A Postemergence Primer

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A postemergence primer
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Postemergence herbicides are the most widely used weed management tool in Iowa's corn and soybean acres. Application of the herbicide directly to the target bypasses the myriad of soil interactions that influence preemergence herbicides. However, killing weeds with postemergence products is not as simple as merely getting the herbicide onto the leaf of the weed. This paper will discuss the factors that influence the activity of postemergence weeds.

Foliar absorption

The first step for effective weed control is to get the herbicide from the leaf surface into the leaf. Movement from the leaf surface is driven by diffusion; the herbicide simply moves from an area of high concentration (leaf surface) to areas with a low concentration (inside the leaf). The amount of herbicide and the speed at which it moves is influenced by many factors, including chemical properties of the herbicide, characteristics of the leaf surface, application parameters (spray volume, droplet size, spray additives, etc.), and environmental conditions. The amount of herbicide that successfully moves off the surface into the leaf largely determines the effectiveness of a herbicide application.

While diffusion of a herbicide into the leaf appears to be a simple process, it is complicated by the fact that the leaf consists of numerous layers, each having unique characteristics that may favor or hinder movement of the herbicide towards the target site. Leaf components that must be traversed include the cuticle, cell wall, cell membrane (plasmalemma), and the cytoplasm.

The cuticle consists of a base resembling a sponge with a thin layer of epicuticular wax on the surface. The base of the sponge consists of polar compounds (cutin), while the pores are filled with non-polar wax. The composition of the epicuticular wax on the cuticle surface varies among species, with some plants having a smooth layer of wax, whereas in other species the surface consists of wax platelets extruding from the surface. The epicuticular wax is believed to be the primary barrier to absorption of most postemergence herbicides. Movement of herbicides across the cuticle varies among species (Figure 1). Three days after application approximately 60% of glyphosate had penetrated the cuticle of foxtail, but less than 40% had made it into the leaves of velvetleaf. The difference in absorption parallels the relative activity of glyphosate on foxtail and velvetleaf.
The absorption pathway of herbicides varies depending on their polarity (solubility). Non-polar herbicides (ester forms of 2,4-D, ACC-ase inhibitors (Poast, Select, etc.)) are believed to readily migrate into the epicuticular wax and penetrate the cuticle through the wax channels, and then migrate into the extracellular space inside the cell wall. Polar herbicides (glyphosate, amine forms of 2,4-D) have a more difficult time penetrating the cuticle since they are naturally repelled by the epicuticular wax. Once polar herbicides pass through the epicuticular wax, they enter the cutin matrix and migrate inwards through the polar components of the cuticle.

Diffusion drives herbicide absorption until the herbicide reaches the cell membrane. The cell membrane separates the living part of plants (cytoplasm, nucleus, organelles, etc.) from the non-living components (cell walls, extracellular space, etc.). Herbicides must penetrate the cell membrane and enter the cytoplasm in order to reach the site of action. Most postemergence herbicides are able to move across the cell membrane against a concentration gradient (move from an area with a low concentration to one with a high concentration). The ability to move against the concentration gradient is critical in achieving the high level of efficacy of modern herbicides.

Environmental effects on postemergence herbicides

Any person involved with weed management recognizes that the performance of herbicide can vary widely among similar situations. Annual weeds are most susceptible to postemergence...
herbicides while small and growing under favorable weather conditions. Researchers in Canada (Harker and Blackshaw, 2003) found that wild oat control with an ALS herbicide was directly related to growth rate, with a 7% increase in control for every 0.2 inch of wild oat growth the day before application. Most herbicide labels state to make applications to weeds that are actively growing.

The exact mechanisms by which the environment influences herbicide activity are poorly understood. Changes in the cuticle are believed to strongly influence herbicide absorption. Plants with adequate moisture have hydrated cuticles which spread the epicuticular waxes apart. This may facilitate movement of polar herbicides through the non-polar waxes. During periods of water stress the cuticle dehydrates, therefore pulling the waxy units together which may impede the absorption of herbicides. Decreased penetration of the cuticle is a major cause of control failures when plants are under water stress.

Rainfall following application may impede herbicide performance by washing herbicide off the leaf surface before it has a chance to penetrate into the leaf. Most herbicide labels have a statement concerning rainfastness, the time required between application and rainfall to eliminate reductions in performance. There is no uniform method of determining rainfastness, and the time requirement varies widely upon the situation (herbicide, rate applied, weed species, etc.). The effect of rain on common lambsquarters control declined as the rainfast period increased, yet control was still negatively affected when rain was delayed for four hours (Figure 2). Addition of additional surfactant to a fully loaded glyphosate formulation did not overcome the negative effect of rain.

