FACTORS AFFECTING GLYPHOSATE PERFORMANCE

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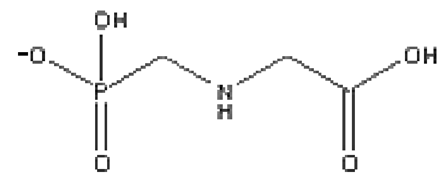
Introduction

Glyphosate provides excellent weed control in the vast majority of times that it is applied. However, weeds are not controlled as expected in certain instances. Several factors may be responsible for these control failures. It is important to understand these factors so steps can be taken to avoid poor performance. There are three distinct places where glyphosate interacts with other elements when it is applied: 1) in the spray tank; 2) on the leaf surface; and 3) in the weed. This article reviews the potential for these interactions to reduce glyphosate performance.

Glyphosate in the Spray Tank



Glyphosate is a weak acid herbicide and has a negative charge at typical pHs. As a consequence, glyphosate is formulated with positively charged "salts" like potassium, isopropylamine, or ammonium so it can be dissolved in water during formulation. Since glyphosate has a negative charge, it can interact with other positively charged ions in spray water and form complexes that are not absorbed as readily as the salts included in the formulation. This interaction results in antagonism. The ions that cause problems can be either from the water source or additives to the spray solution.

Hard water is one potential source of antagonism. Hard water is the description of water with high concentrations of minerals like calcium, magnesium, sodium, and iron. These minerals have a positive charge and are attracted to the negative charge of the glyphosate molecule. This interaction results in glyphosate-salt complexes. Unfortunately, some glyphosate-salt complexes are not absorbed easily into leaves. For example, the glyphosate-calcium complex is less readily absorbed than the glyphosate-potassium or glyphosate-isopropylamine complexes that exist in glyphosate formulations.

Micro-nutrient fertilizers are the most likely additives to glyphosate spray solutions that could antagonize glyphosate if not mixed correctly. These products may contain iron, manganese, sodium and other nutrients, which are positive ions that can interact with glyphosate.

Tank-mixed herbicides that are formulated with clay carriers such as herbicides with dry flowable or flowable formulations are another source of antagonism in the spray tank. The clay particles can bind the glyphosate similar to glyphosate binding to soil.

In all three of these cases of antagonism, the solution is the same. Ammonium sulfate is added to the spray water to increase the ammonium salt concentration to reduce the unfavorable glyphosate complexes. The key step is that ammonium sulfate must be added to the water and dissolved before glyphosate is added.

The amount of ammonium sulfate required to overcome hard water depends on the minerals and their concentration. Research in North Dakota has shown that water with 300 ppm

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of sodium or greater than 150 ppm of calcium causes noticeable antagonism to glyphosate. Fortunately, most ground water in Wisconsin has low or moderate mineral concentrations. Examples of the average and the highest mineral concentrations for sampled wells are listed for nine counties from across the state (Table 1). Potassium and iron concentrations averaged less than 3 ppm across the state and were not included in the table.

Table 1. Mineral concentrations for ground water in nine selected counties. Adapted from UWEX Geological and Natural History Survey. 1981. Ground-water-quality atlas of Wisconsin. Information Circular 39.

	Calcium		Magnesium		Sodium	
County	Ave.	High	Ave.	High	Ave.	High
	ppm					
Chippewa	15	48	6	18	3	7
Dane	68	110	35	61	4	10
Grant	70	211	34	120	5	63
La Crosse	58	78	22	32	3	12
Manitowoc	81	368	38	101	14	107
Pierce	66	121	25	34	6	8
Rock	69	90	35	52	4	9
Waukesha	82	340	35	73	13	240
Waushara	38	76	20	41	7	19

Although these minerals are generally at concentrations below levels reported to cause antagonism, some wells have mineral concentrations that may antagonize glyphosate activity. This is especially true for some wells in eastern Wisconsin as shown with Manitowoc and Wauskesha counties. Also, the antagonistic effect of minerals on herbicides is additive so water with 150 ppm of calcium and 100 ppm of sodium will cause more antagonism than water with only 150 ppm of calcium. The spray volume also affects the level of antagonism. At the same mineral concentration, minerals will cause more antagonism if glyphosate is sprayed in 20 gal/a than in 10 gal/a of water.

