

## Off-Site Movement of Herbicides

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The fate of herbicides or other pesticides in the environment can be grouped broadly into “degradation processes” and “transfer processes”. *Degradation* implies one or more changes in chemical structure that alters the potency or activity of the compound. Usually this means reduced phytotoxic activity but there are cases where intermediate degradation products also have some level of activity. Generally speaking, all herbicides degrade in the environment but the rate of degradation can vary widely among specific herbicides and environments. *Transfer* processes, on the other hand, refer to changes in the location or availability of the herbicide not associated with changes in the chemical structure. There are four primary ways that herbicides can move off-site: volatilization, physical particle movement, water (leaching or runoff), and through uptake and removal in plants or animals. The potential for any type of off-site herbicide movement is greatly affected by the chemistry of the specific herbicide and the environmental conditions.

### Off-target vs off-site:

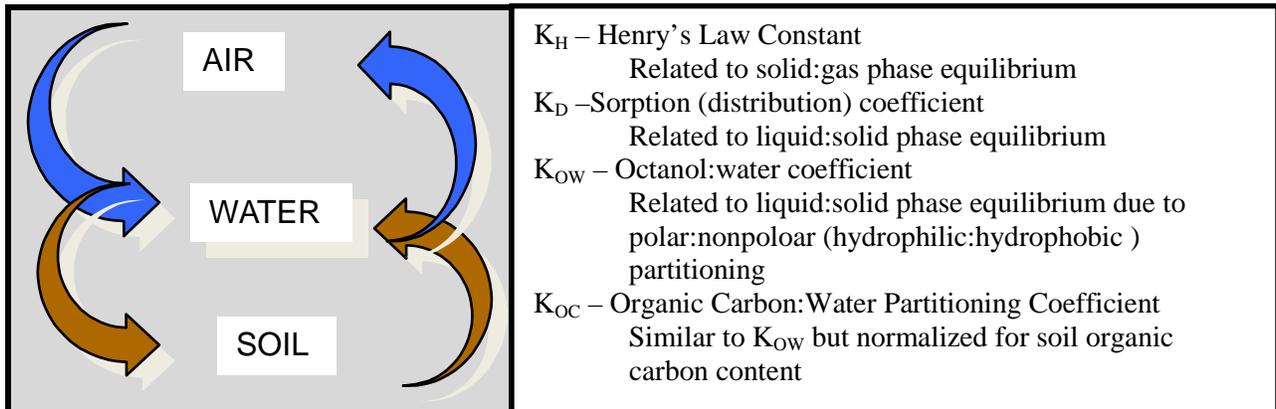
Two similar sounding terms have very different meanings in the context of herbicide applications. Off-target applications are those that miss the target site or zone. For example, the target of a post emergence herbicide is weed foliage. Thus, a post emergence herbicide that misses the plant and hits the soil technically is “off target”. Similarly, a soil-applied herbicide is usually targeted to the surface of the soil or a shallow three dimensional layer of soil to ensure that germinating seedling are exposed to the herbicide. Herbicides incorporated too deeply or not deep enough are not on target. While obviously these are not ideal situations, off target applications usually result simple cases of reduced weed control efficacy and wasted money. Of greater concern for the environments are cases of off-site herbicide movement. Off-site movement refers to herbicides that misses or moves from the treated zone. The intended treatment zone could include whole fields or portions of a field such as blocks, strips, berms, furrows. The intended site could also be defined areas such as road shoulders, fence rows, lawns, or landscape areas or even individual plants. Herbicides that move off site also reduce efficiency and economics of weed control but can also result in non-target plant injury, environmental contamination, legal issues, and negative public perceptions of weed management operations and agriculture in general.

### Herbicide Chemistry:

The chemical structure and formulation of an herbicide can have a large impact on the potential for off-site herbicide movement and the most likely routes of movement. The chemistry of the herbicide directly impacts the solubility, volatility, stability, and phase equilibrium of the product in the soil and water environment. With any pesticide in a relatively stable environment, the

active ingredient will reach an equilibrium (not necessarily equality) among the solid, water, and gas phases of the soil or water environment. There can also be significant interaction between specific herbicides and the environment, especially soil type, texture, pH, organic matter content, and moisture.

Figure: generalized herbicide partitioning diagram and coefficients.



Information on the phase partitioning of many herbicides is available online or in resources such as the WSSA Herbicide Handbook. In general, herbicides with relatively lower Henry’s Law Constant ( $K_H$ ) tend to partition into the liquid or solid phase while higher  $K_H$  values are associated with greater partitioning into the gas phase (more volatile). Compounds with high sorption coefficients (either  $K_d$  or  $K_{oc}$ ) tend to be more tightly bound to soil particles or soil organic matter while products with low sorption are less tightly bound and tend towards the liquid phase. Lipophilic herbicides (those with high  $K_{ow}$ ) tend to bind to lipids, especially those in organic matter while low  $K_{ow}$  compounds are much more likely to be found in the water phase. It is important to remember that these are “rules of thumb” and behavior of any herbicide depends simultaneously on all of these coefficients and other factors.