![Graph](image)

**Figure 2.** Effect of rainfast period on 12" common lambsquart control with 0.75 lb ae/A glyphosate. C. Boerboom, Univ. Wis, 2005, unpublished data.
Plant growth, and therefore herbicide activity, is affected by the interaction of many factors, including temperature, relative humidity, solar radiation, and soil water content. Understanding the influence of weather on herbicide performance is complicated by the fact that conditions prior to herbicide application, in addition to those at the time of application, influence activity. Minimum temperatures during the week prior to application, soil moisture deficits in the ten days prior to application, and maximum temperature on the day of application were all found to significantly influence postemergence control of wild oat (Medd et al. 2001). The complexity of plant: environment interactions have prevented the development of tools that would allow precise adjustment of herbicide treatments (rates, additives, etc.) based on weather conditions.

**Application parameters effects on postemergence herbicides**

Essentially all postemergence applications in corn and soybean production use water as a carrier for the herbicide. Spray nozzles are used to fracture the water into small droplets, therefore allowing a relatively small volume of liquid to provide adequate coverage of the target vegetation. Carrier volume and droplet size influence the activity of herbicides, with optimum application parameters varying with specific herbicide.

Decreasing droplet size generally improves herbicide performance due to the following factors (Knoche, 1994):

- Improved canopy penetration;
- Decreased deposition variability;
- Improved droplet retention; and
- Improved efficiency for herbicides with limited mobility within the leaf.

However, too small of droplets can result in significant problems due to: 1) evaporation of the droplet before deposition on the target, and 2) off-target drift. Glyphosate is much less responsive to changes in droplet size than other herbicides, both contact and systemic, due to its efficient transport throughout the plant. There is very little correlation between coverage and effectiveness of glyphosate compared to other herbicides. This allows glyphosate to be applied with low-drift nozzles that would compromise the activity of most postemergence herbicides.

The effect of carrier volume on herbicide efficacy is less consistent than that of droplet size. Decreases in carrier volume may influence herbicide efficacy by:

- Increasing deposition variability and increasing the likelihood of completely missing the target;
- Increasing droplet retention on difficult-to-wet plant surfaces;
- Increasing concentration of active ingredients and adjuvants in droplets; and
- Decreasing antagonistic effects of the carrier (glyphosate).

Applicators frequently must compromise when selecting droplet size due to the conflicts between target coverage and off-target drift (i.e. small droplets provide better coverage yet are prone to drift). In addition, the optimum droplet size and carrier volume differs among target species due to differences in leaf surfaces and density of crop canopy. No one setup will provide optimum performance for all herbicides and situations.
Spray adjuvants effects on postemergence herbicides

As discussed earlier, the plant cuticle is a formidable barrier to the absorption of postemergence herbicides. Spray adjuvants are used with postemergence herbicides to help overcome the barriers that impede movement of the herbicide from the leaf surface to the interior of the cell. The Weed Science Society of America defines an adjuvant as any substance in a herbicide formulation or added to the spray tank to modify herbicidal activity or application characteristics. Some products are formulated with sufficient additives such that the user usually does not need to add them to the tank (2,4-D), whereas other products require addition of adjuvants for all uses (Pursuit, Option, etc.). This article will discuss the types of adjuvants commonly used with postemergence products to improve herbicide absorption.

There are three primary types of adjuvants used to enhance herbicide performance: surfactants, crop oil concentrates and ammonium fertilizers. Surfactants are a class of adjuvant widely used with herbicides in corn and soybean production. The word surfactant is derived from the term surface active agent, and describes the ability of these compounds to function at the interface between compounds with different solubilities. Surfactant molecules have two distinct components, one is hydrophilic (water soluble) whereas the other is lipophilic (oil soluble). The lipophilic portion of the molecule typically is a long alkyl chain. The two portions of the surfactant molecule allow it to associate with liquids having wide ranging solubilities. Addition of surfactant to a mixture of oil and water will allow a suspension to form by creating an emulsion the oil to go into suspension in water by creating an emulsion.

There are several types of surfactants available, but most products marketed for use with postemergence herbicides are classified as nonionic because they have a neutral charge. Cationic surfactants are formulated with several herbicides, including most glyphosate products. A measurement frequently used to describe surfactants is the HLB (hydrophilic/lipophilic balance). The HLB describes the ability of the surfactant to associate with hydrophilic and lipophilic compounds. Surfactants with a high HLB balance associate better with water soluble compounds than with oil soluble compounds. Most surfactants used with postemergence herbicides have HLB values of 12 or greater. In recent years silicone surfactants have been introduced for agricultural uses. The carbon-based lipophilic chain is modified with silicone in silicon surfactants to dramatically change their characteristics.

