

ROUNDUP READY ALFALFA: AVOIDING INJURY WHILE MAXIMIZING WEED CONTROL

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ABSTRACT

Roundup Ready (RR) alfalfa is a popular weed management strategy for alfalfa producers in California and other western states, with the greatest advantages considered to be excellent weed control without crop injury. However, recent research and field observations have documented that injury is possible under certain conditions. In several instances in the Intermountain region of northern California, glyphosate treatment followed by cold temperatures have resulted in crop injury. It appears that the specific combination of herbicide timing, alfalfa physiological stage, and weather conditions associated with the observed injury may not be common, which may explain why this has been observed in some areas and not others. In addition, there is some evidence that this glyphosate-associated injury may also be masked by more severe frost damage that also can occur under similar conditions. Research results and field observations to date suggests that injury is affected by the temperatures after an application, height of the alfalfa (taller alfalfa being more prone to injury), and stand age (no injury to seedling alfalfa and less injury to recently established alfalfa compared with fields established for over a year). From what we know now, treating when the alfalfa is 2-inches tall or less is advised to avoid injury in areas prone to cold temperatures after an application. While this relatively cautious recommendation shortens the herbicide application window, it also minimizes the possibility of injury. Application to 2-inch tall alfalfa also helps ensure effective weed control because the weeds are typically small and easier to control and spray coverage is often better at this crop growth stage. For most annual weeds, the highest labeled rate of glyphosate (44 oz. of PowerMax or equivalent for other glyphosate formulations) is not needed, and a lower labeled rate will provide acceptable control while minimizing the possibility of injury. This application timing is also compatible for tank mixes with soil residual herbicides, which also are recommended sometime during the life of the alfalfa stand to help avoid the evolution of glyphosate-resistant weeds. Glyphosate-induced injury symptoms have been observed only in the first cutting; no visible injury or yield reductions have been observed in second and later cuttings.

Key Words: Herbicides, glyphosate, weed control, phytotoxicity, transgenic alfalfa, application timing

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INTRODUCTION

The advent of Roundup Ready (RR) alfalfa has had a significant impact on current-day alfalfa production. Glyphosate is a highly effective, broad spectrum herbicide that is very cost effective for growers. The development of RR varieties allows this effective herbicide to be applied directly over the top of alfalfa without injuring the crop and presents a huge advantage, especially for difficult-to-control weeds. The technology has been readily adopted in the West and has become a popular weed management strategy in many alfalfa production regions. Aside from issues related to exporting GMO alfalfa to some countries, most growers are pleased with the technology.

The technology and its fit in alfalfa production systems has been thoroughly researched throughout the U.S. In addition, RR alfalfa has now been used extensively in commercial fields since it was first released in 2005 and subsequently rereleased in 2011. The main advantages are improved weed control, ease-of-use, and avoidance of crop injury. Most of the research to assess crop injury was conducted with seedling alfalfa, believing that—if injury was possible—it would be far more likely with seedling than established alfalfa. No published results have indicated risks of crop injury under normal or extreme use rates.

OBSERVATIONS OF INJURY

Two years ago, in the spring of 2014, we observed significant crop injury in a grower's established field of RR alfalfa in Scott Valley, a high-elevation valley located in the intermountain area of northern California. A portion of a field where irrigation wheel-lines were anchored for the winter was left untreated, and the alfalfa growth was much taller in that area compared with the treated portions of the field. This was a mystery, as previous research and grower experience after years of RR alfalfa use had not indicated an injury problem. Logical potential causes for poor growth in the glyphosate-treated area, such as spray-tank contamination, a bad batch of glyphosate or non-herbicide-related management practices (fertilization, irrigation, pest management, etc.), were systematically ruled out. A test plot was conducted in the untreated strip using Roundup PowerMax from different sources at two rates with and without surfactant to see if the injury could be duplicated. No injury symptoms or effect on alfalfa growth was observed in any of the plots during that later-spring trial.

This was a perplexing problem but at that point, was attributed to being an unexplainable single-year aberration. However, the same type of injury was observed again in the region during spring of 2015. Yield was monitored in three affected commercial RR alfalfa fields in the Scott Valley by harvesting treated and untreated areas with a plot harvester. In the most severely affected field, a first-cutting yield reduction of 0.8 tons per acre was observed; however, the alfalfa recovered by second cutting.

After considerable deliberation, the theory was developed that cold temperatures after an application of glyphosate was a key contributing factor. This could explain why some fields were affected and others were not, and why we did not observe any symptoms in the test plot that was conducted in 2014 in the untreated area of the field where injury was first detected. (No frosts occurred after the late date when the application was made in the test plot.)

