PRODUCTION

Herbicide Behavior in Soils

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Quick Facts...

The chemical and biological characteristics of herbicides determine their behavior in soils.

Additional determinants of herbicide behavior include soil texture and organic matter content, soil pH, time, temperature, topography and moisture.

Leaching and runoff are environmental concerns with herbicides that exhibit low soil retention or that are subject to changing solubility with changing water or soil pH.

Herbicides that exhibit high soil retention can travel with soil or sediments in runoff.

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Herbicides are important management tools in agriculture because they can be used instead of tillage for weed control, thereby conserving soil and moisture. The current trend in multiple crop rotations and conservation tillage practices allows growers to use a greater variety of herbicides to effectively manage weeds (Table 1). These herbicides have diverse biological and chemical characteristics. The spectrum of weeds they control and their soil behavior vary.

Chemical and Biological Behavior

The behavior of herbicides in soil and water is regulated by herbicidal properties, soil characteristics and climatic conditions. It is a function of acid or base strength, water solubility, volatility, soil retention and persistence. Table 2 describes the relative strength of these chemical and biological features. Table 3 gives the associated range of values. Figure 1 summarizes these features.

Acid or base strength. This measure refers to whether the pesticide has basic, acidic or nonionizable properties. This determines its ability to exist in the soil water or be retained onto soil solids. Thus, the acid or base strength of both the herbicide and the soil determines potential herbicide movement and plant uptake. In general, herbicides whose pH is close to the pH of the soil are strongly retained and are not subject to runoff, erosion and/or leaching. In contrast, herbicides whose pH is not close to that of the soil are less strongly retained and are subject to runoff, erosion and/or leaching. Also, they are more available for plant uptake than strongly retained herbicides.

Water solubility. This measure refers to how readily the herbicide dissolves in water. This determines the extent to which an herbicide is in the solution phase (plant available) or the solid phase. Water solubility plays a major role in determining the fate of herbicides in water, soil and air. An herbicide that is water soluble will not be retained by the soil.

Volatility. Volatility refers to the tendency of the herbicide molecule to become a vapor. The vapor pressure (VP) at 25 degrees C is an index of this characteristic. Herbicides with high vapor pressures are likely to escape from the soil and volatilize into the atmosphere. This may result in the unwanted movement of herbicide to sensitive areas or a loss of effectiveness at the application site.

Soil retention. Soil retention is an index of the binding capacity of the herbicide molecule to soil organic matter and clay. In general, herbicides with high soil retention are strongly bound to soil and are not subject to leaching. Those not exhibiting high soil retention are not strongly bound and are subject to leaching.

Soil persistence. The longevity of a herbicide molecule is normally expressed in terms of half-life ($t_{1/2}$), as determined under normal conditions in the

Table 1: Classification scheme for organic herbicide behavior in soils[1].

Chemical Category	Herbicide Family	Commonly Used Herbicides
Nonionic	dinitroanilines	Treflan/Prowl/Sonalan
	thiocarbamates	Sutan+/Eptam/Eradicane
	chloroacetamides	Lasso/Dual/Frontier/Harness/Surpass/Ramrod
	substituted ureas	Lorox/Karmex/Linnex
Acidic	phenoxys/benzoics/picolinates	2,4-D/MCPA/Banvel/Tordon/Stinger
	sulfonylureas	Accent/Beacon/Ally/Harmony/Pinnacle/Peak/Glean/Amber/Finesse/ Battalion/Permit
	imidazolinones	Pursuit/Arsenal/Assert
	organic phosphorus	Roundup/Touchdown/Ignite
Basic	triazines	atrazine/Bladex/Evik/Milogard/Igran/Sencor/Lexone
Strongly basic	dipyridiniums	Cyclone/Gramoxone Extra/Diquat

[1]Adapted from J.B. Weber, 1991. *Properties and Behavior of Pesticides in Soil*. In: Amer. Chem. Soc. Symposium Series, 1991. Atlanta, Georgia.

Table 2: Summary of the relative behavior of herbicides in soil. See Table 3 for associated values.