Crop oil concentrates (COC) are a combination of a surfactant and a non-phytotoxic oil. Most COCs contain between 15 and 20% emulsifier. COCs are frequently classified by the type of oil used to manufacture them, either a petroleum-based oil or a modified vegetable oil. A methylated seed oil (MSO) is manufactured with a vegetable based oil that has been chemically altered by attaching methanol units to the oil. The attachment of methanol to the oil alters the HLB of the oil to an optimum level. Methylated seed oils seem to have the greatest advantage over traditional COCs in situations where weeds are under stress from environmental conditions.

A new class of COC has recently been introduced that contains approximately twice the concentration of surfactant as traditional COC, and are known as high surfactant crop oil concentrates (HSCOC). Use rates typically are half of a typical COC. While HSCOC have performed similarly to COC in many tests, currently they are not specified on herbicide labels.

The final class of additives is nitrogen based fertilizers. Ammonium sulfate (AMS), 28% N and 10-34-0 have all been used at some time for this purpose. It is believed that the ammonium
Adjuvants can enhance herbicide activity in several different ways. The effect of surfactants on the surface tension of spray droplets is well documented. The epicuticular wax on the surface of leaves repels water, resulting in beading of spray droplets as they land on leaves. In some situations a high percentage of spray droplets may simply bounce off leaves, resulting in the herbicide falling harmlessly to the ground. Surfactants reduce the surface tension of spray droplets, increasing spray retention and allowing the spray droplets to spread over a larger area (Figure 3). An increase in spray coverage is especially important with contact herbicides. In most situations the optimum effect of surfactants is reached at concentrations higher than needed to minimize droplet surface tension. This indicates that the effect of surfactants on herbicide activity is due to more than a simple reduction in spray droplet surface tension.

Silicon surfactants reduce the surface tension of water much more than traditional surfactants, resulting in a rapid spreading of spray droplets. These products have been found to increase rainfastness with some products. While in some situations silicon surfactants may have advantages over traditional surfactants, they can also be deleterious to herbicide absorption. Silicone surfactants do not always perform well with herbicides that require small, concentrated spray deposits to maximize uptake.

While the effect of surfactants and crop oil concentrates on spray retention and spread are well documented, the other mechanisms by which they enhance herbicide absorption are less clear. It is believed these products are primarily involved in aiding herbicide movement through the cuticle, but there is evidence that they may also facilitate movement across the cell membrane. Some additives have been shown to disrupt the integrity of the epicuticular wax layer on leaf
surfaces. The wax platelets on the surfaces of many leaves may be softened or disrupted by the oils in COCs. It is speculated that some additives act as humectants. As spray droplets dry on the leaf surface the herbicide molecules may form solid crystals. It has been demonstrated that herbicide absorption from a solid is much slower than from a herbicide in solution. An additive that reduces the rate at which the spray droplet evaporates may enhance absorption by keeping the herbicide in solution for a longer time.

Ammonium salts are also widely used with postemergence herbicides. The primary benefit of AMS when used with glyphosate is to reduce the antagonism between glyphosate and calcium and other salts present in the carrier. AMS should be added to the tank prior to glyphosate in order to prevent formation of inactive complexes between glyphosate and the salts present in the carrier.

Most postemergence herbicides are weak acids, and their polarity is dependent upon the pH of the solution they are in. At lower pHs (acid) these herbicides become more lipophilic and better suited to penetrate through waxes and cell membranes. Plants are efficient at absorbing ammonium due to their need for nitrogen. An active transport mechanism has been proposed where ammonium absorption is driven by the transfer of hydrogen ions (H⁺) to the outside of the cell. Pumping hydrogen ions to the extracellular space will reduce the pH of this area. Thus, use of ammonium as a spray additive may enhance herbicide absorption by creating a pH gradient across the cell membrane that favors absorption due to the behavior of weak acid herbicides. The benefit of ammonium salts on herbicide absorption is frequently more consistent on velvetleaf than other weed species. This may be due to the fact that the leaf surface of velvetleaf is alkaline (high pH). The specific benefit of the ammonium ion for enhancing herbicide absorption in velvetleaf has yet to be elucidated, but it may be due to preventing the formation of calcium salts of the herbicide parent acid.

Selecting the appropriate adjuvants can be confusing even for experts, but it can make the difference between success and failure in weed control (Figure 4). There are many products available, and since adjuvants are not regulated, manufacturers usually do not provide specific information about the composition of their products. This makes comparing products difficult, if not impossible. The herbicide label is the best source of information and specifies the legal requirement for the type of adjuvant to be used with that product.
Summary
Postemergence applications allow the herbicide to be placed directly onto the target. However, to be effective, the herbicide must move from the leaf surface into the plant and reach the site of action at toxic concentrations. Understanding factors that influence absorption, and the role of spray additives, can improve the consistency of postemergence products.

References
Harker, K.N. and R.E. Blackshaw. 2003. Leaf expansion rate may help determine when low wild oat herbicide rates will be effective. Weed Technol. 17:829-835.