

ROUNDUP READY ALFALFA RESEARCH RESULTS: CALIFORNIA AND THE US

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INTRODUCTION

Glyphosate-resistant crops, also known as 'Roundup Ready' (RR) have become an important part of cropping systems in the United States. In 2004, approximately 13% of corn, 85% of soybean and 60% of cotton acreage is occupied by RR varieties. Alfalfa (*Medicago sativa*) is the nation's third most important crop in economic value, and occupies more than 22 million acres in the US (USDA, 2004). It is considered the premier forage crop. It is the primary feed for dairy production, and is commonly fed to beef cattle, sheep, and horses. Alfalfa is also used for greenchop and silage in many areas. California is the leading producer of alfalfa hay in the US, followed by Wisconsin, South Dakota, Minnesota and Idaho. Hay exports are primarily from Western United States, led by Washington (15-20% of US hay exports) and California (17% of US alfalfa hay exports). (Is this all needed? I would delete.) Roundup Ready technology has been successfully incorporated into alfalfa and is scheduled for commercial release in 2005.

Roundup Ready alfalfa as a weed control system has significant merit for alfalfa producers. Weed control costs could potentially be reduced while improving the level of weed control. Most alfalfa herbicides injure the crop to some degree. In theory, crop injury could be dramatically reduced or eliminated with Roundup Ready alfalfa. In addition, there are no effective weed control programs for some of the most difficult-to-control perennial weeds (dandelion and quackgrass). Bermudagrass, nutsedge, and Johnsongrass control could also be improved with glyphosate. Adequate control of these tough perennials could help extend stand life in some areas.

QUESTIONS

Even with these potential advantages, questions remain regarding the value of the Roundup Ready System in alfalfa production systems. Glyphosate has no soil residual activity. Many of the herbicides used for winter and summer annual weed control have soil residual activity so they persist long enough to provide extended weed control. In new plantings Pursuit and Raptor each have soil activity, which helps control weeds that emerge following the herbicide application.

Could complete season-long weed control be achieved with a foliar herbicide like glyphosate given the prolonged emergence of the weeds that infest alfalfa? Field trials

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were needed to compare the Roundup Ready weed management system with standard weed control strategies under the diverse environmental conditions and weed spectrum encountered in California. In addition, the Roundup Ready approach to weed control may require different application timing(s) than other conventional herbicide treatments.

FIELD TRIALS

Seedling Alfalfa – Establishment Year

Uniform weed control trials were conducted throughout production areas of California and the United States. Testing the Roundup Ready concept over varied environments allows for a better comparison of the benefits and shortcomings of the system. Roundup Ready alfalfa trials were established and evaluated based on the geographical requirements of the location. But in general the research trials involved the following :

1. The glyphosate rates tested were 1 and 2 pounds active ingredient per acre (0.75 and 1.5 lbs. ae/A).
2. There were different herbicide application timings based on the alfalfa growth or weed stage: i.e., unifoliate to 6–9 trifoliate leaf stage.
3. Conventional standards were evaluated as well: imazamox (Raptor), imazethapyr (Pursuit), bromoxynil (Buctril), and tank mixes with clethodim (Prism). Tank mixes of glyphosate and Pursuit were also evaluated.
4. Sequential treatments (when deemed necessary) were evaluated to ascertain the need for multiple treatments to control weeds that emerged after the initial application. Treatments used in the California field experiments are listed below. Most other areas of the US conducted similar experiments but treatments may have differed by location.

Description of Treatments used in California:

1. Roundup (0.75 lb. a.e./ac) Timing A - Very early application of Roundup at unifoliate to 1st trifoliate.
2. Roundup (0.75 lb. a.e./ac) Timing B - Early application of Roundup at the standard 3-4 trifoliate stage.
3. Roundup (0.75 lb. a.e./ac) Timing C - Late application of Roundup applied at 6 - 9 trifoliate stage, which would be generally too late for most conventional herbicides and effective weed control, but late applications are a common occurrence due to herbicide timing restrictions on alfalfa or environmental limitations which prevent timely treatments.
4. Roundup (1.5 lb. a.e./ac) Timing B - Early application of Roundup at the 3-4 trifoliate stage with higher rate to address problem weeds.
5. Roundup (1.5 lb. a.e./ac) Timing C - Late application of Roundup at 6-9 trifoliate stage. Weeds are expected to be bigger and harder to kill. Higher rate to address increased weed size.
6. Conventional, Timing B (Pursuit, Prism, 2,4-DB, Poast, Buctril) - One application of Pursuit or other herbicides applied alone or in a tank mix combination at the 3-4 trifoliate stage to control the weed spectrum. Other herbicides could include Buctril, Prism, Poast or 2,4-DB.
7. Conventional, Timing B (Raptor alone) - Raptor alone applied at 3-4 trifoliate stage. No further weed control measures.
8. Conventional, Timing C (Pursuit, Prism, 2,4-DB, Poast, Buctril) - One application of Pursuit and/or other herbicides applied alone or in tank mix combinations applied at the later stage of 6-9 trifoliate alfalfa.
9. Mix Strategy, Timing B (Roundup + Pursuit) - A tank mix of Roundup (0.75 lb. a.e./ac) and Pursuit applied at the 3-4 leaf stage of alfalfa

