OVERLAPPING RESIDUAL HERBICIDES

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Problematic Weeds

Weed infestations in agronomic fields are dynamic and continually evolve in response to the weed management tactics that farmers implement. Prior to the adoption of glyphosate-resistant corn and soybean rotations, the most problematic weed species reported by farmers were foxtail, velvetleaf, and cocklebur (Kruger et al. 2009). Following the use of glyphosate-resistant soybean and corn, approximately two-thirds of farmers suggested their weed pressure was reduced (Kruger et al. 2009). Certainly, this perception of reduced weed problems and the effectiveness of glyphosate as a postemergence weed management tool influenced farmers to abandon the use of soil residual herbicides and rely exclusively on glyphosate (Young 2006). Repeated use of glyphosate as the only weed management tactic had two consequences:

1. It created an opportunity for weed species with extended emergence periods to become more prevalent
2. It provided the selection pressure for the evolution of glyphosate-resistant weeds

Currently, the most problematic weed species confronting farmers in the major corn and soybean production regions of the U.S. are waterhemp, Palmer amaranth, and horseweed (aka marestail), which is a direct result of the evolution and subsequent wide-scale spread

Glyphosate-Resistant Palmer Amaranth

Glyphosate-Resistant Horseweed

Glyphosate-Resistant Waterhemp

of resistance to glyphosate in these weed species (Heap 2014; Prince et al. 2012). Horseweed has traditionally been regarded as a winter annual weed species that emerges in the fall, overwinters as a rosette growth stage, and finally bolts for reproductive development and seed production in the early summer. However, current challenges associated with management of horseweed include the occurrence of horseweed emergence from the late summer through late fall and again in the early spring through mid-summer. Some have described that horseweed emergence in their fields can occur at any point during which the soil is not frozen and will continue with vegetative growth through the late summer before seed production. Essentially, horseweed has evolved from being primarily a winter annual weed with management concerns primarily focused on control tactics to ensure a clean, weed-free seedbed for spring crop planting to a weed species that must be managed throughout the year and can compete vegetatively with crops during the summer growing season to impact yields.

Palmer amaranth and waterhemp are related species within the Amaranthaceae (pigweed) family and share similar characteristics for emergence periodicity, reproduction, and management tactics. Waterhemp can start to emerge in late April with peak emergence in late May or early June (Figure 1). Waterhemp can continue to emerge throughout the remaining growing season in response to rainfall, or irrigation, and the presence of an open crop canopy. Palmer amaranth originates from the desert Southwestern U.S. and requires slightly higher soil temperatures to germinate than waterhemp. Thus, Palmer amaranth may start to emerge one to two weeks later (early May) than waterhemp and then continue similar to waterhemp following the initial spring emergence. Both of these species have been shown to be a continual threat to emerge throughout the growing season as well as following an early crop harvest in the fall. An important aspect of controlling these weed species is to implement a management strategy that overlaps the primary emergence period of the species. Unfortunately, 10% or more of the total emergence for waterhemp and Palmer amaranth can occur after July 1st.

Furthermore, these species can be very aggressive in competing with crops and can reduce soybean yields by 40% or greater, depending on environmental conditions and the level of the weed infestation. Palmer amaranth and waterhemp exhibit robust seed production with average plants developing 600,000 and 250,000 seeds per plant, respectively, with the potential to produce over a million seeds per plant for each species.

Horseweed, Palmer amaranth, and waterhemp have developed into the major problematic weeds for farmers due to:

1. Prolific seed production
2. Discontinuous weed emergence throughout the growing season

3. Ease of seed dispersal through wind, water, through contaminated livestock feed or carried by wildlife
4. Ease of overcoming or escaping herbicide-based management tactics

In terms of the latter issue, the evolution of glyphosate-resistant populations for all three weed species has increased the prevalence of these weeds, and further complicates management with herbicides. Certainly, farmers should resist placing all their attention on just these three weed species as other weed threats include giant ragweed, common ragweed, common lambsquarters, kochia, barnyardgrass, Italian ryegrass, and fall panicum. These additional weed threats are a concern for many of the same reasons as those mentioned for horseweed, Palmer amaranth, and waterhemp, such as emergence patterns and reduced control options due to weed tolerance or resistance to major herbicide site of action groups.

