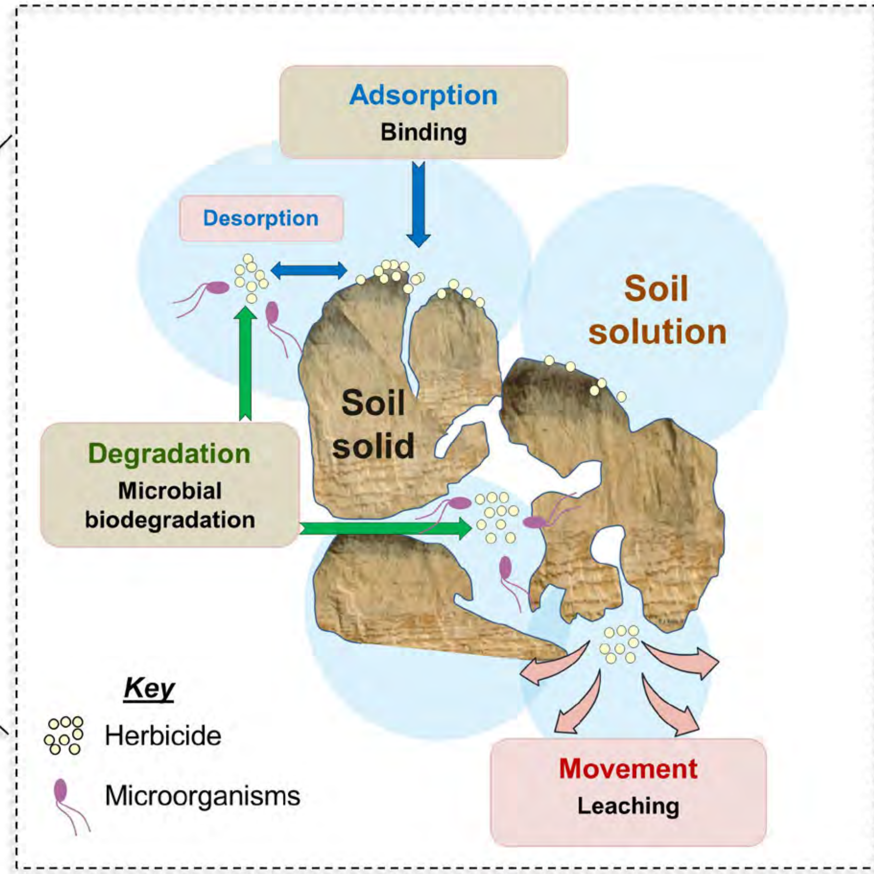

Figure 1. Multiple processes determine the fate and persistence of herbicides in citrus grove soils.

Understanding the fate and persistence of herbicides in soils

By Ramdas Kanissery, Rachel Fenn, Biwek Gairhe and Davie Kadyampakeni

Chemical weed control, using herbicides to manage weeds, is an important production practice in citrus groves. Herbicides applied in groves can end up in the soils from direct spray hits, indirect or non-target spray movement (also known as drifts) or release from the dead weeds and vegetation. In soil, the retention and distribution of herbicides are determined by the physicochemical and biological characteristics of the soil, properties of the herbicide and the environmental conditions in which the interaction is taking place.

Adsorption, desorption, degradation and movement are the key processes that determine the fate and persistence of herbicide in the soil (Figure 1). Understanding these processes helps growers select an effective chemical weed management strategy while minimizing impacts on the crop and environment.

ADSORPTION AND DESORPTION

Adsorption (sometimes known as 'sorption') is the retention of herbicide compounds onto the soil surface through chemical interactions that are often weak and reversible. Adsorption plays a critical role in determining the herbicide persistence throughout the soil environment by affecting bioavailability (availability of herbicides for microorganisms, plants etc.). Herbicides adsorbed to soil are temporarily non-bioavailable for weed uptake or microbial transformation.

It is helpful to think about the composition of soils to understand the process of adsorption. Typically, soil contains roughly 50 percent solid material and 50 percent pore space. Clay minerals and organic matter form the solid component of the soil and provide the specific binding sites for herbicide adsorption. There are space-forming pores between the solid components of soil that hold moisture (soil water) and air.