Herbicides	Water Solubility	Volatility	Soil Retention	Persistence
Dinitroanilines	very low	moderate-high	moderate-high	short-moderate
Thiocarbamates	low-moderate	high-very high	low-moderate	very short-short
Chloroacetamides	moderate	low-moderate	low	very short-moderate
Substituted ureas	very low-low	very low-moderate	low-high	short-moderate
Phenoxys/benzoics/ picolinates	low-high	very low-moderate	very low-low	very short-short (pH dependent)
Sulfonylureas	very low-high (pH dependent)	very low-low	very low-low (pH dependent)	short-long
Imidazolinones	moderate-high (pH dependent)	very low	very low-low (pH dependent)	short-long
Organic phosphorus	very high	very low	very high	N/A
Triazines	low-moderate (pH dependent)	very low-low	low-high (pH dependent)	very short-moderate
Dipyridiniums	very high	very low	very high	N/A

Table 3: Descriptive terminology and ranges for chemical and biological properties of organic herbicides.

Descriptive Teminology[1]	Acid Strength	Base Strength	Water Solubility	Volatility (VP)	Soil Retention[2]	Persistence
	pH	pH	(mg/L)	(mm Hg x 10^{-6})		(days)
Very low or very short	<2	>8	<10	<1	$<10^2$	<10
Low or short	2-4	6-8	$10-10^2$	1-10	10^2-10^3	10-30
Moderate	4-6	4-6	10^2-10^3	$10-10^2$	10^3-10^4	30-90
High or long	6-8	2-4	10^3-10^4	10^2-10^3	10^4-10^5	90-180
Very high or very long	>8	<2	$>10^4$	$>10^3$	$>10^5$	>180

[1]Adjectives describing the relative base or acid strength, water solubility, volatility, soil retention and soil persistence given in Table 2.
[2]Higher numbers mean greater soil retention.

region where it is used. This measure also can be called length of residual weed control and is generally expressed in some unit of time (days, weeks or years). This affects what and when farmers can plant again.

Nonionic Herbicides

Dinitroanilines *(Treflan, Prowl, Sonalan)*. As a rule, these herbicides are very low in water solubility, moderate to high in soil retention, and moderate to high in volatility. For adequate weed control, incorporate them within 24 hours to 7 days after application. Soil composition is important in determining the rate of application, because soil texture and organic matter determines the degree of soil retention. These herbicides are broken down by microbial decomposition. Residual weed control ranges from 10 to 90 days.

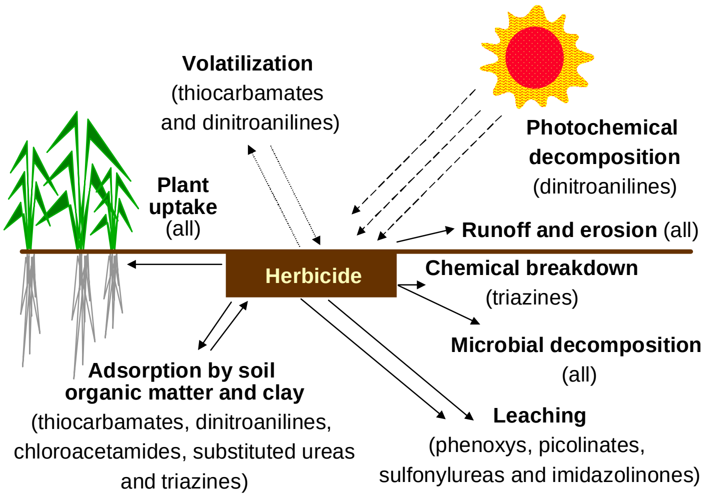

Figure 1: Processes that make herbicides inactive.

Thiocarbamates *(Sutan+, Eptam, Eradicane).* These herbicides exhibit low to moderate water solubility, low to moderate soil retention, and high to very high volatility. Major atmospheric losses could occur if they are not immediately incorporated. As with the dinitroanilines, the rate of application is highly dependent on soil texture and organic matter. Higher clay and organic matter mean a higher rate of application, because more herbicide is retained on soil surfaces. In addition, soil texture, temperature and moisture influence volatilization. Higher temperatures and soil moisture speed volatilization, as does coarser (sandier) soil. Depending on environmental conditions, the herbicides persist in soil from less than 10 to 30 days. The major means of dissipation is microbial decomposition.

