GWC-2

The Glyphosate, Weeds, and Crops Series

Understanding Glyphosate To Increase Performance

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This publication was reviewed and endorsed by the *Glyphosate, Weeds, and Crops* Group. Members are university weed scientists from major corn and soybean producing states who have been working on weed management in glyphosate-resistant cropping systems.

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Reference to products in this publication is not intended to be an endorsement to the exclusion of others that may be similar. Persons using such products assume responsibility for their use in accordance with current directions of the manufacturer.

Understanding Glyphosate To Increase Performance

Glyphosate and Roundup Ready® crops are popular because they provide consistent, broad spectrum weed control with minimal risk of crop injury. On occasion, however, growers experience poor weed control with glyphosate, generally because of application or weather-related factors. This publication examines the factors that affect glyphosate performance and offers management strategies to minimize fluctuations in its effectiveness.

Product Formulations

If you look at any glyphosate product label, you'll notice the ingredient statement. For example, the Roundup Ultra® label states its active ingredient as "Glyphosate, N-(phosphonomethyl) glycine, in the form of its isopropylamine salt." Glyphosate is the common name of the active ingredient, and the rest of the information describes the chemical's structure.

Regardless of the product, the active ingredient that actually kills weeds — glyphosate — is the same. Glyphosate products vary only in the type of salt and proprietary products included in the formulated products. Manufacturers add these components to create products that are convenient to handle, mix well with other agricultural products, or facilitate movement of the active ingredient into plants. The differences in performance among glyphosate products are due to the types and amounts of proprietary compounds included in the formulation. Manufacturers are not required to reveal these components, and they are listed as inert ingredients on the label.

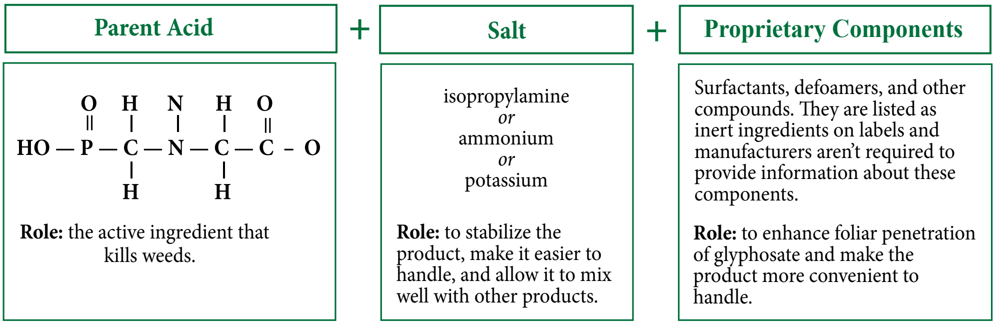

Figure 1. Components of a Glyphosate Product. *Every glyphosate product is composed of three parts: the parent acid, salt, and proprietary components.*

Several newer product formulations contain higher concentrations of glyphosate, or a different salt than the original Roundup® formulations (Table 1). On each product label's ingredient statement, the glyphosate concentration is stated in terms of pounds of acid equivalent (ae) per gallon. A formulation's acid equivalent is just a measure of the parent acid — the component that kills weeds (glyphosate).

Many labels also state the quantity of active ingredient (ai), which includes both the glyphosate and the salt present in the formulation. Do not use the active ingredient concentration to compare formulations that use different salts of glyphosate. When comparing the performance and cost of different products, compare them based on acid equivalent, not product rate or cost per gallon. The following formula is a simple way to fairly compare the costs of different glyphosate products:

$$\text{cost (\$) per lb. of glyphosate} = \frac{\text{price (\$) per gallon}}{\text{lbs. ae per gallon}}$$

Table 1. Composition of Selected Glyphosate Formulations. *This table shows the relationship between the ae concentration and amount of product required to apply equivalent amounts of glyphosate.*

Formulation	Salt	Active Ingredient (ai)/Gallon	Acid Equivalent (ae)/Gallon	Product to apply 0.75 ae/A
Roundup Original®/ Glyphomax®/GlyStar Plus®, etc.	isopropylamine	4 lbs.	3 lbs.	32 oz./A
Roundup UltraMax®	isopropylamine	5 lbs.	3.7 lbs.	26 oz./A
Roundup UltraMax II®/ Roundup WeatherMax®	potassium	5.5 lbs.	4.5 lbs.	21.3 oz./A
Touchdown®	diammonium	3.7 lbs.	3 lbs.	32 oz./A
Touchdown HiTech®	potassium	6.2 lbs.	5 lbs.	19.2 oz./A

Glyphosate products differ primarily in the surfactants and concentration of acid equivalent they contain. Surfactants enhance the movement of the herbicide from the leaf surface into the plant tissue. Although the blends and amount of surfactants vary among the many glyphosate products, Purdue University researchers found no significant differences in the performance of six glyphosate formulations (Table 2). Similar results have been found at other universities throughout the Midwest. Differences in performance occasionally occur, especially when below-labeled rates are used. However, these differences are inconsistent and do not support any one product being superior to others.

