

Multiple herbicide-resistant Palmer amaranth & waterhemp in Michigan

Keys to management in soybean, corn and alfalfa

Christy Sprague & Erin Burns, Extension Weed Science

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Palmer amaranth (*Amaranthus palmeri*) and waterhemp (*A. tuberculatus*) are pigweed species that have become more prevalent in Michigan agronomic fields. Both species pose severe management challenges for Michigan growers with herbicide resistance being the greatest threat. In Michigan, Palmer amaranth and waterhemp range from being resistant only to glyphosate (Group 9) or ALS-inhibiting herbicides (Group 2) (i.e., Classic, Raptor) to many of these populations being **resistant to multiple herbicides**, including Group 2 and Group 9 or Group 2 herbicides and atrazine (Group 5). In fact, in Michigan we have populations of Palmer amaranth and waterhemp that are resistant to **three** different herbicide sites of action. More recently, resistance to PPO-inhibiting herbicides (Group 14) (i.e., Flexstar, Cobra) have also been confirmed in Michigan Palmer amaranth and waterhemp populations. Many of these populations are also resistant to an additional one or two more herbicide sites of action. In other states, Palmer amaranth and waterhemp have evolved resistance to a combined eight different herbicide sites of action, including Groups 2, 3, 4, 5, 9, 14, 15 and 27. This leaves very few herbicide options available for management. The ability of these species to emerge throughout the growing season, rapid growth rates, prolific seed production, and ability to evolve resistance quickly makes these species two of the more difficult weeds to manage.

Identifying characteristics:

Palmer amaranth and common waterhemp are dioecious, having separate male and female plants. The stem and leaf surfaces of both of these species are smooth and due to genetic variability within each species there are several variations in stem and flower structure color.

Palmer amaranth			Waterhemp	
<ul style="list-style-type: none"> • Rounded leaves 			<ul style="list-style-type: none"> • Long narrow leaves 	
<ul style="list-style-type: none"> • Leaves are in a symmetrical arrangement 			<ul style="list-style-type: none"> • Open canopy 	
<ul style="list-style-type: none"> • Petioles are as long or longer than the leaf 			<ul style="list-style-type: none"> • Leaves appear shiny or waxy 	
<ul style="list-style-type: none"> • Spiny bracts are at leaf axils on female plants 			<ul style="list-style-type: none"> • No spiny bracts 	
<ul style="list-style-type: none"> • Flowering structures are thick, unbranched, and 1 to 2 feet long 			<ul style="list-style-type: none"> • Flowering structures are slender, unbranched, and usually only 6 inches long 	
				
Long leaf petiole	Female plant spiny bracts	Flowering structure Palmer amaranth	Long narrow leaves	Flowering structure waterhemp

Multiple herbicide-resistant Palmer amaranth & waterhemp

Keys to successful management in soybean

Soybean varieties with different herbicide-resistant traits provide additional options for management of herbicide-resistant Palmer amaranth and waterhemp. Following the six steps outlined below helps ensure successful management of these weeds, regardless of soybean trait.

Consider planting LibertyLink, LibertyLink GT27, Enlist E3, or XtendFlex soybean

Due to the limited postemergence (POST) herbicide options available, label restrictions, and lack of consistency observed with postemergence herbicides control of multiple-resistant Palmer amaranth and waterhemp is a challenge in Roundup Ready soybean. With LibertyLink, LibertyLink GT27, Enlist E3, and XtendFlex soybean there is more flexibility in use rates and the number of *glufosinate* (Liberty, others) applications that can be made. Information on *glufosinate* use for POST Palmer amaranth and waterhemp control is outlined in Step 3.

Enlist E3 soybean:

In addition to *glufosinate* resistance, Enlist E3 soybean are also resistant to the choline salt of 2,4-D and glyphosate. The use of Enlist One (2,4-D choline) or Enlist Duo (2,4-D choline + glyphosate) in Enlist E3 soybean provides additional POST options for Palmer amaranth and waterhemp control (see Step 3). Additional information and **guidelines** on the use of Enlist One and Enlist Duo in Enlist E3 soybean are outlined in Table 2G of the MSU Weed Control Guide (E0434).



