Indiana Soybean Alliance

Final Technical Report
FY 16 Research Project

Title: **Characterization and Management of Herbicide-Resistant Weeds in Indiana**

Project Dates:
May 1, 2016 to April 30, 2017

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Background

The persistent use of glyphosate as the primary weed management tool in soybean has resulted in widespread weed resistance to glyphosate. Populations of glyphosate-resistant waterhemp, Palmer amaranth, giant ragweed, and horseweed (aka marestail) have continued to increase across Indiana and the frequency of multiple herbicide resistance beyond just glyphosate continues to be a major challenge in gaining effective control. The proposed research activities were focused on improving weed management in soybean by characterizing the extent of herbicide-resistant weed biotypes in the Indiana landscape and developing management strategies for these problematic weeds.

Objectives

<u>Broad, long-term objective</u>: Reduce the impact of herbicide-resistant weeds on soybean production and profitability and develop best management practices for herbicide-resistant weed species.

<u>Specific objectives</u>:

Survey and Screening for Herbicide-Resistant Weeds

1) *Document the confirmation and distribution of Palmer amaranth, waterhemp, giant ragweed, horseweed, and other emerging weeds that are resistant to glyphosate and other key herbicide modes of action.*

Best Management Practices for Herbicide-Resistant Weeds

2) *Develop weed management strategies for glyphosate-resistant Palmer amaranth, waterhemp, giant ragweed, and horseweed.*

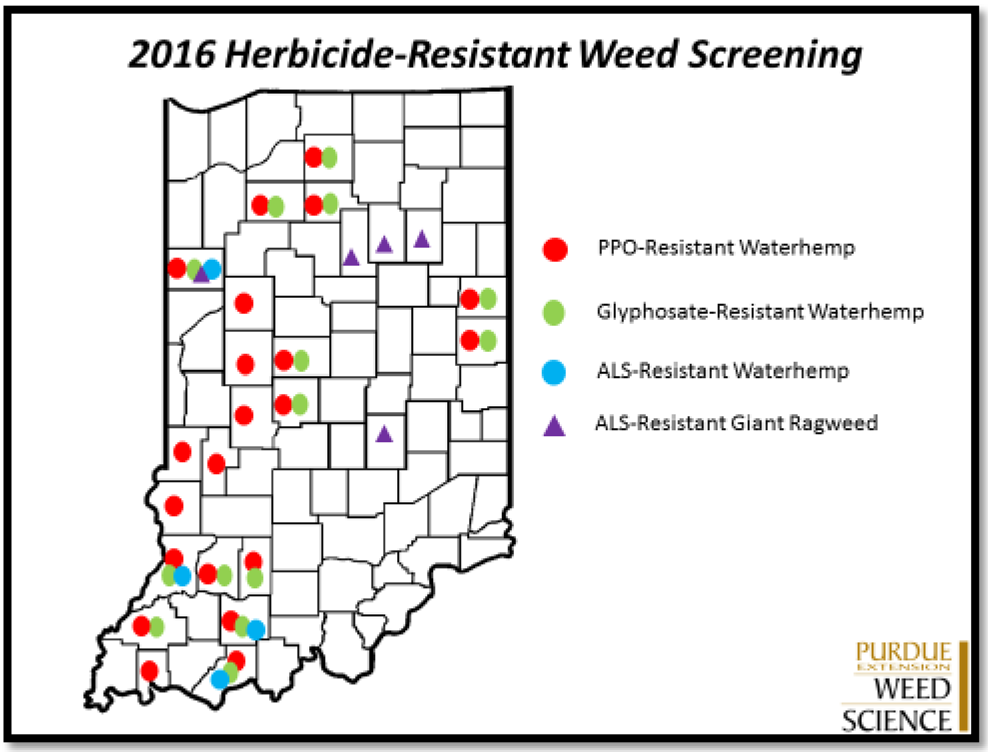
Characterization of Glyphosate-Resistant Giant Ragweed

3) *Characterize the difference in plant response to glyphosate between the two giant ragweed phenotypes with the two different resistance mechanisms.*

Findings

Survey and Screening for Herbicide-Resistant Weeds

Our lab provided a screening service for suspected herbicide resistance in waterhemp, Palmer amaranth, and giant ragweed through the Purdue Plant Diagnostic Lab during the 2016 field season. Waterhemp was the primary weed of concern in 2016 for the samples submitted to our lab for resistance screening, with some giant ragweed samples and no Palmer amaranth samples submitted. Waterhemp was also the most common weed species submitted for resistance screening in 2015, which cements waterhemp as the greatest developing weed resistance problem in Indiana. A map that summarizes our findings for the submitted samples in 2016 is below.



A total of 42 field populations of waterhemp (227 individual plants) were submitted representing 21 different counties in Indiana. Boone, Knox, Vigo, and Randolph counties submitted over half of all the waterhemp samples and represent the Southwest, Central, and East regions of Indiana. This is markedly different from 2015 in which the primary counties were located in just the Southwest region (Gibson, Vanderburgh, and Warrick).

Of the individual waterhemp plant samples submitted 40% were resistant to PPO-inhibiting herbicides (e.g. Flexstar, Cobra), 52% were resistant to glyphosate (e.g. Roundup), and 20% exhibited multiple resistance to both glyphosate and PPO herbicides. These results are similar to the waterhemp samples submitted in 2015 (61% resistant to PPO-inhibiting herbicides; 65% resistant to glyphosate). The above results describe the variability in herbicide resistance among individual plants; however, the percentage of fields with at least one individual plant exhibiting herbicide resistance would be of greater practical importance for guiding weed management recommendations to growers on those fields. In that regard, 69% of the fields with suspected waterhemp resistance to PPO-inhibiting herbicides were confirmed as resistant with our lab assay. Likewise, 84% of the fields with suspected waterhemp resistance to glyphosate were confirmed and 52% of the fields contained multiple resistance to both PPO-inhibiting herbicides and glyphosate.

Giant ragweed samples were submitted from 10 fields (47 plants total) in Indiana with suspected resistance to ALS-inhibiting herbicides (e.g. Firstrate, Classic). Giant ragweed plants with resistance to the ALS herbicides were identified in 8 of the 10 field locations and represented 38% of the individual plants submitted. The giant ragweed with confirmed resistance to ALS-inhibiting herbicides in 2016 originated from Benton, Miami, Wabash, Shelby, and Huntington counties (generally the Central region of Indiana).