- Sequential Treatments (D is timing of the second flush of weeds and is not tied to a stage of the alfalfa).
10. Roundup followed by Roundup, Timing A & D (0.75 lb. a.e./ac followed by 0.75 lb. a.e./ac) Roundup applied very early at unifoliate to 1st trifoliate followed by second application to control second flush if necessary.
 11. Roundup followed by Roundup, Timing B & D (0.75 lb. a.e./ac followed by 0.75 lb. a.e./ac) Roundup applied early at 3-4 trifoliate followed by second application to control second flush if necessary.
 12. Conventional followed by Conventional (Conventional Timing A & D) Treatment begins at the very early trifoliate stage. A second application (e.g. Prism or Pursuit, or Pursuit + Pursuit low rate) made for later weeds.
 13. Roundup followed by Conventional (Timing B & D) Roundup application (0.75 lb. a.e./ac) early. Follow up with conventional herbicide to control second flush if necessary.
 14. Untreated Control - This treatment will demonstrate the penalty for not controlling weeds during the seedling phase.

RESULTS

There was very little to no injury to seedling alfalfa with the Roundup treatments. Some locations showed very slight injury symptoms but they were insignificant and short-lived. The Raptor and the Pursuit plus Buctril tank mix treatments resulted in more injury. However, the injury was generally less than 20 percent at most locations and the alfalfa had recovered by first harvest. Alfalfa mortality occurred at the first application of Roundup treatments, which was expected given there is a small percentage of seed (5%) that doesn't contain the glyphosate resistance gene. Once those plants are removed out of the population the problem ceases.

In California, approximately 95 percent control of nearly all weeds was achieved with 1 lb/A of glyphosate at all sites. The weeds present were mostly winter annual weeds and grasses with no perennials weeds making the 1.0 lb/A rate acceptable. While the 2.0 lb/A (1.5 lbs. a.e./A) rate of glyphosate resulted in faster weed kill, it was not needed for annuals. One application of glyphosate was less effective on henbit and burning nettle but was sufficient to control all other small annual weeds. Additional applications or higher rates will be required to control perennial weeds beyond the seedling stage i.e., quackgrass, Bermudagrass, dandelion, tall fescue, Aster's plantain, curley dock and nutsedge.

The importance of timing of glyphosate application varied depending on weed species, location, and time of the year. In Northern California and the Southern SJ Valley sites, an application at the unifoliate to first trifoliate stage of alfalfa resulted in later germinations of prickly lettuce and henbit, but shepherd's purse was completely controlled. A second application was needed to control all the weeds that could infest first cutting. In other sites, with plantings made during warmer conditions providing faster germination and alfalfa growth, one early application was sufficient.

Raptor and the Pursuit combinations controlled most weeds, but not as well as with glyphosate. Weeds not adequately controlled with Pursuit alone were purslane, prickly lettuce, henbit, kochia and the grasses. Raptor was more effective than Pursuit for the grass control and was generally slightly more effective on some of the broadleaf weeds.

The reduced rate of Roundup and Pursuit as a tank mix provided excellent control of all weeds.

Established Alfalfa

Field trials to study weed control in established alfalfa were also conducted at the same locations. In established stands from years 2 to 4, glyphosate was compared with a commercial standard herbicide treatment for established alfalfa, Velpar (hexazinone), Gramoxone (paraquat) and Treflan (trifluralin). These are applied during the dormant period to control the winter complex of weeds that germinate during the rainy period. Treflan controls later germinating summer grasses. Winter dormant treatments included:

1. Roundup (1.5 lb a.e./A) one application for winter annual weeds and additional in season applications as needed.
2. Roundup (0.75 lb a.e./A) one application for winter annual weeds and additional in season applications as needed.
3. Roundup – variable Roundup rates (each at least 0.75 lb a.e./A) to address special weed problems with a maximum yearly rate of 6 lb a.e./A.
4. Velpar (.05 lb ai/A) during dormant period with or without paraquat (Gramoxone Max) (0.375 lb ai/A) followed by either trifluralin (Treflan Granules) (2 lb ai/A) or Prism (0.176 lb ai/A) during the growing season depending upon location.
5. Velpar (0.5 lb ai/A) during dormant season with or without Gramoxone followed by Roundup as needed during the growing season.
6. Untreated Control.