RESEARCHING THE CAUSE

These were field observations on farmer's fields, but could we repeat these results with a more controlled study with a scientific approach? A replicated field experiment was conducted in the spring of 2015 at the University of California Intermountain Research and Extension Center in Tulelake, California. Compared to Scott Valley, alfalfa growth in Tulelake typically is slower in the spring, and very late-spring frosts are more commonplace. Alfalfa was treated with 22 and 44 fluid ounces of Roundup PowerMax per acre, and fortunately followed by a cold weather system a few days later. A reduction in alfalfa height was observed as well as a yield reduction of 0.3 and 0.4 tons per acre for the 22- and 44-ounce rates of Roundup, respectively. Injury did not carry over into the second cutting.

An additional field trial was conducted during the summer of 2015 in the same commercial field that had significant injury in the spring. The same rates used in the spring trial in Tulelake were applied after first cutting to 6- to 8-inch-tall alfalfa in the commercial field. The plots were carefully inspected after the application. No injury symptoms were ever observed on the alfalfa and there was no difference in alfalfa yield with any of the treatments. These results again suggested that cold weather after application was required for injury to occur.

Fall 2015 Studies. Additional trials were conducted in the fall of 2015. While fall is not a time of year when growers ordinarily treat fields with Roundup, a frost sometime after application is virtually guaranteed, enabling us to further evaluate the theory that cold temperatures after application can result in injury. Alfalfa was treated on weekly intervals at the same rates as the studies mentioned above from mid-September through October. Cold temperatures followed within a week of these treatments and resulted in the same injury symptoms observed in the spring in some of the trials (Figure 1). These fall studies suggested that injury was related to the height of the alfalfa (taller alfalfa, around 10 inches, seemed to be more susceptible than shorter alfalfa), the age of the stand (older fields more susceptible than a field planted within a few months), and higher Roundup rates resulted in more injury.



Figure 1. *This Roundup Ready alfalfa test plot in the fall of 2015 shows a high rate of glyphosate injury in front of the research assistant, as compared with untreated plots to the sides and back.*

Spring 2016 Studies. To get a better handle on the conditions that lead to injury and to quantify the amount of injury, we conducted 16 field trials in the spring of 2016 in locations throughout the intermountain area of Northern California (Scott Valley, Butte Valley, Tulelake and the Susanville area) and a trial in Christmas Valley in Central Oregon, managed by Mylen Bohle with Oregon State University. There were four different protocols for these trials with different levels of intensity but the objectives were similar: to better understand the conditions that lead to injury, and more specifically, to evaluate the effect of glyphosate rate and alfalfa growth stage at the time of application to develop recommendations on how to avoid potential injury.

The core set of treatments in the field trials included an untreated control, a standard herbicide treatment, and glyphosate (Roundup PowerMax) applied at 22 and 44 ounces of product per acre at specified alfalfa growth stages or on a weekly basis from March through April. The standard treatment was Sencor (metribuzin) plus Gramoxone (paraquat) at 0.67 pounds and 1 quart of product per acre, respectively. Raptor (imazamox) was used as the standard treatment in Christmas Valley, OR because it was too late to use Sencor and Gramoxone when this trial was established. Temperature data loggers were installed at each site to record nighttime low temperatures at alfalfa canopy height.

As is often the case with field research, a few of the trials were influenced by factors outside of our control including: severe hail at one site, significant alfalfa weevil infestation at others, and general field variability. Fortunately, reliable data was obtained from most of the trials implemented. Injury symptoms were observed at all but one of the 16 trials, including those affected by factors listed above. The trial where no injury was observed was the only new seeding field in the study. Because it was a new planting, its development lagged behind the other fields in the spring and therefore each growth stage treatment was applied somewhat later when temperatures were generally warmer. In addition, this location was the warmest of all the sites and the combination of being a warmer site and a new planting may explain the lack of symptoms.

The degree of injury varied somewhat by field, and in general related to the extent of cold temperatures after application. For the sites in the Scott Valley (Siskiyou County), the colder sites generally had more injury as did older stands compared to sites that were less cold or younger. Overall, the injury was not as severe as was seen the previous two years. This was likely due to a significantly wetter spring with mild nighttime temperatures for the first half of April (minimum temperatures for early April 2016 were nearly 13 degrees higher than in 2015).

Even with the more mild temperatures in 2016, alfalfa height at most sites was reduced slightly with the application of Roundup, with the 44 fl oz rate causing more stunting than the 22 fl oz rate. At the sites where yield data was collected, yield decline was typically 0.3 to 0.4 tons per acre for the 44 fl oz rate and 0.1 to 0.3 tons per acre for the 22 fl oz rate. Alfalfa that was taller at the time of treatment (8-10 inches) tended to have a greater yield reduction than when the alfalfa was shorter (4-5 inches) at application. However, some injury was still evident when alfalfa had 4 inches of growth at the time of treatment. In another trial with more treatment timings, an application was made to 2-in tall alfalfa and this treatment did not have reduced 1st cutting yield.