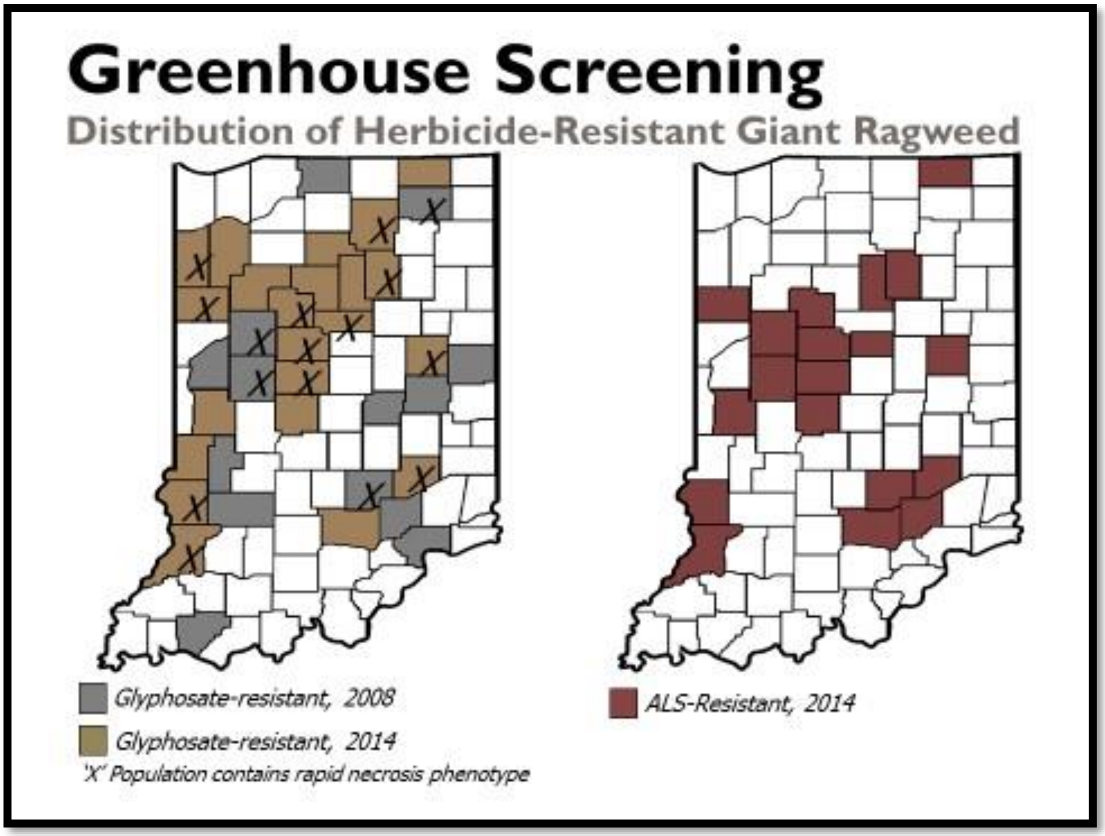
In addition to the samples that were submitted from professionals within the crop production industry, we also screened weed samples that we collected based on previous knowledge of response to herbicides or observation of commercial weed control failures. Through this effort we identified and developed rapid lab DNA assays for a second mutation (R98) in the target PPO enzyme in waterhemp and Palmer amaranth. The importance of this second mutation in terms of herbicide failures or the magnitude of resistance to PPO-inhibiting herbicides has not yet been fully investigated, but is the subject of ongoing research in our lab. The initial mutation to the PPO enzyme (G210) largely reduced the performance of PPO-inhibiting herbicides applied postemergence, but the soil residual herbicides in this group (site of action #14) still maintained significant activity. Our work will try to determine if this second mutation found alone or in combination with G210 can overcome group 14 herbicides applied PRE or POST. We have also found mutations in the ALS target enzyme in waterhemp and horseweed (marestail) that have not been documented previously in Indiana. We are trying to determine the importance of these mutations as well, but can report that plants with some of these mutations can still be partially managed using select ALS-inhibiting herbicides, such as achieving 80% residual control of waterhemp with chlorimuron (Classic) despite having negligible control with Classic applied POST or imazethapyr (Pursuit) applied in any manner. In general, herbicide screens using random collection methods and those submitted by farmers or industry representatives continue to be an effective means for characterizing the herbicide resistance challenges facing Indiana soybean farmers. The results of this research were communicated at numerous venues and through different media outlets (see Communication section below for more details).

Best Management Practices for Herbicide-Resistant Weeds

Field research experiments designed to identify practices, herbicide products, herbicide strategies, or soybean traits that would improve weed management were conducted on herbicide-resistant waterhemp, giant ragweed, Palmer amaranth, and horseweed (marestail) in 2016. These field trials were conducted by Purdue University and collaborating investigators (Drs. Mark Loux and Aaron Hager) at The Ohio State University and the University of Illinois. Each year, we conduct over 50 trials at these sites and the results are either shared directly with clientele or synthesized and delivered to clientele at numerous venues and through different media outlets (see Communication section below for more details). Some research highlights include: the inconsistency of auxin herbicides (2,4-D and dicamba) for control of glyphosate-resistant horseweed when used as the sole means of control; the importance of application timing for both residual (close to period of peak emergence) and foliar (weed size under 4 inches) active herbicides for all four of these problematic weed species; and the potential for reduced herbicide activity when applying postemergence herbicides with extremely large spray droplets that may reduce spray coverage on target weeds. Overall, the greatest weed challenges arise when the herbicide applications are performed later than desired, as once these problematic weeds gain an advantage it can be nearly impossible to regain control to satisfactory levels for the remainder of the growing season. The results of this field research were delivered through various formats with clientele including the "Take Action" website sponsored by the United Soybean Board and the 2017 Weed Control Guide for Ohio, Indiana, and Illinois, in addition to other outreach activities (see Communication section below for more details).

Characterization of Glyphosate-Resistant Giant Ragweed

Giant ragweed is among the most competitive summer annual weeds in corn and soybean production. Difficulty in controlling giant ragweed is exacerbated by the evolution of herbicide-resistant (HR) biotypes to both ALS-inhibiting herbicides and glyphosate. Glyphosate resistance (GR) in giant ragweed is unique as there exist two distinct phenotypic responses following application. The rapid response (RR) biotype displays a lesion-causing oxidative burst (rapid necrosis) in mature leaves in as little as two hours after treatment and quickly results in leaf desiccation, thus restricting glyphosate translocation. The non-rapid response (NRR) biotype of giant ragweed exhibits slightly chlorotic leaves and stunted plant growth (similar to glyphosate-resistant marestail response). Both biotypes resume normal growth within a week. Glyphosate-resistant giant ragweed was found in 36 counties in Indiana compared to only 14 counties in a 2008 survey (see figure below).



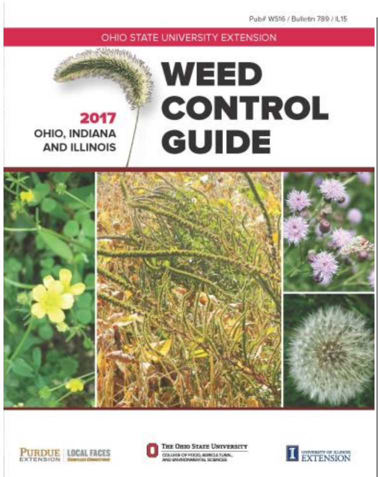
Based on glyphosate dose-response experiments, the rapid response (necrosis) biotype was nearly twice as resistant to glyphosate as the non-rapid response biotype. The RR to glyphosate results in foliage loss and reduced glyphosate translocation. Therefore, experiments were performed to determine how this influences the efficacy of five co-applied selective herbicides. In a field trial, combinations of glyphosate plus dicamba (Clarity) or topramezone (Impact or Armezon) were antagonistic on the RR biotype across multiple years. For both biotypes, the greatest efficacy was achieved with the tank-mixture of glyphosate plus dicamba. However, the magnitude of glyphosate-induced antagonism tended to be greater at 86 F (versus 50 F) and under high soil moisture levels.