The herbicide in the soil will be partitioned between the soil solution and the solid phase (Figure 1). Surface sites where the herbicides can be adsorbed or bound vary depending on the type of herbicides. For instance, clay minerals rather than organic matter play a significant role in the strong adsorption of glyphosate in the soil.

Desorption is the reversal of adsorption, in which adsorbed herbicide returns to the soil solution. The return of a herbicide from the solid phase to soil solution makes herbicides available for microbial degradation and plant uptake once again.

Certain herbicides used in citrus have the potential to interact with soil nutrients, and adsorption seems to facilitate such effects. For instance, glyphosate has shown to influence the mobility of phosphates (P) in the soil. Researchers attribute this to the similarity in mechanisms by which glyphosate and P are adsorbed to the soil solids. Competition for adsorption sites in soil between glyphosate and P may have potential impacts on phosphate mobility, and therefore, its availability to crops. Inadequate P availability is one of the major constraints for productivity in citrus.

An ongoing research project at the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) Citrus Research and Education Center and the Southwest Florida Research and Education Center (SWFREC) is investigating this relationship between glyphosate and phosphate in Florida sandy soils. Although this relationship has been determined in several other types of soils and production systems, investigation of these effects have not yet been determined for Florida citrus production, which could likely be impacting citrus tree health and local water quality.

DEGRADATION

Degradation is the major route for herbicide transformation and loss from soil. For most herbicides, soil microorganisms (bacteria and fungi) facilitate the biological degradation (hence, biodegradation) through enzymatic transformations. These organisms utilize the herbicide as a source of energy and food.

Several factors, such as microbial activity and diversity, water availability, soil temperature and pH affect biodegradation of herbicides in soils. Many herbicides, originally thought to not stay active long-term, are found to form residues in the soil due to lack of microbial activity.

For example, glyphosate can be found persisting in the soils for up to 200 days when there is no or minimal soil microbial activity. The persistence of a herbicide in the soil can be estimated from its half-life, which is the time required for half of the initially applied herbicide to degrade and

Active Ingredient	Example Product	Adsorption *Soil binding capacity*	Movement *Leaching in sandy soil*
Bromacil	Hyvar	Low	Highly Likely
Simazine	Princep	Moderate	Likely
Diuron	Karmex	High	Moderate
Norflurazon	Solicam	High	Moderate
Indaziflam	Alion	High	Likely
Flumioxazin	Chateau	High	Unlikely
Pendimethalin	Prowl H_2O	Very High	Very Unlikely

Table 1. Adsorption and leaching potential of pre-emergent herbicides used in citrus weed management.

Source: *National Pesticide Information Center (http://npic.orst.edu/)*

decompose in the soil.

Certain herbicides (e.g., 2,4-D) are rapidly decomposed by microorganisms and hence have a very low half-life in soil. Degradative products formed as a result of biological degradation are known as metabolites, and their presence indicates microbial activity in the soil. Mineralization is the complete transformation of a herbicide compound into carbon dioxide by microorganisms.

In addition to biodegradation, non-biological loss of the herbicide from soil occurs through volatilization, photodegradation and chemical degradation.

Volatilization is the transformation of herbicides in liquid or solid form to a gaseous phase in the field. It can result in the loss of applied herbicides from the target areas and increase the potential for herbicide drift and consequent adverse effects in non-target areas.

Photodegradation is the decomposition of herbicides by sunlight. The ultraviolet rays in sunlight are primarily responsible for degrading herbicides.

Chemical degradation is the transformation of herbicides through complex chemical reactions in the soil (e.g., oxidation, reduction and hydrolysis).

Most herbicides used for weed control in citrus have low volatilization, photodegradation and chemical-degradation potential.

LEACHING

The vertical transport of herbicides in the soil by water is known as leaching. Leaching usually occurs when herbicides in the soil move in a downward direction. Herbicide movement can occur in any direction, and lateral movement is termed as herbicide runoff.