Two ways to determine the amount of ammonium sulfate needed for glyphosate applications are:

1. Use the following equation, which was developed by North Dakota State University.

   AMS (lb/100 gal) = 0.005 x (sodium ppm) + 0.002 x (potassium ppm) + 0.009 x (calcium ppm) + 0.014 x (magnesium ppm)

2. Follow the label recommendations and add 8.5 to 17 lb AMS per 100 gallons of water. Unless severe water quality problems are known, ammonium sulfate at 8.5 lb/100 gallons (or about 1 lb/a) should be sufficient.

Our field tests to measure micro-nutrient interactions with glyphosate did not detect significant antagonism when ammonium sulfate was added to the spray water prior to adding glyphosate and the micro-nutrient. In these trials, glyphosate was applied at a reduced rate to large common lambsquarters to increase the potential for antagonism. Antagonism occurred at the reduced rate, but was minimal when labeled glyphosate rates were used (Table 2).

Table 2. Common lambsquarters control with glyphosate plus ammonium sulfate applied alone or with a micro-nutrient and rated 4 to 7 weeks after application.

			2004 Early		2004 Late		2005	
Glyphosate	AMS	Max-in†	Height	Control	Height	Control	Height	Control
lb ae/a	lb/a	qt/a	inch	%	inch	%	inch	%
0.38	2.5	-	14	100	20	93	18	93
0.38	2.5	1	14	98	20	76	18	88
0.75	2.5	-	14	100	20	100	18	98
0.75	2.5	1	14	100	20	96	18	94

†The Max-in rate was increased to 2 qt/a in 2005.

Glyphosate on the Leaf Surface

After glyphosate is sprayed, it must be absorbed from the spray droplets into the cells of the leaf. In general, only about 30 to 40% of the glyphosate is absorbed from the spray droplets into the leaves. Several factors can affect the total amount of glyphosate absorbed.

Spray volume affects the concentration of glyphosate in the spray solution. Because glyphosate diffuses from the spray droplet into the leaf, higher glyphosate concentrations in the droplets increase the rate of diffusion. Glyphosate is more concentrated in spray droplets at lower spray volumes (Table 3). As a result, glyphosate control is generally greater at lower spray volumes such as at 10 GPA as compared with 20 GPA. (Lower spray volumes also have less potential for antagonism from minerals, which is another benefit).

As a demonstration of this effect, oats and wheat were sprayed with low rates of glyphosate in 2.5, 5, 10, and 20 GPA of water (Ramsdale et al. 2003). Although these low glyphosate rates are not recommended, grass control increased with lower spray volumes at the low glyphosate rate (Table 4). At the higher glyphosate rate, the spray volume did not affect control.

Table 3. Concentration of glyphosate when applied at different rates in increasing spray volumes.

	Glyphosate concentration Glyphosate rate (oz/a)		
Spray volume	8	16	32
gal/a	(grams/liter)		
5	4.4	8.8	17.6
10	2.2	4.4	8.8
20	1.1	2.2	4.4

This assumes a glyphosate formulation with 3 lb ae/gallon.

Table 4. Oat and spring wheat control with glyphosate applied in increasing spray volumes.

	Oat and wheat control Glyphosate rate	
Spray volume	1.3 oz/a	5.3 oz/a
(gal/a)	(%)	(%)
2.5	82	99
5	72	99
10	58	99
20	44	99

Surfactant concentration is also affected by the spray volume when glyphosate formulations are used that are “loaded”. On a relative basis, surfactant concentration is four times higher when spraying at 5 GPA than at 20 GPA with the same glyphosate rate (Table 5). This low surfactant concentration may become limiting under extreme conditions (e.g. low glyphosate rates and high spray volumes). In such cases, it may be beneficial to add additional surfactant to ensure an adequate surfactant concentration in the spray mixture.

Table 5. Surfactant concentration when a preloaded glyphosate formulation is applied at different rates in increasing spray volumes.