Collectively, this research indicates that under continued glyphosate use, GR giant ragweed will continue to spread and the RR biotype may become more prevalent due to a greater magnitude of resistance compared to the NRR biotype. An ancillary consequence of the RR to glyphosate is the propensity to antagonize selective herbicides, particularly those herbicides which are phloem-mobile (systemic). Under optimum plant growing conditions, the degree of antagonism intensifies. Despite an antagonistic interaction between glyphosate and dicamba on the RR biotype, results show this herbicide combination to be highly effective for the control of both GR giant ragweed biotypes, and thus it remains an effective management option in glyphosate- and dicamba-resistant cropping systems. Although this research represents a significant advancement in characterizing glyphosate-resistant giant ragweed, the specific mechanism(s) that allow for resistance remains undetermined. The ultimate goal should remain focused on identifying this specific mechanism as it will aid in managing glyphosate-resistant giant ragweed and improve our understanding of how weeds can evolve resistance to herbicides. The results of this research have been submitted for publication in scientific journals and have been communicated at numerous venues and through different media outlets (see Communication section below for more details).

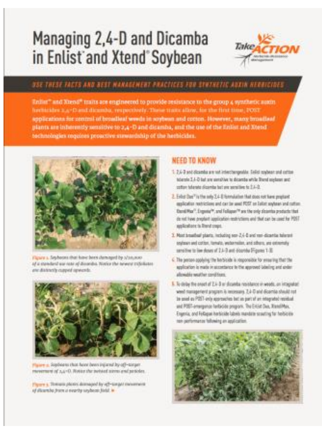
Project Communication

The deliverables from this research were communicated through various methods and individuals throughout the project period. The Purdue Weed Science Field days are held during the last week of June each year. In 2016, we held a field day at our Palmer amaranth site near Medaryville, IN and attendance was nearly 100 people. We held a second field day the same week at a site that contains giant ragweed, glyphosate resistant waterhemp, and glyphosate-resistant horseweed (marestail). We also give presentations at late-summer field days at Purdue Ag Centers, we present data from our summer trials and make recommendations for next year to primarily growers. In 2016, we had over 1,000 people attend these field days and hear our presentations on our herbicide screening and weed management trials. We also summarized the data and presented it in newsletter articles and during private applicator recertification programs (PARP) during the winter Extension meeting season. Each year extension weed scientist Bill Johnson gives presentations in over 30 PARP meetings. Average attendance is 25 to 50 people per meeting. The results were shared at the Purdue University Crop Management Workshops (attendance is approximately 900 people over the course of the 5 day workshop), and the Indiana CCA Convention (attendance is approximately 650 people). The number of acres managed by crop advisors at the Indiana CCA Convention is estimated to be in the millions. Other methods of communicating research results include weekly newsletters during the growing season (Pest & Crop) with over 1,000 subscribers, and Dr. Johnson maintains a website where he can house the results of this work in the form of downloadable decision tools where farmers can evaluate the profitability of a BMP for their operation, and downloadable presentations.

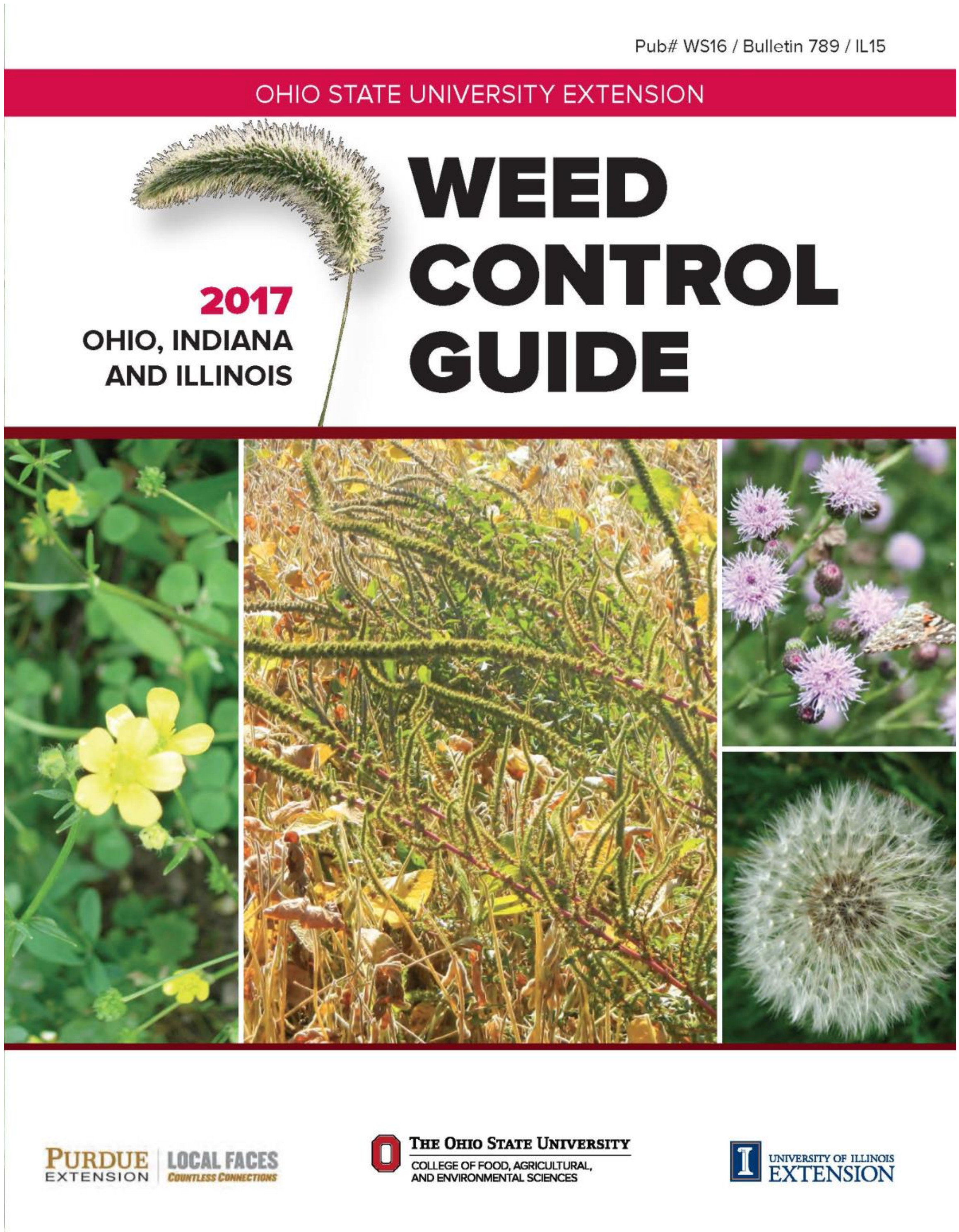
Applied research results are also delivered to growers via the Weed Control Guide for Ohio, Indiana, and Illinois. This multistate endeavor is a 200-page guide that contains concise information for controlling weeds in soybeans, corn, wheat, alfalfa, and forages. This publication is updated annually based on results from our field and greenhouse research programs. In the back of this guide we have special, detailed sections for control of our most problematic weeds. (excerpt from 2017 provided below).