Michigan soybean field infested with waterhemp

What about Roundup Ready 2 Xtend and XtendFlex soybean?

The use of registered dicamba products in Roundup Ready 2 Xtend or XtendFlex (dicamba-resistant) soybean provides growers with an additional option for POST Palmer amaranth and waterhemp control. However, due to label restrictions growers should weigh the risks associated with POST dicamba applications prior to using these technologies. XtendiMax or Engenia may be applied as the POST herbicide option (see Step 3). If using any of the registered dicamba formulations in Xtend soybean make sure to follow the **restrictions** and **additional precautions** outlined in Table 2H of the MSU Weed Control Guide (E0434) and remember the label must be followed.

XtendFlex soybean:

In addition to dicamba resistance, XtendFlex soybean are also resistant to *glufosinate* and glyphosate.

Steps for Successful Management:

Step 1: Start clean!!

Make sure that all Palmer amaranth or waterhemp plants are controlled with tillage or an effective burndown herbicide, i.e., Gramoxone or Liberty prior to planting soybean.

Step 2: Effective soil-applied (PRE) herbicides are essential.

Apply the **full-rate** of an effective soil-residual herbicide, prior to or soon after soybean planting. Fierce and Fierce MTZ have been the most consistent control options. Valor (*flumioxazin*) and other Valor-based products: Dimetric Charged, Envive, Surveil, Trivence, and Valor XLT also provide good control. Premixes that contain Spartan (*sulfentrazone*); Authority Assist/Edge/First/Supreme/XL, and Sonic have also shown positive results. However, rates need to be equivalent to 8 oz/A of Spartan (0.25 lb ai/A of *sulfentrazone*). Adding *metribuzin* to Valor or Authority or applying premixtures that contain these products may provide additional residual control. Remember, higher rates of these herbicides also increase the likelihood for soybean injury. The Group 15 herbicides (i.e., Dual II Magnum, Warrant, Outlook, or Zidua) or premixes containing these herbicides also provide good Palmer amaranth and waterhemp control, however many of these herbicides are best used as a residual tank-mixture with the postemergence herbicide application (Step 4).

Multiple herbicide-resistant Palmer amaranth & waterhemp

Keys to successful management in soybean (continued)

Step 3: Timely postemergence herbicide applications.

Proper timing is everything!! Postemergence herbicides must be applied before Palmer amaranth and waterhemp are 3-inches tall. Spray coverage is essential with any of these herbicides, so a minimum of 15 gallons per acre of spray solution should be used. Once plants exceed 3-inches tall, control with many of the postemergence herbicides is substantially reduced.

- **Roundup Ready or non-GMO soybean:** Flexstar, Cobra, or Ultra Blazer should be used. Flexstar has been the most consistent of these herbicides for Palmer amaranth control. These herbicides will not control Group 14 resistant Palmer amaranth or waterhemp. The use of a methylated seed oil (MSO) with these herbicides may also improve control.
- **LibertyLink, LibertyLink GT27 soybean:** Use 32-43 fl oz/A of Liberty or other *glufosinate* herbicides. Ammonium sulfate (AMS) should always be included. Use the higher glufosinate rate to control taller plants or plants that have escaped initial control. *One POST application of glufosinate will not effectively provide season-long control.*
- **Enlist E3 soybean:** Enlist One (32 fl oz/A), Enlist Duo (4.75 pt/A), or Liberty (32-43 fl oz/A) can be applied POST prior to plants exceeding 4-inches in height. Under high waterhemp populations the combination of Enlist One + Liberty provides the most consistent control. Only approved spray additives and herbicides can be tank mixed with these products. The list of these approved products are found at **Enlist-Tankmix.com**.
- **Roundup Ready 2 Xtend soybean:** Apply XtendiMax (22 fl oz/A) or Engenia (12.8 fl oz/A) POST prior to plants exceeding 4-inches in height. Only approved spray additives and herbicides can be tank mixed with these products. Consult Table 2H of the MSU Weed Control Guide (E0434) and the label for **restrictions** and **additional precautions** for use of these products.
- **XtendFlex soybean:** Liberty or dicamba products registered for use in RR2 Xtend soybean can be applied POST. Recommended use rates and restrictions are listed under the LibertyLink and RR2 Xtend soybean sections above.