	Surfactant concentration Glyphosate rate (oz/a)		
Spray volume	8	16	32
gal/a	(relative to 32 oz/a at 20 GPA)		
5	1X	2X	4X
10	0.5X	1X	2X
20	0.25X	0.5X	1X

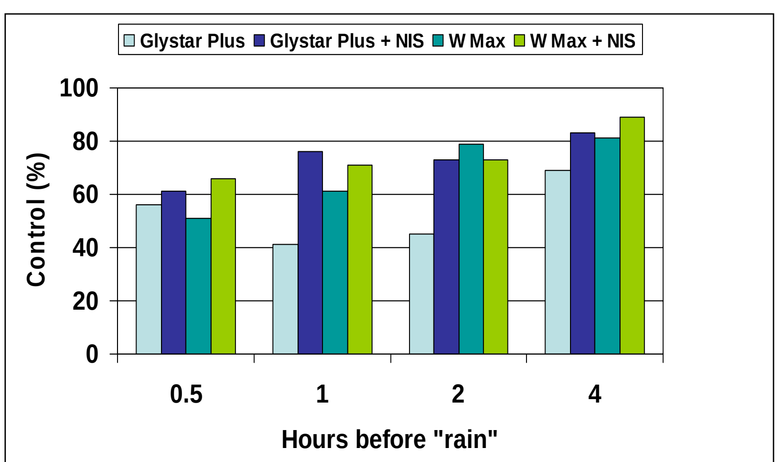
This information means that spraying glyphosate at lower spray volumes should give equal or better weed control than applications at high spray volumes. Using high spray volumes to get more thorough spray coverage of weeds may actually lower the performance of glyphosate in some cases. Glyphosate translocates in weeds so the leaf surface does not need to be uniformly covered by spray droplets for glyphosate to work.

If the "glyphosate science" says that lower spray volumes are better, are there situations where this science fails when glyphosate is applied in the field? This could happen in some situations when spray coverage is not uniform such as when tall weeds prevent spray from reaching shorter weeds. Another case may occur at faster sprayer speeds with low spray volumes. Wind may swirl around the sprayer and displace some of the spray swath if low spray volumes (and small droplet sizes) are being applied. In these cases, higher spray volumes may increase uniformity.

Ammonium sulfate also plays a role on the leaf surface of certain weed species. For example, ammonium sulfate in the spray solution increases glyphosate absorption into velvetleaf (even when hard water antagonism is eliminated) (Young et al. 2003). However, ammonium sulfate made no difference in glyphosate absorption in common lambsquarters. It is suggested that ammonium sulfate is more important with velvetleaf than lambsquarters because velvetleaf has a higher calcium content than other weeds. The calcium ions may form salt complexes with glyphosate, which limit its uptake. In contrast, the addition of ammonium sulfate may lead to ammonium salt complexes with glyphosate that are more readily absorbed by velvetleaf.

Rain after a glyphosate application has the greatest potential to make a glyphosate application fail. Glyphosate is absorbed into the leaf over time. Without adequate time, glyphosate absorption will not reach its full potential. In 2005, we applied 0.75 lb ae/a glyphosate and simulated a rain at 0.5, 1, 2, and 4 hours after the application. At all timings, lambsquarters

Figure 1. Effect of simulated rainfall and glyphosate formulation (Glystar Plus or Roundup Weathermax ± non-ionic surfactant) on common lambsquarters control. Without simulated rainfall, control averaged 96% across treatments.



control was reduced compared to lambsquarters that did not receive the simulated rain (Figure 1). The rain-free period required to achieve a high level of control will depend on the glyphosate rate applied, sensitivity of the weed species, and their size.

Dew. It is logical to question if dew might reduce glyphosate performance because dew could dilute the glyphosate concentration similar to spraying at higher spray volumes. Also, glyphosate spray droplets might run off dew covered leaves. On the positive side, dew could increase the hydration or water content of the cuticle of the leaf and aid glyphosate uptake. Research suggests that moderate or high levels of dew at the low spray volumes does not reduce glyphosate's control (Table 6, Kogan and Zuniga 2001)). This is probably because the cuticle is fully hydrated (e.g. swollen like a sponge) and allows better glyphosate absorption. In this example, the high dew level reduced oat control when glyphosate was sprayed in the highest spray volume, which may have occurred if some spray droplets ran off the leaves due to the large amount of water on the leaves. It appears that moderate levels of dew will likely have little effect on the performance of glyphosate when applied at normal spray volumes. These results are consistent with previous research on quackgrass.