Chloroacetamides *(Lasso, Dual, Frontier, Harness, Surpass, Ramrod).* This family of herbicides exhibits moderate water solubility, low soil retention, and low to moderate volatility. As with the dinitroanilines and thiocarbamates, soil texture and organic matter are important in determining application rates. Volatilization rates are generally quite low. However, if no rainfall occurs within seven days following application, mechanical incorporation may be needed to retain adequate pre-emergence activity. Soil persistence ranges from less than 10 to 90 days. The major means of dissipation is microbial decomposition.

Substituted ureas *(Lorox, Karmex, Linnex).* These herbicides exhibit very low to low water solubility, very low to moderate volatility, and low to high soil retention. They display a wide range of behaviors in soils, depending on texture, moisture and organic matter. They have short to moderate persistence and are degraded in soil by microorganisms.

Acid Herbicides

Phenoxys/Benzoics/Picolinates *(2,4-D, MCPA, Banvel, Tordon, Stinger).* These compounds have high to very high acidity, low to high water solubility, and very low to moderate volatility. Both water solubility and soil retention are dependent on soil pH, with maximum soil adsorption occurring under acid conditions. Soil retention ranges from very low to low. Organic matter is the major component that binds this class of herbicides to soil. Persistence ranges from very short to short, with the exception of Tordon, which exhibits long persistence. The major means of breakdown is microbial decomposition.

Sulfonylureas *(Accent, Beacon, Ally, Harmony, Pinnacle, Peak, Glean, Amber, Finesse, Battalion, Permit, Upbeet).* These herbicides have moderate to high acidity and very low to low volatility. Herbicide retention ranges from very low to low, and water solubility from very low to high. Both water solubility and soil retention are pH dependent. Retention is directly related to organic matter, and mobility is inversely related to it. Persistence ranges from short to long and is greatly influenced by environmental conditions. Both chemical and microbial decomposition are important in degradation. However, these herbicides appear to be more persistent under basic than acidic conditions.

Imidazolinones *(Arsenal, Pursuit, Assert).* These compounds have high to very high acidity, moderate to high water solubility, and very low volatility. Both water solubility and soil retention depend on soil pH, with maximum soil adsorption occurring under acid conditions. Soil retention is very low to low. Soil binding is greatly influenced by soil organic matter. Persistence ranges from short to long. Dissipation is due to microbial decomposition, with warm, moist conditions favoring decomposition.

Organic phosphorus *(Roundup, Touchdown, Ignite).* These herbicides exhibit high acidity, very high water solubility and very low volatility. They readily react with clay and metal oxides in soils to form insoluble iron, aluminum and calcium precipitates. As a result, they have very high soil retention. Soil mobility is very low. Persistence is very short due to the formation of insoluble precipitates, making them biologically inactive upon contact with mineral soils.

Basic Herbicides

Triazines *(atrazine, Bladex, Milogard, Evik, Igran, Lexone, Sencor).* The base strength of these herbicides ranges from very low to low. As a consequence, water solubility is dependent on soil pH. These herbicides range from low to moderte in solubility, very low to low in volatility, and low to high in soil retention. Soil retention is generally highest at low soil pH. Higher pH soils exhibit low herbicide binding and increase the potential for crop injury and leaching. Both soil organic matter and clay mineral content are important in binding these herbicides to soil. Soil persistence ranges from very short to moderate. Chemical decay is a major avenue of herbicide degradation, with degradation dependent on soil pH. Degradation generally occurs faster under acidic than under neutral or basic conditions.

Strongly Basic Herbicides

Dipyridiniums *(Cyclone, Gramoxone Extra, Diquat).* These compounds exhibit very high base strength, very high water solubility, and very low volatility. They readily bind to the organic matter, and clay minerals are chiefly responsible for this binding. Although they are very soluble in water, because of their cationic nature and their soil retention, they are considered to be immobile in soil. The reported values for soil persistence are long to very long. However, when these herbicides are bound to the internal surfaces of clay minerals, the compounds are unavailable to microorganisms for decomposition. Thus, these compounds are found in a biologically inactive, yet stable form.

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