Finally, Purdue University is the lead institution on the USB Take Action grant and we have developed a number of deliverables that are hosted on their website. See one example below of a new publication that was develop over the past year. All of the relevant outreach publications are provided in a larger format in the Appendix of this report.



Appendix – Outreach Materials for Problematic Weeds



Control of Marestail in No-till Soybeans

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Find Herbicide Labels at:
cdms.net
agrian.com
greenbook.net

Marestail Biology

- Marestail (aka horseweed) has two primary periods of emergence - from late summer into fall, and from late March through June.
- Marestail plants overwinter in the rosette stage, and remain in this low-growing stage through late April, followed by stem elongation (bolting) and growth to an eventual height of 3 to 6 feet. Plants that emerge the previous fall will start stem elongation earlier than spring-emerging plants.
- Marestail is most easily controlled when in the seedling or rosette stage
- Marestail competes with the soybeans throughout the growing season, and reduces crop yield. Marestail matures in late summer or early fall, and large mature plants can interfere with soybean harvest.
- Marestail plants can produce up to 200,000 seed that are transported by wind, providing for effective spread of herbicide-resistant populations.

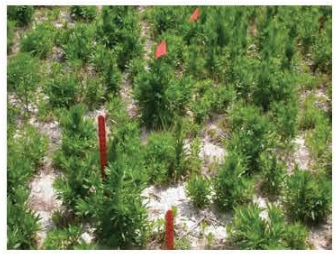
Soybean yield loss due to marestail

- Herbicide programs should consist of: 1) fall and spring burndown treatments (or two spring treatments - early spring and at plant) to ensure that the field is free of marestail at the time of soybean planting, and 2) spring-applied residual (PRE) herbicides to control marestail for another 6 to 8 weeks after planting.
- Failure to follow these guidelines can result in poor control and reduced soybean yield. We observed the following soybean yields in a 2010 OSU marestail study:

51 bu/A - the burndown treatment failed to control emerged plants
57 bu/A - the burndown treatment was effective, but there was no residual herbicide
65 bu/A - the burndown was effective and included residual herbicides

Herbicide resistance in marestail

- Most populations of marestail in Ohio and Indiana are resistant to glyphosate (group 9), and will not be controlled by burndown or postemergence applications of glyphosate alone.
- Many marestail populations are now also resistant to group 2 (ALS-inhibiting - e.g Classic, FirstRate) herbicides Growers should therefore not expect to obtain effective POST control in soybeans with combinations of glyphosate plus Classic, Synchrony, or FirstRate. Postemergence group 14 herbicides, such as Flexstar, Cobra, and Cadet, also do not control marestail.


Photos: multiple-resistant marestail surviving treatment with (from left to right): glyphosate alone, ALS inhbitor alone, and a combination of ALS inhibitor and glyphosate

Other impacts of multiple resistance (group 2 + 9)

- Fall-applied Canopy or other chlorimuron- or cloransulam-containing herbicides will not provide residual control of group 2-resistant marestail into spring. Activity of other residual herbicides does not persist from fall into spring, and their use should be reserved for spring applications
- The ALS component of residual premix products will not contribute to marestail control when applied in spring. Spring-applied residuals should include active rates of non-ALS herbicides - metribuzin, flumioxazin (Valor), sulfentrazone (Authority), or higher rates of saflufenacil (Sharpen).
- In burndown applications, there will be no added effectiveness on emerged marestail from products that contain chlorimuron or cloransulam, which makes selection of the other herbicides in the mix more important.

LibertyLink soybeans - the most effective marestail control strategy

- LibertyLink soybeans are the most effective tool for management of herbicide-resistant marestail, especially in fields with high marestail populations.
- Use burndown and residual herbicides as outlined on the next two pages. Apply glufosinate POST (29 oz/A) before marestail plants exceed 6 inches in height. Glufosinate can be applied POST at rates up to 36 oz/A for taller plants or plants that have survived previous herbicide treatments, but control may be variable. Follow with a second POST application of glufosinate as necessary.

Steps for effective management of marestail

1. **Use fall herbicide treatments** in fields with a history of problems or where marestail seedlings are observed in fall. Consider using 2,4-D as the base herbicide to control marestail, and combining it with one of the following to ensure control of other winter weeds:

- glyphosate; dicamba (dicamba/2,4-D premixes - Brash, WeedMaster, Outlaw, Rifle); Basis/Crusher/Harrow; Express/Nuance; a low rate of Canopy/Cloak EX or DF; or metribuzin
- can add Canopy/Cloak to other herbicide combinations to obtain residual control of weeds into spring, but do not expect residual from fall-applied Canopy/Cloak to adequately control spring-emerging marestail. We do not recommend the use of other residual herbicides in the fall due to cost and lack of residual control into spring.
- Do not overspend on fall treatments. Keep the cost of herbicides in the $6 to $15 range.

2. **Apply effective burndown herbicides in spring**. Do not plant into existing stands of marestail. Start weedfree at the time of planting by using one of the following preplant herbicide treatments, applied when marestail plants are still in the rosette stage. Note - tillage close to time of planting also effectively removes marestail, but must thoroughly mix the upper few inches of soil and uproot existing plants.

- 2,4-D ester plus glyphosate (1.5 lb ae/A) - see note below
- Sharpen/Zidua PRO plus MSO (1% v/v) plus either glyphosate or Liberty
- 2,4-D ester plus glyphosate plus Sharpen/Zidua PRO plus MSO (1% v/v)
- 2,4-D ester plus Gramoxone (3 to 4 pts/A) plus a metribuzin-containing herbicide
- glufosinate - 29 to 36 oz/A (addition of 2,4-D and/or metribuzin can improve control)

- The mixture of glyphosate and 2,4-D ester applied in the spring has become variable for control of marestail over time, especially in fields that were not treated the previous fall. Plants should be newly emerged, small rosettes at the time of application for best results. In fields where this mixture has previously failed to provide effective control, use one of the other burndown treatments listed above.
- Control can be improved by using the highest rate of a 2,4-D ester product that is allowed, based on the interval between application and soybean planting. For all 2,4-D ester products, rates up to 0.5 lb active ingredient/A must be applied at least 7 days before planting. Rates between 0.5 and 1.0 lb/A should be applied at least 30 days before planting, with the the exception of several products (E-99, Salvo, and Weedone 650) that allow 1 lb/A to be applied 15 days before planting.
- Mixtures of Sharpen with herbicides containing other group 14 herbicides (flumioxazin, sulfentrazone, fomesafen) must be applied 14 days prior to soybean planting on most soils, and 30 days prior to planting on coarse-textured soils with less than 2% organic matter.
- The addition of dicamba to early spring burndown treatments can improve control or emerged marestail, especially plants that have overwintered. Dicamba can be more effective than 2,4-D on marestail in the spring, but has more potential to injure soybeans if the recrop guidelines are not followed. Following dicamba application, soybeans can be planted 14 to 28 days **after an inch of rain has occurred** (in total). For example, the Clarity label states the following - "following application of Clarity and a minimum accumulation of one inch of rain, a waiting interval of 14 days is required for rates of 8 oz/A or less, and 28 days for rates up to 16 oz/A".