Table 2. Performance of Selected Glyphosate Formulations. *All products were applied at 0.75 lb. ae/A (equivalent to 32 ounces of original Roundup®) to 4-inch weeds.*

Formulation	Giant Foxtail	Ivyleaf Morningglory	Velvetleaf
	% Control		
Clearout 41 Plus®	97	86	99
Glyphomax Plus®	98	86	99
Roundup WeatherMax®	98	80	99
Touchdown Total®	97	84	99
Touchdown 4®	98	84	99
Roundup Original®	96	83	97

Source: Thomas Bauman, Mike White, David Hilger and Chad Dyer; 2003; Purdue University.

Weed Species and Size

When glyphosate fails to control weeds, use of an inappropriate rate for the specific weed species or size is frequently the reason. Weed species differ in their sensitivity to glyphosate. And generally, the bigger the weed, the higher the rate required for control. For example, to control waterhemp, nearly twice the rate of Roundup WeatherMax® was required at a late postemergence application as for an early one (Table 3). In other words, the rate of any product used on a field should be based on both the species and size of weed found in the area to be sprayed.

Table 3. Influence of Glyphosate Application Timing on Control of Three Weed Species.

Weed Species	Application Timing					
	Early		Mid		Late	
	oz./A of Roundup Weathermax® for 90% Control	Weed Height (Inches) at Application	oz./A of Roundup Weathermax® for 90% Control	Weed Height (Inches) at Application	oz./A of Roundup Weathermax® for 90% Control	Weed Height (Inches) at Application
Ivyleaf morningglory	37	4	50	8	>60	12
Velvetleaf	28	5	34	10	40	21
Waterhemp	16	4	28	9	30	14

Source: Stevan Knezevic, University of Nebraska Haskell Agricultural Laboratory, Concord, Nebraska.

Certain weeds (such as yellow nutsedge, wild buckwheat, and Asiatic dayflower) are naturally tolerant to glyphosate. Acceptable control of tolerant weeds is unlikely regardless of application timing or rate. Including alternative herbicides in weed management programs will provide more consistent control of glyphosate tolerant weeds than programs relying solely on glyphosate.

Spray Additives

Most glyphosate products recommend adding ammonium sulfate (AMS) under certain conditions (see Water Quality below), but surfactant recommendations vary widely. That's because the amounts and types of surfactants included in formulated products also vary widely. Follow the product's recommendations for additional surfactants to optimize performance. Most studies have shown little benefit to adding extra surfactant to "fully loaded" formulations that do not specify the need for additional surfactant.

Manufacturers of surfactants and other spray additives are not required to provide information on their products' active ingredients. Thus, it is difficult to compare the numerous products available to find the optimum surfactant. The risk of obtaining a poor quality surfactant can be minimized by using products with a high concentration of active ingredients (typically greater than 80 percent), avoiding products that make unrealistic claims, and purchasing spray additives from the same location as the herbicide.

Water Quality

Glyphosate products are formulated to be mixed with water to facilitate application. Often, that water (whether it comes from a well or rural water association) contains large amounts of dissolved salts. Hardness is a measure of how much salt water contains. The harder the water, the higher the salt concentration.

These dissolved salts in hard water may reduce glyphosate's effectiveness, particularly calcium and magnesium salts. These salts have a positive charge and may associate with the negatively charged glyphosate molecule, displacing the isopropylamine or other salt used in the formulated product. Plants absorb less glyphosate bound with calcium or magnesium salts than the formulated salt of glyphosate, thus reducing glyphosate activity.

Although specific recommendations vary, most glyphosate labels recommend adding AMS. The role of AMS is considerably different than the function of nonionic surfactants. Surfactants are active primarily on the leaf surface and improve herbicide absorption into plants. AMS, on the other hand, is active primarily in the spray tank where it prevents the antagonistic salts from interacting with glyphosate. AMS should always be added to the tank prior to glyphosate to prevent the formation of inactive complexes between glyphosate and antagonistic cations.

There are several products marketed as alternatives to AMS for reducing the antagonistic effects of hard water. Although these products may be more convenient to use than AMS, studies show many of them are less effective.

Spray Volume

Label recommendations for carrier volumes vary among products. For example, the Roundup WeatherMax® label recommends using a volume of 5 to 20 gallons of water per acre, and the Touchdown HiTech® label recommends 3 to 40 gallons of water per acre. Research has documented that glyphosate applied in water volumes less than 10 gallons per acre often performs better than when it is applied in water volumes of 20 or more gallons per acre.

