g and solubility greater than 15,700 mg/L for all forms. The potential for leaching is low due to the strong sorption of glyphosate to soil particles.

***In plant tissues:*** Slow to metabolize in plants, glyphosate can be found in underground tissues, immature leaves, and meristems.

## Hexazinone

Hexazinone is applied in non-crop areas to control both annual and perennial broadleaf and grass weeds. Hexazinone is also applied in dormant alfalfa and used to prepare sites and maintain selective reforestation of conifers. The herbicide is used for both foliar application and residual weed control.

***In soil:*** The soil persistence of hexazinone is moderately long with a 90-day typical half-life. Other studies have indicated 30-day, 60-day, and 180-day half-lives.

***In water:*** Hexazinone has a solubility of 33,000 mg/L at 25°C and a $K_{oc}$ of 54 mL/g. These properties combined with the long persistence of hexazinone can lead to leaching and runoff.

***In plant tissues:*** In plants hexazinone is absorbed by the roots and transported to the leaves where it blocks photosynthesis.

## Imazethapyr

Imazethapyr is applied pre-emergence or post-emergence for control of annual broadleaf and grass weed species in soybeans and in imadazolinone-resistant corn.

***In soil:*** The soil persistence of imazethapyr is moderate with a 60 to 90 day field half-life.

***In water:*** Lab studies have shown imazethapyr to photodegrade in water with a half-life of 46 hours under constant light exposure. The $K_{oc}$ for imazethapyr is 97 to 283 mL/g and the solubility is 1400 mg/L, suggesting a low potential for leaching. Field studies have not observed significant leaching (WSSA, 2007).

***In plant tissues:*** Imazethapyr is adsorbed through plant foliage and roots. Soybeans and resistant field corn rapidly metabolize the herbicide while susceptible weeds are very slow to metabolize imazethapyr.

## Isoxaflutole

This herbicide can be applied pre-plant, pre-plant incorporated, or pre-emergence, or certain formulations can be applied early post-emergence to selectively control broadleaf weeds and some grass weeds in corn.

***In soil:*** In laboratory studies isoxaflutole has a documented short $T_{1/2}$ of 1.5 to 9.6 days (Taylor-Lovell et al., 2002). In field studies the half-life of isoxaflutole and the active metabolite was 8 to 18 days, and herbicide concentrations were usually undetectable after 100 days (Papiernik et al., 2007).

***In water:*** The solubility of isoxaflutole is 6200 mg/L at 20°C. Studies indicate that isoxaflutole has a high sorption coefficient, $K_d$, of 1240 mL/g to 3950 mL/g and likely has a higher $K_{oc}$ (Sims et al., 2009). Isoxaflutole’s active metabolite, diketonitrile, has a low sorption coefficient, and thus has the potential to leach.

***In plant tissues:*** Isoxaflutole indirectly disrupts the production of carotenoid within affected plants. The lack of carotenoid leads to bleaching of new growth and weed death.

## Mecoprop

Mecoprop is applied post-emergence to kill broadleaf weeds and provide residual control of broadleaf weeds in wheat, oats, and non-crop areas. Mecoprop is sprayed on weed foliage and is slowly absorbed into the leaves. A small percentage of the absorbed mecoprop is translocated from the leaves to the roots. This herbicide is similar to 2,4-D in chemical structure and in development of symptoms.

***In soil:*** Mecoprop has an average field half-life of 21 days and typically provides residual broadleaf control for a month. Grasses planted after application may have slightly reduced emergence rates for 2 weeks.

***In water:*** The acid formulation of mecoprop has a solubility of 620 mg/L, and the dimethylamine salt has a solubility of 660,000 mg/L. The $K_{oc}$ of mecoprop is 20 mL/g. The high solubility of the dimethylamine salt and the low $K_{oc}$ suggest it has a potential for leaching.

***In plant tissues:*** Mecoprop accumulates at plant growth points like other synthetic auxins. Susceptible weeds typically die within 3 to 5 weeks of application.

## Mesotrione

Mesotrione affects carotenoid biosynthesis and is used for control of broadleaf weeds in corn and also to control crabgrass in turf.

***In soil:*** Mesotrione in the soil has a half-life of 5 to 15 days, while mesotrione exposed on the soil surface photodegrades with a half-life of 15 to 21 days.

***In water:*** The solubility of mesotrione varies from 2200 mg/L (pH 4.8, 20°C), 15,000 mg/L (pH 6.9, 20°C), and 22,000 mg/L (pH 9, 20°C) (WSSA, 2007). The $K_{oc}$ varies from 14 to 390 mL/g. In more basic soils, mesotrione has the potential to leach; however, such conditions also cause more rapid degradation of mesotrione, resulting in a small potential for mobility in field conditions.