One site had no statistical, or even a numerical difference, in yield between the untreated control and any of the glyphosate treatments regardless of application rate or timing. This was the coldest site of

all and had low temperatures in the teens after some of the applications. This site also had four inches of snow within a month of harvest. While this site showed injury symptoms earlier in the season, it appears that frost injury caused by extremely low temperatures may mask the effects observed in other fields. At this very cold site, all the alfalfa, whether glyphosate treated or not, was equally injured.

Second cutting yield was also measured for most of the field sites where we harvested the first cutting. The alfalfa recovered at all sites and there was no yield difference on second cutting, which is in agreement with what was observed in 2015.

WHAT THE INJURY LOOKS LIKE

After observing this phenomenon for a few years now in commercial fields and research plots, we have a good sense for the symptoms and when they appear after an application. Unlike typical herbicide injury symptoms, the injury observed after a glyphosate application and cold temperatures takes several weeks to appear. The earliest we have observed even the very initial symptoms is about a week after application.



Figure 2. Individual wilted stems that are tipped over are the first indication of injury.



Figure 3. Affected stems curl downward forming a shepherd's crook and eventually the leaves turn necrotic and dry up.

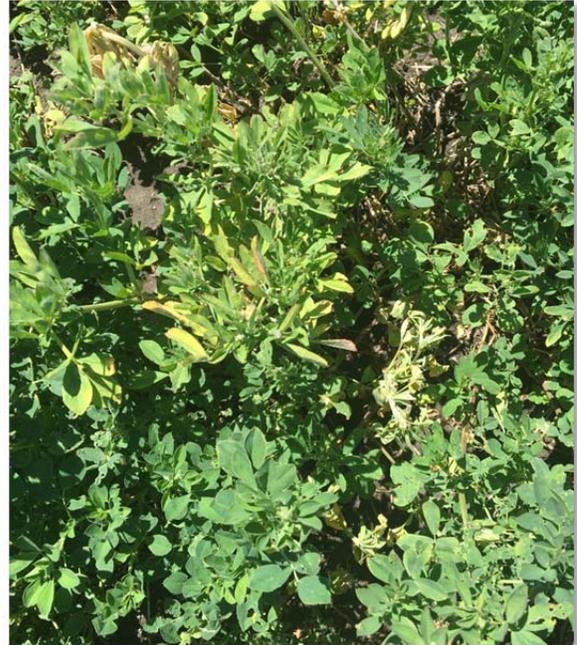
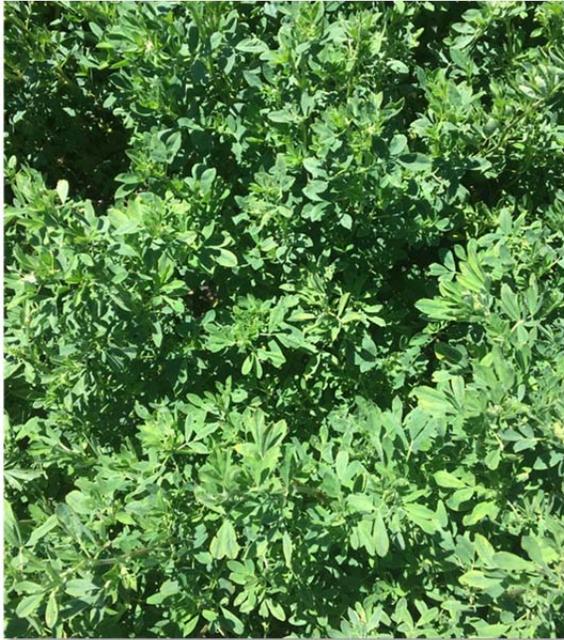


Figure 4. Untreated plot on the left and glyphosate treated on the right. Note the chlorotic plant in the middle of the treated alfalfa photo and wilted stems to the right of this plant and in the top left corner

This was with a fall application. The earliest we have observed injury in the spring has been 10 days to 2 weeks after an application. An untrained eye would have difficulty picking up these very initial symptoms—individual stems that are slightly tipped over and wilted (Figure 2). Only scattered plants show symptoms and they are commonly an individual stem to a few stems per plant. Affected stems wilt at the tip and curl downward forming a shepherd's crook. Eventually, the leaves turn chlorotic and then gradually become necrotic and dry up and die (Figure 3). As alfalfa growth continues in the spring, these damaged stems can disappear in the canopy.

Alfalfa leaves on affected plants may look somewhat pinched or narrow and dull green rather than a lush vigorous bright green color. The plants appear less vigorous and are typically stunted (Figure 4). Most of these symptoms are not readily apparent until 3 weeks to a month after application unless you are familiar with the symptoms and know what to look for. The symptoms look essentially like frost damage, and if there is not an untreated area for comparison, they may be hard to discern.