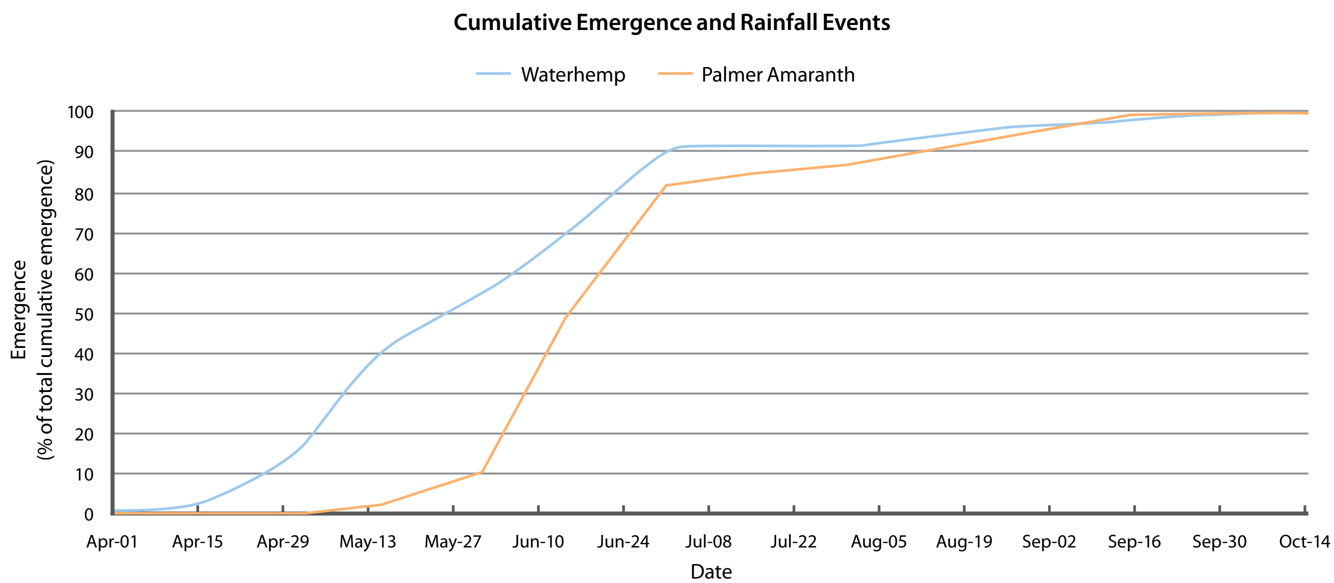


Figure 1. Relative emergence of waterhemp and Palmer amaranth near Belleville, IL in 2014

Species		Emergence	Seed Production	Herbicide Resistance
	Horseweed *(Conyza Canadensis)*	Late summer through late fall; early spring through mid-summer	200,000 seeds per plant	Groups 2, 5, 7, 9, 22
	Palmer amaranth *(Amaranthus palmeri)*	May through October	600,000 seeds per plant; small size	Groups 2, 3, 5, 9, 27
	Waterhemp *(Amaranthus tuberculatus = syn A. rudis)*	April through October	250,000 seeds per plant; small size	Groups 2, 4, 5, 9, 14, 27

Table 1. Characteristics of Problematic Weed Species

Herbicide-Resistant Weed Evolution

Ideally, weed management strategies should include diverse tactics that integrate cultural and mechanical methods along with the most predominant practice, herbicide applications (Owen et al. 2014). Since the dawn of modern herbicide use in major crops in the 1950s, farmers have progressively favored the use of herbicides as their primary tool for weed management because of the cost, effectiveness and low labor requirements compared with alternative control measures. Exclusive reliance on a single weed management practice or, more specifically, a single herbicide site of action will eventually shift the weed population to those species or biotypes genetically adapted to the selection pressure exerted by those practices. The evolution of weeds resistant to the herbicide glyphosate has been a colossal example of long-term disadvantages of not implementing more diverse weed management tactics.

The inclusion of non-chemical weed management tactics along with herbicides would be the preferred method to address management of herbicide-resistant weed species. However, the most common response to the development of a herbicide-resistant weed species in a field is to apply an alternative herbicide with a different herbicide site of action. This requires the selection of an "effective" herbicide for control of the problematic weed.