***In plant tissues:*** Mesotrione is absorbed by plants through the shoots and in the roots. In sensitive plants, mesotrione blocks the production of carotenoid pigments. The lack of carotenoid pigments causes chlorophyll to degrade (USEPA, 2001).

## Metolachlor

Metolachlor is applied pre-emergence and early post-emergence in corn to control annual grass weeds and certain broadleaf weeds. It can also be used for weed control in soybeans, landscape areas, and in turfgrass.

***In soil:*** The average field half-life of metolachlor in studies varies from 97 to 112 days. Microbial degradation is the major pathway for breakdown in the field.

***In water:*** Metolachlor has a solubility of 488 mg/L and a $K_{oc}$ of 200 mL/g. Metolachlor weakly sorbs to soils low in organic matter. If the soil organic matter is greater than 2 percent, the herbicide sorption is greater and leaching is minimal.

***In plant tissues:*** Emerging plants absorb metolachlor through the shoots. Tolerant crops are believed to detoxify metolachlor within a few hours.

## Metribuzin

Metribuzin is a selective herbicide for control of annual broadleaf weeds and some annual grass weeds. It is normally applied pre-emergence in soybeans and pre-emergence and post-emergence in corn.

***In soil:*** The persistence of metribuzin in the soil is highly variable and dependent upon soil type and climatic conditions. The average field half-life is 30 to 60 days, but depending on conditions, it can last up to 4 months. Metribuzin is primarily degraded by microbial action.

***In water:*** The solubility of metribuzin is 1100 mg/L at 20°C. The average $K_{oc}$ is 60 mL/g, but may be as low as 3.14 mL/g for sandy loam soils. The moderately high solubility and the variable sorption are properties that lead to leaching and runoff under certain field conditions. Metribuzin is quickly degraded by photolysis in exposed surface waters.

***In plant tissues:*** Metribuzin can be foliar applied or incorporated in the soil where it is absorbed by the roots and translocated to the shoots. Metribuzin disrupts photosynthesis in sensitive plants. Tolerant crop species quickly convert metribuzin into nontoxic metabolites.

## Paraquat

Paraquat is a nonselective herbicide often used for burn-down of weeds prior to no-till planting of corn or soybeans. The herbicide is also labeled for use in many other crops and vegetables.

***In soil:*** The average field half-life for paraquat in the soil has been estimated at 1000 days. Paraquat in the soil is unavailable and does not affect plant emergence or growth. The long persistence is due to very limited microbial degradation and the strong sorption of paraquat to clay particles.

***In water:*** Paraquat has a $K_{oc}$ of 1,000,000 mL/g and is not transported by leaching or runoff.

***In plant tissues:*** Paraquat is quickly absorbed through plant foliage and remains in the leaves. The herbicide destroys the cell membranes and the affected leaves desiccate rapidly.

## Pendimethalin

Pendimethalin is applied to control grass weeds and certain broadleaf weeds in numerous crops.  It can be applied pre-emergence or early post-emergence in field corn and sweet corn or pre-plant incorporated and pre-emergence in soybeans. Since pendimethalin is somewhat volatile, it requires rainfall or incorporation within 7 days to prevent herbicide loss.

***In soil:*** The average field half-life for pendimethalin is 44 days. Anaerobic conditions such as water-logged soils will cause rapid degradation. Aerobic microbial degradation of pendimethalin is slower.

***In water:*** Pendimethalin is not mobile due to its low solubility of 0.3 mg/L at 25°C and the high $K_{oc}$ of 17,200 mL/g. Photodegradation of pendimethalin in surface water occurs with a half-life of 7 days under full sunlight and warm temperatures.

***In plant tissues:*** Absorption of pendimethalin occurs in the plant roots and coleoptiles. Pendimethalin limits the production of microtubule protein that plants need for cell division and cell wall formation.

## Picloram

Picloram effectively controls both annual and perennial broadleaf plants, vines, and woody species. Used in forest management, noncrop-areas, and pastureland, picloram can be either foliar-applied, injected into trees, sprayed in girdle cuts, or sprayed on stumps. Picloram can also be applied post-emergence at a low rate to control broadleaf weeds in wheat, barley, and oats.

***In soil:*** Picloram has an average field half-life of 90 days. Degradation is accelerated in warm, moist soils with high organic matter content. Microbial action is the primary mechanism for degradation.

***In water:*** Picloram is susceptible to leaching and runoff due to a moderate solubility of 430 mg/L at 25°C and a low $K_{oc}$ of 16 mL/g. In surface water picloram degrades rapidly with a half-life of 2.6 days due to photolysis.

***In plant tissues:*** Picloram is absorbed through the roots, foliage, and bark cuts of treated plants and translocated to the growing points. Plant death may take 3 to 5 weeks to occur.