### Volatilization

Movement of volatile herbicides generally is due to herbicide active ingredients that “evaporate” from leaf or soil surfaces after deposition on the intended site. Herbicide movement in the gas phase is somewhat affected by air temperature, wind speed, and soil moisture (e.g. high temp, high wind, and high moisture tend to increase volatilization). However, vapor pressure, which is related to the chemical structure and formulation of the herbicide, is the most important factor affecting potential for off-site movement due to volatilization. In certain cases, formulation technology is used to change the volatility of herbicides. For example, the 2,4-D ester is considerably more volatile than the amine formulation. Relatively speaking, most herbicides are not especially volatile (Table) but we do tend to require incorporation of herbicides that are more volatile than  $1 \times 10^{-6}$  mm Hg to minimize losses due to volatilization. Proper herbicide selection

and understanding of factors influencing volatility, and timely incorporation can minimize the potential for off-site movement of volatile herbicides

Table. Vapor pressures for some herbicides and example compounds.

■ methyl bromide	vp	1640 mm Hg @25C
■ rubbing alcohol	vp	60
■ water	vp	20
■ EPTC	vp	$3.4 \times 10^{-2}$
■ clomazone	vp	$1.4 \times 10^{-4}$
■ trifluralin	vp	$1.1 \times 10^{-4}$
■ oxyflourfen	vp	$2.0 \times 10^{-6}$
■ simazine	vp	$2.2 \times 10^{-8}$
■ glyphosate	vp	$4.3 \times 10^{-10}$
■ sulfonylureas	vp	$\sim \times 10^{-15}$

### Physical Drift

Herbicide drift generally refers to the off-site movement of herbicide droplets before they are deposited on the target surface. This type of off-site movement is a common cause of problems if sensitive plants are growing near a treated area and is most subject to equipment setup and decisions made by the applicator in the field. Environmental conditions contribute to potential for drift; the effect to high wind speed should be fairly obvious but high temperature and low humidity can also lead to drift conditions because of rapid evaporation of the water droplets – small droplets are lighter and can move off-site more easily than large droplets. Occasionally, temperature inversion conditions can lead to very still air and very slow settling of fine spray droplets; these can also be prone to drift. Equipment setup and application decisions strongly affect the potential for drift. Nozzle type, orifice size, spray pressure, and nozzle orientation can all affect the size distribution of spray droplets. Similarly, boom height (whether ground or aerial) can affect drift because greater distances between nozzle and target allow more time for evaporation and lateral movement due to winds. The consequences of herbicide drift can vary depending on the level of drift, the activity of the herbicide, and the sensitivity of nearby plants. Physical drift can best be managed by setting up equipment to apply fewer fine droplets, leaving appropriate buffers to sensitive areas, and monitoring environmental conditions at the applications site. Above all, physical drift potential can be reduced by adequately training sprayer operators and avoiding applications during adverse weather conditions.

### Off-site movement on soil particles:

Herbicides bound to soil particles can move off site along with soil eroded by wind or water. When significant off site herbicide movement occurs due to wind erosion, it is usually associated with dry soil conditions, very little vegetation cover, and high wind speeds. Injury is more common with herbicides that are persistent and active at very low concentrations and the

presence of highly sensitive non target plant species. Herbicides bound to soil particles can also be moved off site with surface water runoff – either irrigation tail waters or heavy rainfall conditions that surpass the infiltration rate of the soil. These herbicides tend to end up in the bottom of water courses or holding areas. Off-site movement of herbicides on soil particles is primarily managed by minimizing soil erosion through water and vegetation management, increasing water infiltration, and decreasing the total amount of surface water leaving the field.

### **Herbicide leaching or percolation losses.**

Herbicides that move too deeply in the soil profile to be active on the target weeds are also “off site”. The usual target zone for soil-applied herbicides is the top inch or two of soil where most weed seeds germinate. Herbicides that are poorly soluble in water and strongly absorbed to soil tend to have low potential for leaching. Conversely, water soluble herbicides with weak binding properties can move to a greater extent in soil. Leaching potential is also affected by the timing and amount of irrigation or rainfall that occurs after the herbicide application. Large amounts of water on the soil surface shortly after the herbicide application is more likely to lead to leaching compared to delayed irrigation or precipitation because of time-dependant binding. Soil texture and structure also can affect leaching potential; coarse texture soils, channels, and cracks can lead to greater losses into the profile due to leaching or mass flow. Once herbicide moves beyond the root zone, they tend to be relatively more persistent in the soil environment due to more anerobic conditions, less microbial activity, and greater temperature stability. Leaching is best minimized through proper herbicide selection, effective and timely irrigation management, and soil management that minimizes channeling and cracks.

### **Plant and animal uptake and removal.**

Off-site movement of herbicides due to plant or animal uptake and removal from a treated field is usually only a very small portion of the herbicide applied to a site. However, this route of herbicide movement can be economically important due to the potential illegal residues in the harvested commodity which is the primary reason for preharvest intervals (PHI), grazing, and crop residue use restrictions. Specific examples include very specific limitations on when and where certain herbicides can be used because of their persistence in plant tissue (even through the composting process) and potential damage to highly susceptible species.

There are many economic and environmental reasons to minimize off-site movement of herbicides. Increased weed control efficacy, economic efficiency, avoiding legal claims and disputes, stewarding soil and water resources, and protecting the environment. The potential for off-site herbicide movement can be greatly reduced through proper equipment setup, operator training, and weather and environmental monitoring. A basic level of understanding of the chemical, soil, and environmental factors that affect herbicide availability and potential routes of movement can lead to better herbicide recommendations, better applications, and more effective weed control treatments with fewer adverse effects on the environment.