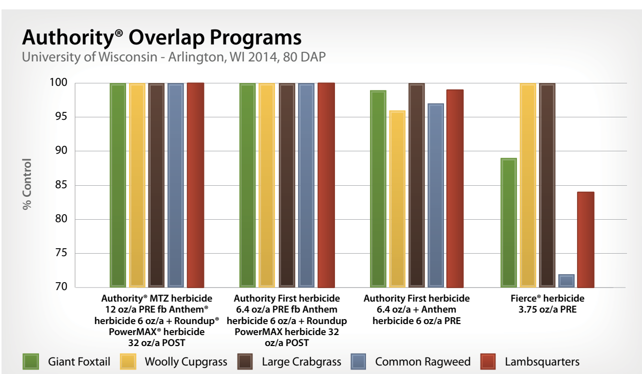
"Effective" alternative herbicides to control herbicide-resistant weed species must:

1. Have the potential to control the target weed species, even if applied alone
2. Be applied in a manner to optimize herbicide efficacy (i.e. proper application rate, application timing and application methods)
3. Represent a different herbicide site of action than the resistance traits found in the target weed species

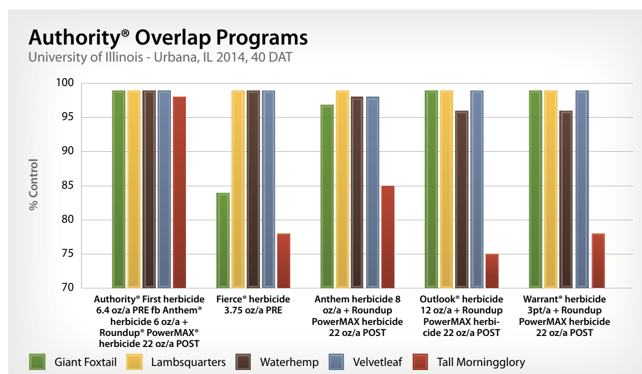
For example, the initial response to control glyphosate-resistant horseweed was to add 2,4-D (Group 4) with glyphosate (Group 9) in foliar burndown applications. This approach to just add one more herbicide site of action can be effective in the short-term, but selection pressure on the weed population shifts toward resistance to 2,4-D. Most weed scientists would suggest that the use of multiple "effective" herbicides is warranted to mitigate the further selection of herbicide resistance. The use of cloransulam (Group 2) with 2,4-D and glyphosate on horseweed with resistance to just glyphosate would be an example of using multiple "effective" herbicide site of action groups.

Strategies for Integrating "Effective" Herbicide Site of Action Groups

The most common approach to managing herbicide-resistant weed species such as glyphosate-resistant horseweed, Palmer amaranth, or waterhemp has been the use of an effective alternative herbicide as a tank-mixture with glyphosate, as a residual herbicide preceding a postemergence application of glyphosate, or a combination of both. The presence of weed biotypes with multiple herbicide resistance, such as waterhemp resistant to glyphosate in addition to ALS- and PPO-inhibiting herbicides (Groups 9, 2, 14) further complicates management as the available herbicides to serve as effective alternatives is diminished.



Overlapping Authority XL preemergence residual herbicide followed by Anthem, an early residual post herbicide, with Roundup herbicide produces clean fields 45 days after treatment. Weeds proliferate when no preemergence residual herbicide is used.



Fifty-four days after treatment, the plot treated with Authority XL herbicide followed by a post application of Anthem herbicide followed with Roundup herbicide is clean, unlike the untreated field.

The most frequently recommended practice within herbicide strategies has been the use of soil residual herbicides to combat herbicide-resistant weed species. Residual herbicides have multiple benefits including:

- Provide long-term control of weeds with extended emergence periods
- Help protect crop yield by eliminating the presence of weeds with the crop
- Reduce the density of weed species that may require a postemergence herbicide application
- Provide a wider window for any necessary postemergence herbicide application
- Provide a different herbicide site of action compared with glyphosate

In instances where extremely limited options, if any, exist for postemergence control of a herbicide-resistant weed species, a tactic may be to apply residual herbicides sequentially to "overlap" the residual activity before the first herbicide dissipates to the point where weed emergence occurs. This approach of overlapping residual herbicides has been successful for management of horseweed by using either fall or early-spring applied residual herbicides followed by another residual herbicide application at planting. Likewise, the most robust level of control for waterhemp and Palmer amaranth has been reported with overlapping a residual preemergence herbicide with another residual herbicide applied in an early postemergence application (e.g. 21 days after planting). The second application of a residual herbicide can be most valuable on weed species that exhibit extended periods of emergence throughout the growing season. Furthermore, the inclusion of a soil residual herbicide with the postemergence application of glyphosate or Liberty® herbicide can encourage farmers to perform these applications on relatively small weeds since they don't have to be concerned about any weed emergence events following the application or before crop canopy closure. This approach is in direct contrast to early adoption of glyphosate-resistant crops where postemergence glyphosate applications were delayed to reduce the risk of any weed emergence following the application. However, this practice ultimately resulted in applications of glyphosate to weeds beyond label recommendations and arguably contributed toward the selection of glyphosate-resistant weeds.