## Prometon

Prometon is a non-selective herbicide used to control many annual broadleaf and grass weeds. Due to a long residual time, prometon is applied in industrial sites, gravel parking lots, railroad rights of way, cracks in asphalt, and in other situations requiring the area to be devoid of plants.

***In soil:*** Prometon has an average field half-life of 500 days. It is degraded slowly by microbial action.

***In water:*** Prometon has a moderate mobility due to a solubility of 720 mg/L at 22°C and a $K_{oc}$ of 150 mL/g.

***In plant tissues:*** Prometon is absorbed by plant foliage and roots where it is then translocated to the mature leaves and disrupts photosynthesis.

## Simazine

Simazine is labeled for early pre-plant or pre-emergence application in corn. Simazine is also used to control many broadleaf and grass weeds in orchards, vineyards, and tree plantings.

***In soil:*** Simazine has an average field half-life of 60 days. Persistence of more than 1 year has caused damage to the next year's crop in certain sites with high pH soils. Degradation of simazine is primarily due to microbial action, but can also be caused by non-microbial hydrolysis in acidic soils.

***In water:*** With a solubility of 3.5 mg/L at 20°C and a $K_{oc}$ of 130 mL/g, simazine has a lower potential than atrazine for leaching or runoff (WSSA, 2007).

***In plant tissues:*** Since simazine is a pre-emergence herbicide, vegetation present during application typically does not absorb simazine through the foliage and instead takes up the herbicide through the roots.

## Tebuthiuron

Tebuthiuron is a non-selective herbicide that controls broadleaf and woody plants at low application rates and controls nearly all species at higher rates. It is used in grass pastures to kill broadleaf plants. The pellet forms of tebuthiuron are commonly used to prevent woody species from sprouting up in fences.

***In soil:*** Residual effects of tebuthiuron are long-lasting. In areas that receive 40 to 60 inches of annual rainfall, the half-life of tebuthiuron is 12 to 15 months. In areas with lower rainfall the persistence can be longer (WSSA, 2007). Microbial action is primarily responsible for degradation of tebuthiuron.

***In water:*** The high solubility of 2,500 mg/L at 25°C, moderate soil $K_{oc}$ of 80 mL/g, and persistence are factors that increase the potential for runoff and leaching. Tebuthiuron strongly adsorbs to clay particles; however, the lengthy persistence of the herbicide applied at higher rates can lead to herbicide runoff and damage to non-target plants.

***In plant tissues:*** Tebuthiuron is absorbed into the plant roots and translocated to the leaves where the herbicide inhibits photosynthesis.

## Triclopyr

Triclopyr is a non-selective herbicide for control of annual broadleaf weeds, trees, and brush species. It is foliar applied on non-crop areas (pipeline right of ways, roadsides, railroads, industrial sites, under power lines, and pastures) to control broadleaf weeds and limit the encroachment of woody species. Triclopyr is also applied in forestry management practices by spraying cut stumps, girdle cuts, and basal spraying saplings.

***In soil:*** Triclopyr has an average field half-life of 30 days.

***In water:*** Triclopyr is available in three formulations: acid, butoxyethyl ester, and triethylamine. Table 3 below has the solubility, $K_{oc}$ values, and the potential for mobility for two formulations.

***In plant tissues:*** Triclopyr is absorbed through foliage, stems, and roots and is translocated to growing points. In tolerant species the herbicide is metabolized in days to non-phytotoxic compounds. Sensitive species metabolize triclopyr at a much slower rate.

**Table 3. Solubility and Soil Organic Carbon Sorption Coefficient for Triclopyr Formulations.**

| Triclopyr Formulation | Solubility (mg/L) | Koc (mL/g) | Mobility Potential |
|---|---|---|---|
| Butoxyethyl ester | 23 | 780 | Low |
| Trimethylamine salt | 2,100,000 | 20 | High |

## Trifluralin

Trifluralin is used for weed control in a wide variety of agricultural and landscaping applications. The herbicide is typically applied pre-plant incorporated to control annual grasses and certain broadleaf weeds. If trifluralin is left exposed on the soil surface, significant volatilization loss occurs.

***In soil:*** Trifluralin has an average field half-life of 45 days. In areas with cool, dry climates the field half-life may increase to 120 days. Primarily degraded by microbial action, trifluralin has been found to decompose more rapidly in anaerobic conditions.

***In water:*** Trifluralin has a low potential for leaching and runoff due to a low solubility of 0.3 mg/L at 25°C and a high $K_{oc}$ of 7000 mL/g.

***In plant tissues:*** Trifluralin is absorbed by the plant shoots and roots. The herbicide accumulates in the shoots and prevents cell division.

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