Steps for effective management of marestail (continued)

3. **Include non-ALS residual herbicides** with the burndown treatment, for control of marestail until the soybean leaf canopy develops.
   - flumioxazin - Valor/Encompass/Outflank/Panther, Valor XLT, Envive/Enlite, Fierce, Fierce XLT, Surveil
   - sulfentrazone - Authority First, Sonic, Authority XL/Maxx, Authority, Authority Assist, BroadAxe
   - Metribuzin - Dimetric, Tricor, Glory (at least 8 oz/A, and preferably 10 to 12 oz/A), but do not exceed recommended rate for soil type
   - Increase rate or add metribuzin to bring total rate to 0.38 to 0.5 lbs ai/A, for premix products that contain metribuzin, such as Boundary/Ledger, Canopy/Cloak DF, Intimidator, Matador, Authority MTZ, Ransom
   - In OSU research, most effective residual control has occurred with mixtures that contain two non-ALS residual herbicide components. Examples: mixture of a flumioxazin or sulfentrazone product with metribuzin; mixture of a metribuzin product with Sharpen (1.5 to 2 oz). Trivence and Ransom are examples of premixes that contain flumioxazin and metribuzin.
   - Residual control of marestail with Sharpen occurs primarily at the 1.5 to 2 oz rate, which must be applied 14 to 30 days prior to planting - see label for specific information on application timing.
   - Where early spring application is needed due to lack of a treatment the previous fall, it is especially important to increase herbicide rates and use more complex mixtures (or consider split spring approach).

4. **No fall treatment? - consider split-spring applications**. Failing to treat fields in the fall can result in a population of overwintered marestail plants the following spring, which should be controlled early in spring to ensure effective burndown. One approach is to apply burndown herbicides with some of the residual herbicide in early spring, and then when soybeans are planted, apply the rest of the residual herbicide. The second application may require some additional burndown herbicide. Examples here include:
   - early spring - glyphosate + 2,4-D + Sonic (2.5 oz/A); at plant - Sonic (2.5 oz) + Gramoxone
   - early spring - glyphosate + 2,4-D + metribuzin (4 oz); at plant - Canopy DF (4 oz) + metribuzin (2 oz) + Sharpen (1 oz)
   - early spring - glyphosate + 2,4-D + metribuzin (6 oz); 7 days preplant - Envive (4 oz) + 2,4-D ester

5. **So this all seems really involved. Can't I just do it all with one spring preplant treatment?**

   Maybe - but this is not an approach that has consistently worked well (see photos below). It can be difficult to accomplish unless the marestail population in the field has been well managed for several years and the population is generally low. Growers should use their own previous experiences here as guidance, and plan on increasing the complexity and rates of the herbicide program. Problems with skipping the fall treatment, and applying everything at once in spring include the following: 1) applying early in spring when plants are small can result in poor control of plants that are emerging in mid-season if the residual herbicide runs out; and 2) applying closer to planting to maximize the length of residual often results in less effective control of larger, older marestail plants, especially those that have overwintered.

Left photo - spring application of glyphosate + 2,4-D + residual herbicides (no fall herbicide treatment)

Right photo - fall application of glyphosate + 2,4-D followed by spring application of glyphosate + 2,4-D + residual herbicides

Fall application = early November

Spring application = April 21 (7 days preplant)

Palmer Amaranth Management in Soybeans

Palmer Amaranth Distribution and Biology

- Native to the southwestern United States, Palmer amaranth (aka Palmer pigweed) has become a devastating weed problem in the South and has recently spread to the upper Midwest.
- Many fields in the eastern Soybean Belt where Palmer amaranth has been found received an application of manure from dairy cows that were fed cotton byproducts as a feed supplement.
- Palmer amaranth is the most competitive and aggressive pigweed species. Season-long competition by Palmer amaranth at 2.5 plants per foot of row can reduce soybean yield by as much as 79 percent.
- Palmer amaranth emerges later than many summer-annual weeds and continues to emerge throughout the growing season. This extended emergence pattern makes it difficult for preemergence and nonresidual postemergence herbicides to control later-emerging plants.
- The high relative growth rate of Palmer amaranth makes control with postemergence herbicides difficult. In the southern United States, Palmer amaranth has been documented to grow as much as 2.5 inches per day. In Michigan, Palmer amaranth grows 4 inches in less than five days during the time of postemergence-herbicide applications.
- Prolific seed production has perpetuated the establishment and spread of Palmer amaranth. A single female Palmer amaranth can produce approximately 600,000 seeds per plant.
- Compared with many other summer-annual weeds, Palmer amaranth seed is relatively short-lived in the soil. Research has shown that only 2 percent of Palmer amaranth seed remains viable in the soil seedbank after six years. However, the sheer number of seeds produced by one female plant makes the eradication of Palmer amaranth difficult once it is established.

Genetic Diversity and Herbicide Resistance in Palmer Amaranth

- Palmer amaranth is dioecious, meaning its male and female flowers grow on separate plants. This increases the genetic diversity of this species and facilitates the spread of herbicide resistance and other adaptive traits that improve the survival of Palmer amaranth in agronomic systems.
- Since the late 1980s, Palmer amaranth has evolved resistance to five different herbicide sites of action.

Group #	Group 2	Group 3	Group 5	Group 9	Group 27
Site of Action	ALS Inhibitors	Microtubule Inhibitors	Photosystem II Inhibitors	EPSP Synthase Inhibitors	HPPD Inhibitors
Product Examples	Classic®, Pursuit®	Treflan®	*atrazine, metribuzin*	*glyphosate*	Callisto®, Laudis®

- Several populations across the United States exhibit resistance to multiple herbicides. For example, many Palmer amaranth populations exhibit resistance to both ALS-inhibiting herbicides (Group 2) and glyphosate (Group 9), and a more recently identified Palmer amaranth population has shown resistance to herbicides from three different sites of action: ALS- (Group 2), Photosystem II- (Group 5) and HPPD-inhibiting (Group 27) herbicides. As the selection pressure from other herbicides increases, multiple resistant populations will evolve.

Management of Herbicide-Resistant Palmer Amaranth in Soybeans

Palmer amaranth with resistance to one or more herbicides is one of the most difficult weeds to manage in soybeans. If you have herbicide-resistant Palmer amaranth in your soybean fields, it is important to follow the steps below for best management. Additionally, cultural practices such as earlier planting, narrow row spacing and optimum planting populations can increase the soybean plant's ability to compete with this weed and will also improve the consistency of the herbicide programs listed below.