There are two primary factors responsible for this response. First, as spray gallonage increases, the ratio of antagonistic salts to glyphosate increases. Thus, the potential for calcium or magnesium salts to inactivate glyphosate increases as spray volume increases. The second factor is a simple dilution effect. As spray volume increases, the ratio of formulated glyphosate to water decreases (Figure 3). The reduction in concentration of both the active ingredient and surfactant in the spray solution may reduce performance under certain situations.

Figure 2. *Increasing spray volume may improve control in areas with high weed density or fully developed crop canopies.*

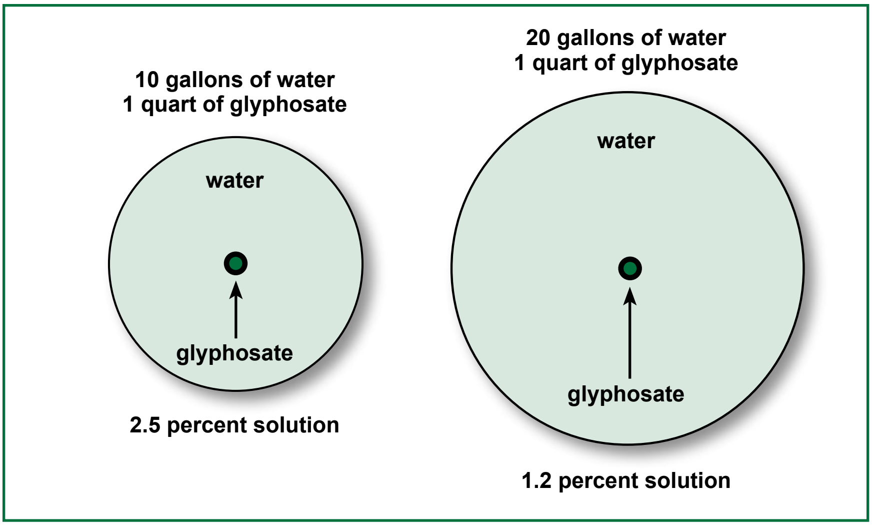

Figure 3. *This figure shows the relationship between spray volume and glyphosate concentration. As the spray volume increases, the ratio of formulated glyphosate to water decreases.*

Several factors should be considered when selecting a glyphosate spray volume. As carrier volume decreases, there may be an increased risk for spray drift and insufficient weed coverage. Relatively small spray droplets are required for uniform coverage at spray volumes less than 10 gallons per acre. Small droplets increase the likelihood of spray drift.

As spray volume is reduced, variability in spray droplet deposition increases and the likelihood that individual weeds may not receive a lethal dose of the herbicide is greater. The variability in spray deposition also increases as the plant canopy's density increases. For most agronomic situations, spray volumes of 10 to 15 gallons per acre minimize the negative effects on glyphosate performance while allowing adequate coverage of weeds present in corn and soybeans. Higher volumes (15 to 20 gallons per acre) may be beneficial in situations with dense weed infestations, well-developed crop canopies, or large weeds.

Spray Nozzle Type

Several new spray nozzles have been introduced that are designed to reduce the number of driftable droplets. While these nozzles may reduce the coverage of target plants by the herbicide solution, glyphosate's mobility within plants reduces the importance of spray coverage compared to other herbicides. Thus, nozzle selection for glyphosate application should be based primarily on managing droplet size and drift potential rather than optimizing spray coverage.

Environment

Plants are continuously responding to stressful environmental conditions (drought, heat, cold). For example, during dry or hot weather, plants conserve water through changes in both the composition and thickness of the cuticle on the leaf surface. These changes influence herbicide absorption and performance. Most herbicide labels contain vague statements regarding environmental influences on herbicide performance. The Touchdown HiTech® label states, "Touchdown® requires actively growing green plant tissue to function." Most growing seasons contain short periods when temperature or moisture extremes essentially cease plant growth. Herbicide applications made during these periods may provide ineffective control.

Managing fluctuations in herbicide efficacy due to changing weather is one of the most difficult challenges in weed control. Attempts to develop tools that determine the optimum herbicide rate or spray additive based on prevailing weather conditions have been largely unsuccessful. Increasing the glyphosate rate may help overcome the effects of adverse weather conditions that occur before or at application. Postponing applications until more favorable conditions return is another option if crop and/or weed size permit delayed action.