RESULTS

In California, the initial herbicide applications were the same at all sites and additional in-season applications scheduled for summer weeds did not occur due to the lack of weed pressure. Evaluations at first cutting indicated excellent control of all weeds with no difference between the Roundup and conventional herbicide systems. First cutting yields indicated little to no difference between the Roundup only, conventional herbicide or the combination of both systems. Alfalfa injury was greater with the conventional system (Velpar + Gramoxone treatments), as would be expected. Plants that did not have the Roundup resistance gene were killed or stunted in plots where the alfalfa had not previously been treated with Roundup during the establishment phase. ., This is a reminder that glyphosate applications will be needed during the establishment phase to remove the susceptible population of alfalfa plants. Injury or death occurred to approximately 5% of the established plant population. Again, this did not appear to significantly affect yield but areas were impacted with stunted or dead plants that can leave a void for weeds to invade.

After three years of winter/dormant treatments, all locations had excellent (90% or greater) winter annual weed control with glyphosate. One exception occurred in the central California Delta site which contained a low population of burning nettle (*Urtica urens*) at stand establishment. Since glyphosate is relatively ineffective on nettle, the population increased over years and spread across the glyphosate plots (Figure 1).

WEED MANAGEMENT

Weed Shifts

In the case of herbicides, weed shifts occur when an herbicide does not kill the entire weed spectrum encountered in a field. The density of the weed species that is not controlled increases over time resulting in a weed shift. Glyphosate effectively controlled the weeds at all sites except one site where burning nettle was allowed to survive. Over a three-year period the population increased proportionally from the low to high rates of glyphosate. Lower rates showed an increase in nettle population each winter. Tank mixes of Velpar with Roundup or Paraquat and Velpar effectively controlled burning nettle. Since glyphosate does not control every weed species completely, rotating to other herbicides or tank mixing glyphosate with other herbicides will be necessary.

Weed Resistance

Another concern about RR technology is the development of herbicide resistance in weed populations. This becomes more of a concern as the acreage treated with Roundup increases. Since the RR technology already encompasses many crops (corn, soybean, cotton, and canola) and is used in non crop weed management such as fallow beds, it is very likely that tens of millions of acres will be treated with Roundup each year nationally. Evidence for Roundup resistance has already been identified in natural populations in some species, such as rigid ryegrass *Lolium rigidum* (Powles et al. 1998). It is highly probable that this might occur in other species. This problem is not unique to glyphosate, but common for other classes of herbicides as well. The potential development of weeds with resistance to glyphosate is thought to be less likely because of glyphosates unique mode of action. However, given the high amount of glyphosate use in the future, the probability of resistance greatly increases. Herbicide strategies, which incorporate cultural methods ahead of planting and rotations with soil active herbicides, are needed to prevent herbicide resistance. This is especially important in alfalfa; a perennial crop once established stays in production from 3-8 years and is dependent on chemical weed control methods.

Stand Removal

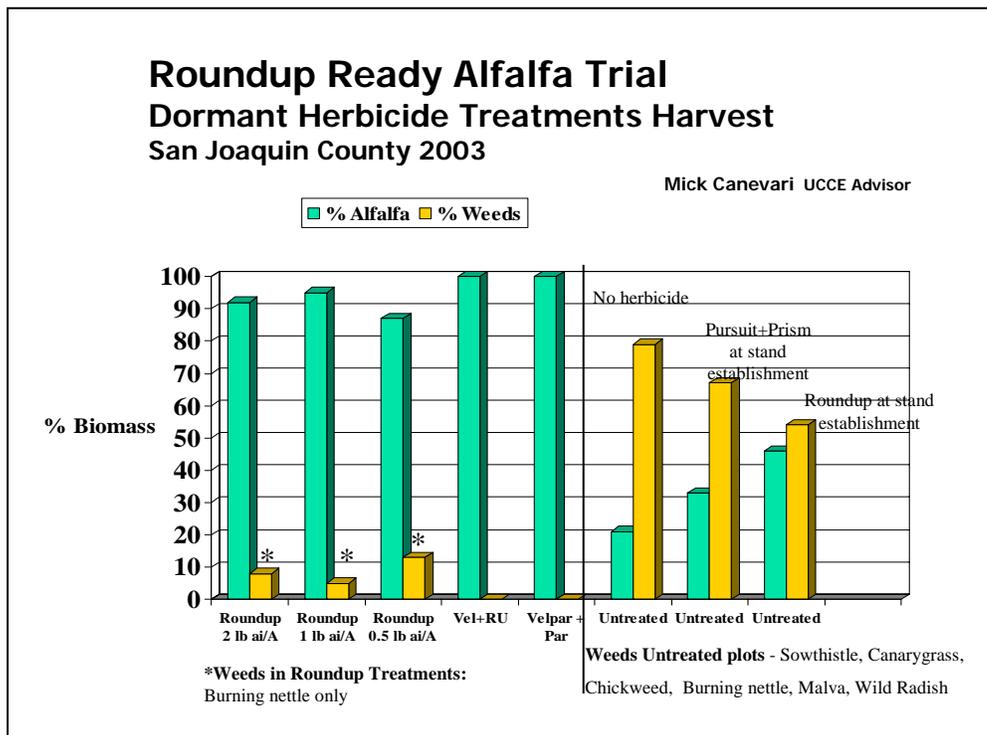
Glyphosate has been the primary herbicide used to take out old alfalfa stands; but could not be used for this purpose in a field of RR alfalfa. Trials were conducted at locations across the U.S. to evaluate the effectiveness of alternative herbicides for alfalfa stand removal. Numerous herbicides and herbicide combinations were tested including 2,4-D, Banvel (dicamba), Stinger (clopyralid), Garlon (tricyclopyr), Liberty (glufosinate), Aim (carfentrazone), and Harmony (thifensulfuron methyl). Treatments containing 2,4-D and dicamba and clopyralid tended to be the most effective, generally controlling greater than 90 percent of the alfalfa. Alfalfa mortality with 2,4-D and dicamba improved to nearly 100 percent, as it did other herbicides, when application was followed with cultivation by disking or chiseling. These results demonstrated that chemical and non-chemical alternatives to glyphosate exist for alfalfa stand removal.