1. ***Consider planting LibertyLink® soybeans***. Controlling herbicide-resistant Palmer amaranth in Roundup Ready® soybeans has been a challenge. That's because of the limited postemergence-herbicide options available, label restrictions and lack of consistency observed with postemergence herbicides. However, LibertyLink soybeans offer more flexibility in use rates and the number of applications of Liberty (Group 10) that can be made.

2. ***Start clean!*** Make sure that all herbicide-resistant Palmer amaranth plants are controlled with tillage or an effective burndown herbicide – i.e., Gramoxone® (Group 22) or Liberty (Group 10), prior to planting.

3. ***Effective soil-applied (preemergence) herbicides are essential.*** Apply the full rate (according to label guidelines for soil type and organic matter content) of an effective soil-residual herbicide, prior to or soon after soybean planting. In many cases, Valor® (Group 14) and Fierce® (Groups 14 & 15) have been the most consistent control options. Valor XLT, Envive®, and Gangster® (Groups 14 & 2) are also Valor (flumioxazin)-based products that have provided good control. Premixes that contain the Group 14 herbicide Spartan (sulfentrazone), Authority® MTZ (Groups 14 & 5), Authority First/XL/MAXX/Assist, and Sonic® (Groups 14 & 2) can also be used. However, rates of these herbicides need to be equivalent to 8 fl. oz./A. of Spartan® (0.25 lb. a.e./A. of sulfentrazone). Adding metribuzin (Group 5) to one of these Group 14 herbicides or herbicide premixtures (where allowed) can provide additional residual control of Palmer amaranth as well as another site of action to the mix. Remember, higher rates of the Group 14 herbicides also increase the likelihood for soybean injury. Group 15 herbicides have provided fair to good initial control of glyphosate/multiple-resistant Palmer amaranth; however, these herbicides may be best utilized as tank mixtures with the postemergence herbicide application.

4. ***Timely postemergence herbicide applications.*** Proper timing is everything! Postemergence herbicides must be applied before Palmer amaranth is 3 inches tall. In Roundup Ready (RR) soybeans, a Group 14 (Flexstar®, Cobra® or Ultra Blazer®) herbicide should be used. Flexstar has been the most consistent of these herbicides for Palmer amaranth control. In LibertyLink soybeans, use a minimum rate of 29 fl. oz./A. of Liberty. Spray coverage is essential with any of these herbicides, so a minimum of 15 gal./A. of spray solution should be used. Once Palmer amaranth plants exceed 3 inches tall, control with any of these postemergence herbicides is substantially reduced.

5. ***Residual product tank-mixtures with postemergence herbicides.*** A residual Group 15 herbicide (i.e., Dual® II Magnum®, Warrant™, Outlook® or Zidua®) should be tank-mixed with the postemergence herbicide application. It is essential for the postemergence herbicide – Flexstar, Cobra, Ultra Blazer or Liberty (LibertyLink soybeans only) – to have effective control of herbicide-resistant Palmer amaranth since the residual herbicides will not control Palmer amaranth that has already emerged. Prefix is one product where the postemergence herbicide Flexstar is premixed with the residual herbicide Dual Magnum.

6. ***Additional postemergence herbicide applications if needed.*** A follow-up application of an additional postemergence herbicide may be needed. Again, proper timing is everything. Make these applications when Palmer amaranth is 3 inches tall or less. In RR soybeans, if Flexstar was used in the first postemergence application, Cobra or Ultra Blazer is the only herbicide option remaining. If Palmer amaranth is larger than 3 inches, you will have to use 12.5 fl. oz./A. of Cobra. The use of a methylated seed oil (MSO) as the adjuvant with these mixes may also improve control. In LibertyLink soybeans, Liberty should be applied at rates ranging from 29 to 36 fl. oz./A., depending on weed height.

While following these strategies may not be 100 percent effective, they can substantially reduce herbicide-resistant Palmer amaranth populations. Additional cultural control measures, such as hand-weeding, should be implemented to eliminate any remaining herbicide-resistant Palmer amaranth plants from the field. It is also important to manage Palmer amaranth around field edges and ditch banks. Remember, one female plant can produce upward of 600,000 seeds per plant. It is important to reduce seed production from this weed to stop its further spread. If you think that you have this weed or other glyphosate-resistant weeds in any of your fields, make sure these are the last fields that you harvest. This will reduce the transportation of resistant weed seed to your other fields.

For more information and links to additional resources, visit www.TakeActionOnWeeds.com.

Technical editing for this publication was led by Christy Sprague, Ph.D., Michigan State University, in partnership with other universities in the soybean-growing regions of the United States.

Waterhemp Management in Soybeans

Take ACTION HERBICIDE-RESISTANCE MANAGEMENT

Waterhemp Biology

- Although several summer annual weeds may be more competitive, waterhemp gains a competitive advantage through the sheer number of plants infesting an area. Season-long competition by waterhemp (more than 20 plants per square foot) has been shown to reduce soybean yield by 44 percent. Waterhemp that emerged as late as the V5 stage in soybeans can reduce yields up to 10 percent.
- Waterhemp compensates for small seed size by having a higher relative growth rate than most weeds or crops—typically between 1 and 1 1/4 inches per day during the growing season. This allows waterhemp seedlings to acquire more sunlight than other weeds.
- Waterhemp emerges throughout the growing season, and a higher percentage of plants can emerge later in the season than is typical with most other summer annual weeds. This emergence pattern allows waterhemp to avoid many pre-emergent herbicides and often allows this weed to flourish after postemergent applications of nonresidual herbicides like glyphosate.
- Waterhemp is a prolific seed producer and able to produce as many as 1.5 times more seeds than most other pigweed species. Waterhemp plants generally produce about 250,000 seeds per plant, although some plants can produce 1 million or more seeds under optimal conditions in noncompetitive environments.
- Like most weeds, waterhemp seeds remain viable in the soil for several years. Research has shown that only 1 to 12 percent of waterhemp seeds remain viable in the soil seedbank after four years.

Genetic Diversity and Herbicide Resistance in Waterhemp

- Because waterhemp is dioecious, meaning there are male and female flowers on separate plants, there is potential for greater genetic diversity within a population than for most agronomic weeds. This genetic diversity increases the potential for evolving and spreading novel herbicide-resistance genes and other ecological traits that improve waterhemp survival in agronomic systems.
- Waterhemp has a remarkable ability to adapt to control tactics and has evolved resistance to many different classes of herbicides. To date, waterhemp has evolved resistance to six herbicide classes, including Group 5 (e.g., triazines like atrazine and simazine), Group 2 (e.g., ALS-inhibiting herbicides like Pursuit® and Classic®), Group 14 (e.g., PPO-inhibiting herbicides like Ultra Blazer®, Cobra® and Flexstar®), Group 9 (e.g., glyphosate), Group 27 (e.g., HPPD-inhibiting herbicides like Callisto®, Laudis® and Impact®) and Group 4 (e.g., 2,4-D).
- Many populations in the Midwest now exhibit multiple herbicide resistances that include several herbicide families. For example, Group 2 and 9 (e.g., ALS inhibitors and glyphosate, respectively) resistance in waterhemp is fairly common, and in many states resistance to as many as five herbicide groups now occurs in some waterhemp populations.