Step 4: Residual product tank-mixtures with postemergence herbicides.

A residual 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, Liberty (LibertyLink, LibertyLink GT27, Enlist E3, XtendFlex soybean only), Enlist One, Enlist Duo (Enlist E3 soybean only), or registered dicamba products (Xtend or XtendFlex soybean only) to have effective control of Palmer amaranth and waterhemp, since the residual herbicides will not control emerged plants. Several premixes (i.e., Prefix and Warrant Ultra) contain an effective POST with a residual herbicide.

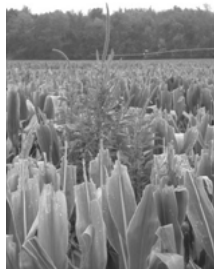
Step 5: Additional postemergence herbicide applications if needed.

Follow-up postemergence herbicide applications may be needed. Make these applications when plants are 4-inches or less. If Flexstar was used in the first postemergence application, Cobra or Ultra Blazer are the only Group 14 herbicide options remaining. If plants are larger than 3-inches you will have to use 12.5 fl oz/A of Cobra. The use of a methylated seed oil (MSO) with these mixes may also improve control. In LibertyLink, LibertyLink GT27, Enlist E3, or XtendFlex soybean, Liberty should be applied at rates ranging from 32 to 43 fl oz/A, depending on weed height. In Enlist E3 soybean, Enlist One or Enlist Duo can be applied if applications occur not later than R2 soybean. Followup applications with a registered dicamba product in Xtend or XtendFlex soybean will be more difficult due to the June 30th/R1 soybean application cutoff.

Step 6: Additional measures to stop seed production.

Additional cultural control measures, such as hand-weeding, should be implemented to prevent any remaining resistant Palmer amaranth and waterhemp plants from going to seed in the field, around field edges, or along ditch banks.

Multiple herbicide-resistant Palmer amaranth & waterhemp



Multiple herbicide-resistant Palmer amaranth in a MI seed corn field

Keys to successful management in corn

Corn provides the best opportunity for management of Palmer amaranth and waterhemp. However, this can also be difficult since there are Palmer amaranth populations in Michigan that are not only resistant to glyphosate and ALS-inhibiting herbicides, but also to atrazine. In order for management strategies to be effective, careful planning is needed. In addition, due to Palmer amaranth and waterhemp's propensity to evolve herbicide resistance, it is important not to rely solely on one herbicide site of action for management. In fields with three-way resistance only relying on one herbicide site of action such as the HPPD-inhibiting (Group 27) herbicides like Callisto, Impact, Laudis, or Shieldex will quickly lead to additional resistances. The following steps should be followed to manage multiple-resistant Palmer amaranth and waterhemp in corn.

Step 1: Consider planting a Roundup Ready/LibertyLink stacked corn hybrid.

While there are several postemergence herbicides available in corn that have some activity on Palmer amaranth and waterhemp, planting a Roundup Ready/LibertyLink stack provides one more additional site of action, Liberty, that can be used to help control resistant Palmer amaranth and waterhemp.

Step 2: Plant into a clean seedbed.

Control all emerged Palmer amaranth and waterhemp plants prior to planting corn.

Step 3: Two-pass (sequential) herbicide programs are needed.

- **PRE:** Full-labeled rates of a minimum of **two effective herbicide sites of action** (Table 1) are required for initial control (i.e., Zidua + AAtrex).
- **POST:** Must be applied before plants are 3-inches tall and requires the use of at least **two effective POST herbicide sites of action** (Table 1). A Group 15 herbicide may also be tank-mixed for additional residual control.