Time of Day

Soon after Roundup Ready® soybeans were introduced, control problems with evening applications of glyphosate were observed. Subsequent research confirmed that glyphosate activity can decline when applications are made early in the morning or in the evening (Figure 4). In certain weed species, this response is partially caused by day-to-night leaf movements. The leaves of velvetleaf and many other plants hang vertically after sunset, then raise parallel to the soil surface during the day. Changes in leaf orientation can influence how much herbicide spray a weed intercepts.

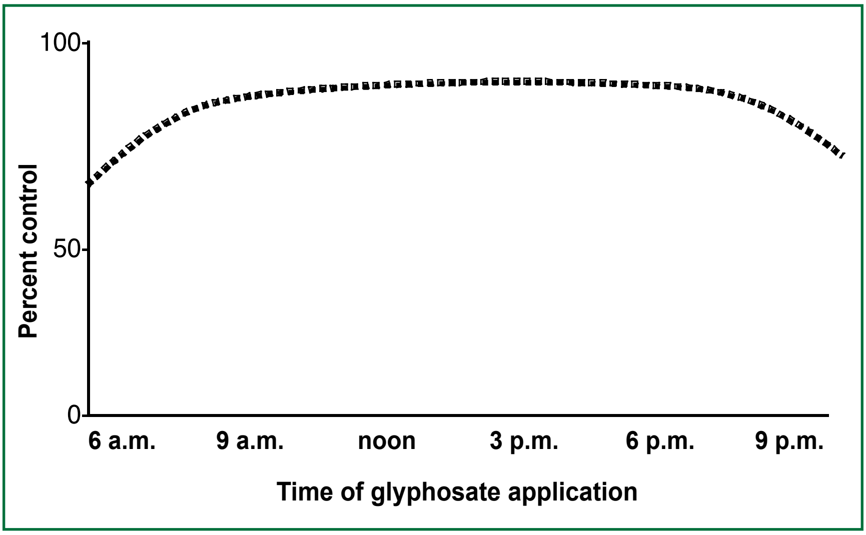

Figure 4. *This graph shows a hypothetical response of glyphosate activity to time of application.*

Reduced glyphosate activity from evening or morning applications is most likely with difficult to control weeds or when applying marginal herbicide rates for the specific situation. The time of day influence may be overcome by increasing the glyphosate rate; however, there are no concrete guidelines to determine when and how much to increase rates to overcome this effect. If weed sizes vary among the fields to be sprayed, try to schedule fields with the smaller, more sensitive weeds during the early morning or evening hours.

Rainfall

Glyphosate must penetrate the leaf surface to provide effective weed control. While absorption occurs relatively quickly, rain after an application can wash glyphosate off before it has a chance to enter the leaf. The rain-free period required to prevent reduced activity is influenced by the susceptibility of the target weed and the glyphosate rate. Small weeds of a sensitive species will require a shorter rain-free period than large or difficult to control weeds. A 30-minute rain-free period may be adequate under ideal conditions. When spraying larger weeds, however, several hours between application and rain may be required to avoid reduced activity. Differences in rainfastness among glyphosate products are generally small. Adding more surfactant appears to have marginal benefits on the rain-free requirement.

Figure 5. *Pay attention to weather conditions before and after glyphosate applications. Rain after an application can wash glyphosate off before it has a chance to enter the leaves.*

Dew

There is a wide range of views among growers about the influence of dew on herbicide performance. Some say they see the best herbicide performance when light dew covers the weeds' foliage. Others believe the presence of dew greatly reduces weed control. The few controlled studies investigating this factor have not found a consistent response to dew. A recent study reported reductions in glyphosate activity only with heavy dew and high spray volumes (48 gallons per acre) where the spray solution triggered runoff from plant leaves.

Dust and Tire Tracks

In glyphosate-treated fields, it is common to find weed escapes in the sprayer's tire tracks. Such failures are likely caused by the mechanical damage by tire traffic to the weeds, or by dust kicked up by the tires that intercept the spray solution. Glyphosate binds very tightly to soil particles, thus any glyphosate that contacts dust in the air or on the leaf surface will be inactivated. Attempts to overcome these effects — by mounting booms on the front of sprayers, mounting extra nozzles behind the rear wheels, or placing larger nozzles in line with wheel tracks — have been inconsistent in resolving this problem. The best way to limit the problem is timely application to small weeds.

Figure 6. *Weed escapes in the sprayer's tire tracks may be due to tire damage or dust.*

Summary

Glyphosate's performance is affected by many factors, and applicators have little or no control over many of them. The primary cause of weed control failures is a delay in application that allows weeds to reach sizes that are difficult to kill consistently. Timely application and using the proper rate for the specific situation minimizes the effects of factors outside of the applicator's control and reduces the likelihood of performance failures.

Figure 7. *Timely application is essential for proper control. Larger weeds, like this velvetleaf plant, are more difficult to control with glyphosate.*

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