Management Steps

Follow the steps below to achieve optimal control of herbicide-resistant waterhemp populations. In addition, cultural practices that enhance the competitiveness of the crop, such as narrow row spacings and optimal soybean planting populations, will improve the consistency of these herbicide programs.

1. Soon before or after soybean planting, apply a full rate (according to label guidelines for soil type and organic matter content) of an ***effective*** pre-emergent, soil-residual herbicide.
   - **Why invest in a soil-residual herbicide?** A waterhemp population resistant to both Groups 14 and 9 herbicides (e.g., PPO inhibitors and glyphosate, respectively) would not be controlled by these postemergent soybean herbicides in Roundup Ready (RR) or conventional soybean systems. Waterhemp is competitive with soybeans and the application of an effective, soil-applied residual herbicide will protect soybean yield from early-season interference.
   - **Why use a full rate instead of a reduced ("setup") rate?** Waterhemp emergence extends late into the growing season. The later waterhemp emergence can be delayed, the greater the potential to achieve maximum

or near-maximum soybean yield and improve the success of postemergent herbicide treatments.

- Depending on the herbicide-resistance profile, effective soil-residual herbicides may include: Authority® First, Authority Assist, Authority MTZ, Authority XL, Boundary®, Dual II Magnum® (or other metolachlor products), Enlite®, Envive®, Fierce, Gangster®, Outlook®, Prefix™, Sencor®, Sonic®, Treflan, Valor®, Valor XLT, Warrant™ and Zidua®.

2. **In conventional or RR soybeans:** If Group 9 (e.g., glyphosate) resistance in waterhemp is known or suspected and there is no reason to believe the population is also resistant to Group 14 (e.g., PPO-inhibitors) herbicides, apply a Group 14 herbicide like Cobra, Flexstar, Phoenix® or Ultra Blazer® to waterhemp not more than 3 to 4 inches in height.
   - In RR soybeans, glyphosate can also be applied in combination with a Group 14 herbicide, depending on the spectrum of other weeds present in the field.
   - The size of the waterhemp at the time of application is a critical determinant of the level of waterhemp control achieved, as Group 14 herbicides are most effective against waterhemp 4 inches or less in height.
   - Group 14 herbicides like Flexstar and Cobra should be applied in a minimum of 15 gallons of water per acre. In dense weed/crop canopies, 20 to 40 gallons of water per acre should be used to ensure thorough spray coverage.
   - If Prefix has been applied pre-emergence, do not apply Flexstar or any fomesafen product after emergence due to label restrictions.
   - If Group 14 resistance is also known or suspected in the waterhemp population, the only additional options for waterhemp control include: 1) applying an overlapping residual herbicide prior to the emergence of any subsequent waterhemp germination events, 2) inter-row cultivation or (3) hand roguing.

   Regardless of the herbicide resistances in waterhemp, the addition of an effective overlapping residual herbicide to the postemergent herbicide is likely to reduce or eliminate waterhemp emergence for the remainder of the season. Effective overlapping residual herbicides include but are not limited to Group 15 herbicides such as Anthem™, Cinch®, Dual II Magnum, Outlook, Prefix, Warrant and Zidua.

   In LibertyLink soybeans: Remember that it is critical to apply an effective, pre-emergence soil-residual herbicide as outlined in Step 1. Then, apply Liberty (Group 10 herbicide) to waterhemp no more than 3 to 4 inches in height.
   - The waterhemp size at the time of the application will be an important determining factor in the level of waterhemp control achieved.
   - Liberty should be applied in a minimum of 15 gallons of water per acre. In dense weed/crop canopies, 20 to 40 gallons of water per acre should be used to ensure thorough spray coverage.
   - Apply Liberty using nozzles and pressures that generate medium (250-350 micron) spray droplets. Do not use nozzles that produce coarse sprays.
   - The addition of an overlapping residual herbicide to the post-emergence Liberty treatment is likely to reduce or eliminate waterhemp emergence for the remainder of the season. Effective overlapping residual herbicides include but are not limited to Group 15 herbicides such as Anthem®, Cinch, Dual II Magnum, Outlook, Prefix, Warrant and Zidua.

3. Scout the field within seven to 14 days after the initial postemergent application to determine treatment effectiveness. If there are still surviving plants present, rogue these plants from the field *before* they reach a reproductive stage of growth.

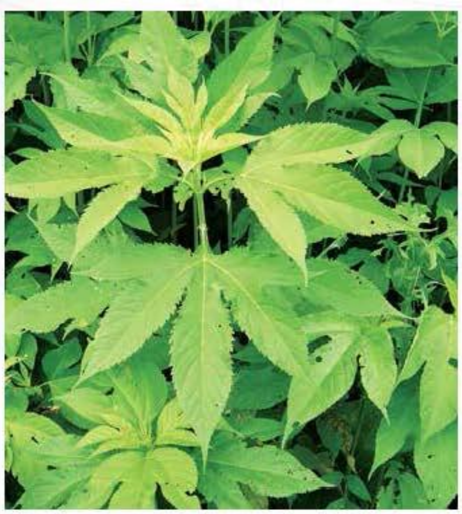
For more information and links to additional resources, visit www.TakeActionOnWeeds.com.

Technical editing for this publication was led by Kevin Bradley, Ph. D., University of Missouri, in partnership with other universities in the soybean-growing regions of the United States.

Management of Herbicide-Resistant
Giant Ragweed

Giant Ragweed Biology

- Giant ragweed is a competitive weed that has adapted to the fertile soil-crop-production acres of the Midwest and Soybean Belt.
- This weed typically emerges early in the growing season – as early as March – although some populations have adapted to extend emergence dates into early summer. Emergence patterns will vary among fields and regions based on prior management practices and when an area was first infested.
- The seeds of giant ragweed are larger than most other weed species. The large seed size allows giant ragweed to emerge from deep burial depths with emergence often being promoted by tillage. **Long-term no-tillage, along with proper herbicide management, can reduce giant ragweed populations.**
- Seedling emergence from various depths also allows giant ragweed to escape many pre-emergence herbicides that exist in the upper soil layers.
- Giant ragweed quickly grows above crops to compete for sunlight and create a dense canopy with its 4- to 8-inch-wide leaves.
- The rapid growth habit and shading ability of giant ragweed lead to soybean yield losses, even at low densities.
- The prolific pollen production of giant ragweed largely contributes to the discomfort humans suffer from allergies.



Herbicide Resistance in Giant Ragweed

- Giant ragweed resistance first occurred to Group 2 herbicides (ALS-inhibitors) in Indiana, Illinois, Ohio and Iowa in the late 1990s and early 2000s.
- Resistance to Group 9 (glyphosate) herbicides was first confirmed in the eastern Soybean Belt and has now been confirmed in 11 states across the Midwest and southern U.S.
- Populations with resistance to both Group 2 (ALS-inhibitors) and Group 9 (glyphosate) have been found in Ohio, Minnesota, Missouri and Indiana.
- Resistance to other herbicide sites of action has not occurred, although the loss of Group 2 (ALS-inhibitors) and Group 9 (glyphosate) is significant, as these were the most effective herbicide groups for control of giant ragweed.
- Resistance to multiple herbicides has not been widely documented, although caution should be taken to avoid creating multiple-resistant populations with heavy reliance of Group 2 (ALS-inhibitors) to control Group 9 (glyphosate)-resistant populations.