Step 4: Hand-weed to eliminate any remaining resistant plants

Table 1. Effective herbicides for management of glyphosate/ALS-resistant Palmer amaranth and waterhemp. No single herbicide active ingredient is 100% effective and a minimum of two effective herbicides are needed PRE and POST.

Trade names*	Active ingredient	Group #	Application timing
AAtrex, others**	atrazine	5	PRE/POST
2,4-D amine, several	2,4-D amine	4	POST
Clarity, (Status)	dicamba (+ diflufenzopyr)	4 (+19)	POST
Liberty (LibertyLink corn)	glufosinate	10	POST
Dual II Magnum	s-metolachlor	15	PRE
Harness	acetochlor	15	PRE
Zidua	pyroxasulfone	15	PRE
Balance Flexx	isoxaflutole	27	PRE
Callisto	mesotrione	27	PRE/POST
Impact, Armezon	topramezone	27	POST
Laudis	tembotrione	27	POST
Shieldex	tolpyralate	27	POST

* Consult the 2024 Weed Control Guide for Field Crops (E-434) for premixtures of these herbicide active ingredients and product restrictions. DO NOT apply more than a maximum of 2 lb ai/A per application or 2.5 lb ai/A total of atrazine for all applications per season.

** If Palmer amaranth is resistant to atrazine, herbicides with other **effective** sites of action are required.

“CORN PROVIDES THE BEST OPPORTUNITY FOR MANAGEMENT OF MULTIPLE-RESISTANT PALMER AMARANTH AND WATERHEMP.”

Financial support for corn research was provided by the Michigan Corn Marketing Program.



Multiple herbicide-resistant Palmer amaranth & waterhemp

Table 2. Example sequential corn herbicide programs and their effectiveness for management of glyphosate/ALS-resistant Palmer amaranth and waterhemp. In populations where atrazine resistance is present, the inclusion of atrazine POST with a Group 27 herbicide has improved Palmer amaranth control.

	Preemergence	Postemergence	Group #	Effectiveness
1	atrazine + Group 15 (i.e., Harness Xtra, Bicep II Magnum)	Callisto Xtra	5+15 fb. 27+5	Good - Excellent
2	atrazine + Group 15 (i.e., Harness Xtra, Bicep II Magnum)	Armezon/Impact + atrazine	5+15 fb. 27+5	Good - Excellent
3	atrazine + Group 15 (i.e., Harness Xtra, Bicep II Magnum)	Laudis + Liberty <i>(LibertyLink corn)</i>	5+15 fb. 27+10	Good - Excellent
4	Verdict	Laudis + Status	14+15 fb. 27+4	Good - Excellent
5	Lexar EZ/Lumax EZ/Acuron	Laudis + atrazine	5+15+27 fb. 27+5	Good - Excellent
6	Lexar EZ/Lumax EZ/Acuron	Liberty + Warrant <i>(LibertyLink corn)</i>	5+15+27 fb. 10+15	Good - Excellent
7	atrazine + Group 15 (i.e., Harness Xtra, Bicep II Magnum)	Liberty <i>(LibertyLink corn)</i>	5+15 fb. 10	Fair
8	atrazine + Group 15 (i.e., Harness Xtra, Bicep II Magnum)	Roundup PowerMax <i>(RR corn)</i>	5+15 fb. 9	Poor

Keys to successful Palmer amaranth management in alfalfa

If not properly managed in alfalfa, Palmer amaranth can produce viable seed that can perpetuate the spread of this devastating weed. Seed heads of Palmer amaranth generally appear after the last cutting of alfalfa. In 2013, we were able to reduce the number of mature seed producing Palmer amaranth plants with the following.

Between-cutting applications:

- Apply Gramoxone 3.0 SL (paraquat) at 0.67 pt/A + surfactant at 0.25% v/v
- Application should be made within 5 days after cutting
- Best results occurred after the 3rd or 4th alfalfa harvest
- DO NOT cut or harvest within 30 days of application



Multiple herbicide-resistant Palmer amaranth in alfalfa