CONCLUSION

The results across the U.S. clearly demonstrate that there is a fit for Roundup Ready alfalfa production systems. Consistent results were obtained across all regions of the U.S. with similar conclusions on application timing for new alfalfa plantings. Only one application of glyphosate was usually required when the application was made at the three to six leaf alfalfa growth stage. Earlier applications required additional treatments as weeds continued to germinate. Later timing gave slower control since weeds were larger and often necessitated a higher rate of glyphosate especially on the less susceptible species. In any event, a glyphosate treatment will be required during stand establishment stage to eliminate the non transgenic population. Although not fully explored to date in any region, it is believed that at least two applications will be required to control perennial weeds if they are allowed to grow beyond the seedling stage before treatment.

The introduction of Roundup Ready alfalfa varieties will be a significant advancement and would likely become a landmark in alfalfa weed control practices. The safety and flexibility of glyphosate is apparent and will be useful once commercial plantings are underway. Although timing with Roundup applications is to some degree still important, it may not prove as important as it is with other alternative herbicides. The degree of glyphosate flexibility on weed timing, broad spectrum weed control and especially control of perennial weed species, are the principle benefits of RR alfalfa.

Figure 1.



South region

Common/Troublesome Weeds -South

Rank	Weed	Weed stage & Glyphosate rate (lb ae/A)
1	Crabgrass	12''- 0.75
2	Chickweed	18''- 0.75
3	Wild Radish	18''- 0.75 ??
4	Henbit	6''-0.75; 12''-1.13
5	Curly Dock	Bud-2.25; split app. 1.5
6	Pigweed spp.	18''- 0.75
7	Mustard spp.	18''- 0.75
8	Johnsongrass	Boot-0.5-2.25; split 1.5
9	Musk Thistle	Rosette-1.5
10	Ryegrass	6''-0.75; 12''-1.13
11	Bermudagrass	Head-2.25-3.7; split 1.5

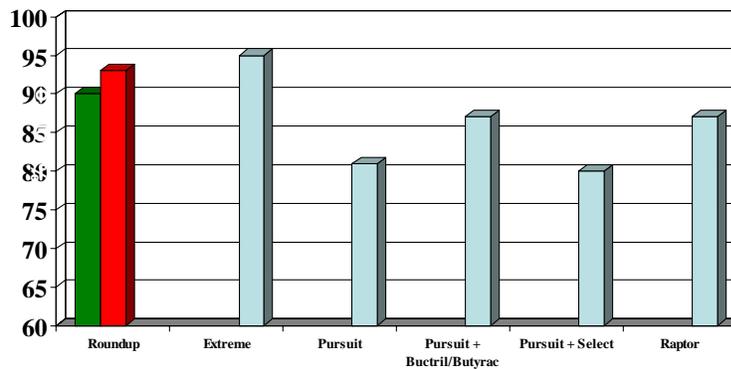
Maximum weed size and rate for control with glvphosate.

East Region

Overall Weed Control in Spring Seedling Establishment

Annual bluegrass, Downy brome, Shepherdspurse (2), Chickweed, Wild mustard, Foxtail (5), Lambsquarters (7), Pigweed (4), Ragweed (6), Smartweed (3), Velvetleaf (3), Cocklebur (2), Dandelion, Plantain, Yellow nutsedge

■ 0.75 lb ae ■ 1.5 lb ae ■ Commercial rate



Summary of 8 Roundup Ready® Alfalfa Tests.

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