Management of Giant Ragweed

Giant ragweed populations vary in their emergence patterns and herbicide resistance depending on management history. Group 2 (ALS-inhibitors) resistance is most likely to occur in fields with a history of non-GMO soybeans that depended heavily on Group 2 herbicides (ALS-inhibitors) for control. Farmers should evaluate the performance of previous herbicide applications, scout and understand emergence patterns in order to determine the best-management practices.

Farmers managing populations of weeds with Group 2 (ALS) and Group 9 (glyphosate) resistance have limited options and will likely have to emphasize the use of Group 14 (PPO-inhibitor) herbicides and Group 10 (glufosinate) in LibertyLink® soybeans. **Rotating to corn and taking advantage of effective corn herbicides may be the best option for dense infestations of Group 2 (ALS)- and Group 9 (glyphosate)-resistant populations.**

Follow the steps below for the best management of herbicide-resistant giant ragweed.

1. ***Start weed-free at planting.*** Take full advantage of early-emerging populations by controlling all emerged weeds prior to planting with either thorough tillage or an effective burndown.
   a. The use of 2,4-D ester or dicamba (Group 4) in combination with glyphosate (Group 9) or paraquat (Group 22) is the most effective treatment on small

Herbicide	Group #	Rates (oz./A.)	Equivalent Rates of Classic (oz./A.) (chlorimuron)	Equivalent Rates of FirstRate (oz./A.) (cloransulam)
Authority® First/Sonic®	14 & 2	3 - 8	–	0.28 - 0.74
Authority Maxx	14 & 2	5 - 9.6	0.78 - 1.5	–
Authority XL	14 & 2	3 - 9.6	0.93 - 3	–
Canopy® EX/Cloak EX	2 & 2	1.1 - 3.3	1 - 3	–
Canopy/Cloak™ DF	5 & 2	2.25 - 7	1 - 3	–
Envive®	2, 2 & 14	2.5 - 5.3	0.92 - 1.94	–
FirstRate®	2	0.6 - 0.75	–	0.6 - 0.75
Gangster®	14 & 2	1.8 - 3.6	–	0.3 - 0.6
Synchrony® XP	2 & 2	1 - 3	0.85 - 2.56	–
Valor® XLT	14 & 2	2.5 - 5	1 - 2	--

Table 1. Pre-emergence herbicides containing chlorimuron or cloransulam that suppress ALS-susceptible giant ragweed. Rates are dependent on soil type, application timing and region. Always refer to the label for appropriate rates.

giant ragweed plants, regardless of the type of herbicide resistance. Be sure to observe planting-restriction intervals of at least seven days after 2,4-D application or 14-28 days plus one inch of rain for dicamba.

b. Products containing saflufenacil (Group 14; Sharpen®, Optill®, Verdict® and Optill PRO) can be used instead of 2,4-D ester and dicamba (Group 4). These should also be combined with glyphosate (Group 9), Liberty® (Group 10) or Liberty plus metribuzin (Group 5). The use of Liberty in a burndown program can restrict the use of post-emergence Liberty applications in LibertyLink soybeans because of the 65-ounce-per-acre growing-season maximum.

2. ***Suppress late-emerging weeds.*** The use of a residual herbicide either in combination with a burndown or at planting in a tilled seedbed will provide suppression of later-emerging giant ragweed plants, providing the soybean crop with a competitive advantage as well as relieving the selection pressure placed by postemergence herbicides.

   a. Herbicide products containing chlorimuron or cloransulam (Table 1) applied before emergence at full rates are the most effective for reduction of giant ragweed emergence. These herbicides will only be effective on Group 2 (ALS)-sensitive populations.

   b. Group 2 (ALS)-resistant populations can be suppressed by pre-emergence applications of products containing fomesafen (Group 14), such as Prefix™, Intimidator™, Vise® or Reflex®. These products are more variable than the products listed above and restrict the use of postemergence products containing fomesafen (Group 14).

3. ***Finish strong with multiple postemergence applications.*** Multiple postemergence applications will likely be needed to control dense infestations of giant ragweed, especially in populations that exhibit extended emergence, even after an effective burndown and residual herbicide have been applied. Postemergence options can be limited, especially in ALS- and glyphosate-resistant populations. Use care in your postemergence product selection with attention toward using multiple sites of action and differing sites of action from the residual products to avoid selection of herbicide-resistant populations. Table 2 (page 4) lists the available postemergence programs with their appropriate rates, soybean traits, application timings and effectiveness for each type of resistance.

   a. In a planned, two-pass postemergence program, the first application should be made according to the size of weeds listed in Table 2 (page 4). Make a second or "followed-by" application three to four weeks after the first application to control later-emerging plants or plants that were not fully controlled by the first application.

   b. Postemergence applications of Group 14 (PPO-inhibitor) herbicides can be variable in performance and should be used with caution because over-reliance could lead to PPO-resistant giant ragweed.

4. ***Consider LibertyLink.*** LibertyLink soybeans provide the additional option for postemergence control of giant ragweed. LibertyLink soybeans are the best option for farmers managing ALS- and glyphosate-resistant giant ragweed. An effective burndown/tillage program, along with a residual herbicide, should still be used in a LibertyLink system to relieve selection pressure and ensure optimal giant ragweed control.

Table 2. Postemergence herbicide options for control of susceptible and herbicide-resistant giant ragweed in soybeans.

Herbicide (Group #)	Rate	Weed Size (Inches)	Soybean Traits[1]	Susceptible	Group 2 (ALS)	Group 9 (glyphosate)	Group 2 (ALS) + Group 9 (glyphosate)
FirstRate (2)	0.3 oz./A.	4 - 8	Non-GMO, RR, & LL	X[2]		X	
Flexstar (14)	1.3 pt./A.	4 - 8	Non-GMO, RR, & LL	X	X	X	X
FirstRate (2) + Flexstar® (14)	0.3 oz./A. + 1 pt./A.	4 - 8	Non-GMO, RR, & LL	X	X[4]	X	X[4]
Glyphosate (9) fb[3] Glyphosate (9)	1.1 - 1.5 lb. ae/A. fb 0.75 lb. ae/A	6 - 10	RR	X	X		
Liberty (10) fb Liberty (10)	29 oz./A. fb 22 oz./A.	4 - 8	LL	X	X	X	X
Flexstar (14) fb Cobra™ (14)	1.3 - 1.6 pt./A. fb 10 oz./A.	4 - 8	Non-GMO, RR, & LL	X	X	X	X

[1] Non-GMO: Non-genetically modified or conventional, RR: Roundup Ready, LL: LibertyLink
[2] "X" indicates control of giant ragweed within given susceptible or resistance category
[3] fb: followed by
[4] Control will be provided by the Flexstar element of the tank mix and will likely be less reliable as compared with the 1.3 pt./A. Flexstar alone or Flexstar fb Cobra programs.

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