The temperature that occurs after the application is believed to affect the severity of the symptoms—less injury after a mild frost, increasing injury with a frost in the mid-20's and, as noted above, very low temperatures may injure all the plants so severely that any additional injury related to a glyphosate application is not discernable. However, the specific thresholds (temperature, duration, and timing relative to treatment) are still not well understood.

Is Glyphosate Injury to RR Alfalfa Unique to the Intermountain Area of Northern California?
Initial observations of injury were in Scott Valley, but our research has since shown that injury

can occur in other locations in the intermountain area of Northern California and Central Oregon. It has now been observed in commercial fields in these areas as well. It is not known how widespread the potential is for injury and additional research and field inspections are needed. It is feasible that injury also could occur in other alfalfa production regions with similar environmental conditions. Frost(s) after an application of glyphosate can occur in many alfalfa production regions; however, injury may be more likely in the intermountain area due to the erratic and often unpredictable springtime weather. Late spring frosts after alfalfa has “broken dormancy” in this region are commonplace as cold fronts move in off the Pacific Ocean and cold temperatures are common the first clear morning after a weather system passes. Other areas of the US may be colder over the winter, but once spring comes, temperatures rise on a more even upward trajectory.

AVOIDING INJURY AND ACHIEVING EFFECTIVE WEED CONTROL

From what we know to date, early application timing appears to be an important practice to help avoid the possibility of injury. Glyphosate is a highly effective postemergence herbicide without appreciable pre-emergence activity. Therefore, when used alone, glyphosate is usually one of the last applications made for winter annual weed control when producers/applicators likely have multiple fields to treat. Growers who use soil-residual herbicides (alone or in combination with paraquat) typically make these applications earlier in the winter or spring and then RR fields are treated with glyphosate later. The advantages of this timing strategy are twofold: it ensures weed emergence prior to the herbicide application and it extends the herbicide application window, which may be desirable when multiple fields need to be treated. In some areas, applications have been made to alfalfa 6 inches or taller. This extended window for herbicide application helps applicators dodge inclement weather and allows fields to be retreated later in the season if there are any weed escapes.

In light of these research results, however, growers are currently encouraged to make applications when alfalfa regrowth in spring is 2 inches or less in areas with spring environmental conditions conducive to injury. This timing is similar to other postemergence herbicides in alfalfa that also have a spring growth restriction, such as Gramoxone. Applying glyphosate to 2-inch tall alfalfa also helps ensure effective weed control because the weeds at this time are typically smaller and easier to control. This application timing is also compatible for tank mixes with soil residual herbicides, which often must be applied before the alfalfa has 2 inches of spring growth. Tank mixing with a soil-active herbicide is an effective practice to help avoid the evolution of glyphosate-resistant weeds. However, if glyphosate is used alone and the application is made too early, especially to a “weak” stand, subsequent weed emergence may be a concern.

A logical question relates to the interval between an application and a frost event. Specifically: *How long should the interval be between a glyphosate application and a frost event to avoid the possibility of injury?* If we knew how long that interval was, perhaps a later application would be feasible if one was confident there wouldn't be a frost for a given time period. However, the specific parameters such as time-to-frost, degree of cold temperature, and duration of cold exposure are not well understood at this time. This has been challenging to answer with field research because the timing or severity of a frost cannot be controlled. There is more control in a

greenhouse or laboratory study, but it has proven extremely difficult to duplicate field conditions, especially using older alfalfa plants. Because we do not know the required time interval between an application and cold temperatures to avoid injury, it is best from what we have observed to date to apply early (before alfalfa has 2 inches of spring growth) to be safe. Cold weather fronts and spring frost events are too difficult to predict to have confidence in many areas that a frost will not occur after an application, so for now the safest strategy in frost-prone areas is to adhere to the recommendation of a 2-inch spring growth cutoff.

The glyphosate application rate also affects injury. We have consistently seen more injury with the 44 fl oz rate of Roundup PowerMax than with the 22 fl oz rate. The maximum label rate per application of 44 fl oz of Roundup PowerMax (or equivalent rate for other glyphosate formulations) is not needed for most annual weeds, especially if they are treated when the alfalfa only has 2 inches of spring growth and the weeds are small. Therefore, for locations prone to late spring frosts, the maximum single application rate is generally not recommended.

CURRENT RESEARCH EFFORT

We are currently conducting extensive research to better understand the actual mechanism for injury. This is important because knowing the underlying cause of these symptoms can help toward further development of recommended management practices to avoid or minimize injury. We have theories as to the cause of injury, but additional investigation is definitely needed to prove or disprove existing theories.

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