Herbicides may also be transported due to the physical movement of soil particles, or erosion, especially if the herbicides are tightly bound to soil particles. Generally, the leaching potential of a herbicide can be limited by its high adsorption or binding capacity in soil (Table 1). Leaching would result in a reduction in herbicide concentration near the soil surface due to the movement of a portion of the herbicide within the soil profile. As a result, the weed-control efficacy, particularly

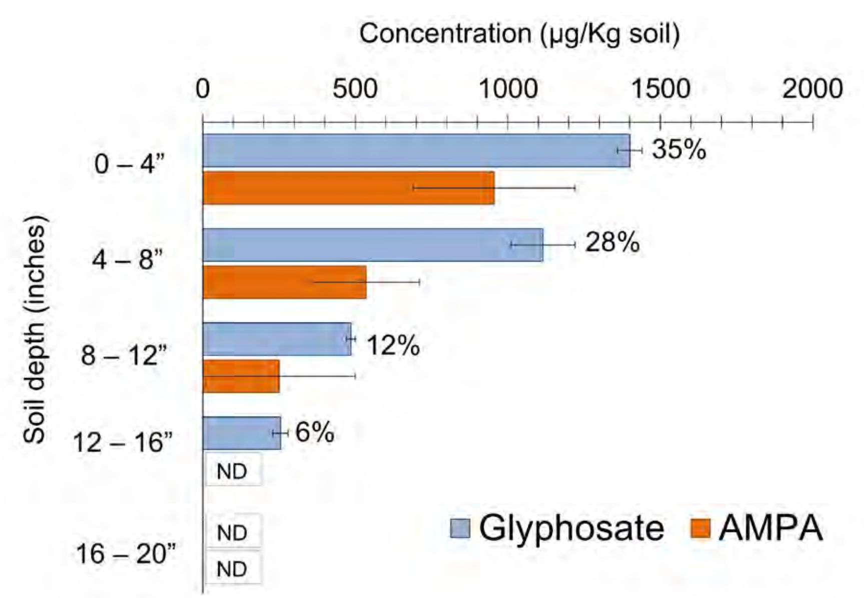

Figure 2. Leaching of glyphosate in flatwood soils was observed at 40 days after herbicide application. Values above the glyphosate bars in the graph indicate the accumulation of glyphosate expressed as the percentage of glyphosate initially applied. Aminomethyl phosphonic acid (AMPA) is the metabolite of glyphosate. ND = not detected.

of pre-emergent herbicides, may decline as they become more dilute in the weed-seed germination zone in the soil.

Soil properties like water-holding capacity and herbicide properties like water solubility determine the extent of leaching of a particular herbicide in soil. In Florida, there is concern about herbicide leaching due to high annual rainfall and the water permeability of sandy soils (with mostly >95 percent sand content). For example, the use of bromacil, a pre-emergent herbicide in citrus, was restricted in non-bedded citrus groves located in permeable, well-drained soils due to its potential leaching and subsequent detection in groundwater.

Similarly, herbicide leaching will be reduced in soils with low drainage properties. In a recent study conducted at SWFREC, glyphosate was found accumulating up to a depth of 16 inches below the surface (Figure 2, page 20). The study was conducted in a flatwood soil, which is known for its relatively high water-holding capacity and high water table. About 80 percent of applied glyphosate was retained in the top 16 inches of soil, at 40 days after the herbicide application. The primary degradation product of glyphosate, i.e., aminomethyl phosphonic acid, was also detected up to the depth of 8 to 12 inches below the soil suface.

CLOSING THOUGHTS

Understanding how long a herbicide persists or remains active in the soil is very important as it determines the window for weed control in citrus groves. This knowledge also helps growers to determine the waiting time before planting new trees and resets on a herbicide-treated site. An ideal herbicide is the one that manages the targeted weed for the desired period without leaching into the groundwater, and then degrades or breaks down in the soil to naturally occurring and environmentally benign compounds.

Ramdas Kanissery is an assistant professor at the UF/IFAS SWFREC in Immokalee. Davie Kadyampakeni is an assistant professor at the UF/IFAS CREC in Lake Alfred. Rachel Fenn and Biwek Gairhe are graduate students at CREC and SWFREC, respectively.