Table 6. Effect of spray volume and dew on oat control by 0.5 lb ae/a glyphosate.

Spray	Dew level		
volume	0%	50%	100%
(gal/a)	(% oat control)		
16	88	89	89
31	82	88	88
47	65	65	59

Dust on the weed leaf surface has the potential to bind and inactivate applied glyphosate. A recent greenhouse experiment found that "dust" or soil sifted onto nightshade leaves at the rate equivalent to 7 lb/a was sufficient to reduce glyphosate activity (Zhou and Messersmith 2005). This rate is apparently similar to the amount of dust that a row cultivation may create. The frequency of problems caused by dusty leaves depends on the frequency of rain and closeness of dusty roads or fields. Similarly, dust that is raised behind sprayers can become a problem. Glyphosate may also be deactivated with the soil that is pressed on the weed leaves in the wheel tracks.

Glyphosate in Weeds

After glyphosate begins to enter the plant, its performance may be affected by several other factors.

Weed species can greatly affect their sensitivity to glyphosate. Differences in glyphosate tolerance among weed species are natural. For instance, annual grass seedlings are much more sensitive to glyphosate than annual broadleaf weeds. Certain annual broadleaf weeds like the morningglories are more tolerant than many other broadleaf weeds. And certain perennial weeds like yellow nutsedge and field horsetail have high levels of natural tolerance. As with any herbicide, weeds become less sensitive as their size increases and the rate of glyphosate should be increased to compensate when spraying larger plants.

Drought is likely the principle environmental stress that may reduce glyphosate's performance. The leaf surface is covered by a wax-like layer called the cuticle. The primary purpose of the cuticle is to reduce water loss. During drought conditions, this purpose becomes even more critical. In response to drought stress, the true waxes on the surface of the cuticle becomes even thicker. The cuticle is also less hydrated by water. Both of these conditions make it more difficult for the glyphosate to diffuse through this barrier. This effect can happen fairly rapidly. For example, glyphosate absorption and translocation was measured in non-stressed in common milkweed (25% soil moisture) as compared to moisture-stressed common milkweed (water withheld for 2 days before glyphosate application; soil moisture decreased from 25 to 13% moisture) (Waldecker and Wyse 1985). The non-stressed milkweed absorbed 44% of the glyphosate whereas the moisture-stressed milkweed only absorbed 29% of the glyphosate. In addition, the moisture-stressed milkweed only translocated half as much glyphosate as the non-stressed plants from the treated leaves.

The time of day when glyphosate is applied can affect the level of weed control. Research has shown reduced glyphosate activity with applications before 6 am and after 9 pm. There are several conditions that change during the day, which affect the plant. Weed leaves at early and late hours may be covered by dew, but this generally should not reduce performance. Leaves of certain weed species (e.g. velvetleaf) move down into vertical positions in the evening, which would reduce the weed's interception of glyphosate spray (Table 7, Sellers et al. 2002). However, even if these leaves are propped up so they receive a full glyphosate dose, control is still reduced at early and late day applications. Light affects many metabolic processes within plants and it is possible that glyphosate's activity (uptake, translocation, and damage to the target site) is being affected by the plant's level of metabolic activity.

Table 7. Effect of velvetleaf leaf angle on spray interception.

Time	Leaf angle	Spray interception
	degrees	% of maximum
4 pm (held flat)	0	100
4 pm	-24	78
6 pm	-34	69
7 pm	-63	44
7:30 pm	-75	42
8 pm (sunset)	-81	42

Summary

Glyphosate's performance is affected by many application, plant, and environmental factors. Applicators can control the application related variables, especially the glyphosate rate and the addition of ammonium sulfate. Applicators cannot control most of the plant or environmental factors with the exception of the size of the weeds and the time of day when glyphosate is applied. Overall, to minimize the risk that the other factors will reduce glyphosate performance, glyphosate applications should be timed so that smaller weeds are treated.

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