A common herbicide program for control of glyphosate-resistant horseweed and waterhemp resistant to ALS-inhibiting herbicides is provided in Figure 2a. The initial burndown and residual herbicide application provides four different herbicide sites of action for control of horseweed and two residual herbicides for control of the ALS-resistant waterhemp. Figure 2b represents a greater challenge in that the waterhemp is now ALS-, PPO-, and glyphosate-resistant. Within a Roundup Ready® soybean system this scenario would leave no effective postemergence herbicides for control of any waterhemp that has emerged. Thus, the LibertyLink® soybeans were included in this program. As a result the four effective herbicide sites of action for control of horseweed and two herbicide sites of

Crop: Soybean (RR)		Target Weeds: Horseweed (glyphosate-resistant) Waterhemp (ALS-resistant)	
		Sites of Action Effective for	
Herbicide Program	**Group #**	**Horseweed**	**Waterhemp**
Gramoxone + Authority® MTZ herbicide + 2,4-D	22, 14, 5, 4	4	2
Planting followed by Glyphosate – POST	9	0	1
Total for Program	5	4	3

Figure 2a

Crop: Soybean (LL)		Target Weeds: Horseweed (glyphosate-resistant) Waterhemp (ALS/PPO/ glyphosate-resistant)	
		Sites of Action Effective for	
Herbicide Program	**Group #**	**Horseweed**	**Waterhemp**
Gramoxone + Authority® MTZ herbicide + 2,4-D	22, 14, 5, 4	4	2
Planting followed by Liberty® herbicide + Anthem® herbicide – POST	10, 14, 15	1	2
Total for Program	6	5	4

Figure 2b

Crop: Soybean (LL)		Target Weeds: Palmer amaranth (ALS / glyphosate-resistant)
		Sites of Action Effective for
Herbicide Program	**Group #**	**Palmer Amaranth**
Tillage followed by planting Authority® Elite herbicide – PRE	14, 15	2
Followed by Liberty® herbicide + Anthem® herbicide – POST	10, 14, 15	2
Total for Program	3	3

Figure 2c

action for residual control of waterhemp remain in the burndown and residual application. The application of Liberty® herbicide and Anthem® postemergence herbicide will provide one effective site of action (Group 10) for horseweed and two for waterhemp (Group 10, 15). The residual activity from the group 15 herbicide in Anthem provides the overlapping residual activity that can be necessary to achieve long-term control of waterhemp. The majority of Palmer amaranth documented with resistance to glyphosate in the U.S. also has resistance to the ALS-inhibiting herbicides (Figure 2c). The preemergence application of Authority® Elite herbicide provides two effective sites of action (Group 14, 15) for initial control of Palmer amaranth. The simultaneous application of two herbicide active ingredients with soil residual can provide more consistent and longer residual weed control. The herbicides may differ in water solubility which influences the amount of rainfall required for the activation of a soil residual herbicide. Likewise, large fluctuations in the performance of residual herbicides under extreme rainfall patterns (low or high) may be partially avoided by using two different residual herbicides. Since Palmer amaranth is a threat to emerge the entire growing season, the residual herbicide Anthem® was once again applied with Liberty® postemergence herbicide to provide an overlapping residual herbicide (Figure 2c). The practice of applying two effective residual herbicide sites of action in combination or the concept of using effective residual herbicides in sequential, overlapping applications would both be considered a best management practice to deter the development of herbicide-resistant weeds.

Summary

The most challenging weeds confronting farmers today have long periods of emergence and typically exhibit resistance to multiple postemergence herbicides. These circumstances justify the use of soil residual herbicides as the foundations for integrated management strategies. Without the use of residual herbicides for weed management farmers are risking lost crop yield due to weed competition and continued movement towards more weed resistance to postemergence herbicides. However, only those weed management programs that carefully select the most effective soil residual herbicides and apply them in a manner to optimize their contribution to weed management (i.e. overlapping residuals) will realize the greatest benefits.

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