Beyond Herbicide Site of Action:
Considering "Effective" Sites of Action

Mark VanGessel[1], Claudio Rubione[1], Michael Flessner[2], and Bob Hartzler[3]
[1]University of Delaware, Georgetown DE; [2]Virginia Tech, Blacksburg, VA; [3]Iowa State University, Ames, IA

HERBICIDES AND SITE OF ACTION

Weeds are the major pest that farmers need to control on an annual basis. Weeds reduce yields through plant competition for light, moisture, and nutrients; they interfere with harvest; their seeds can contaminate grain; and they can harbor other pests.

Many growers have relied on herbicides for controlling weeds, but some biotypes have evolved resistance to herbicides. Often, when resistance develops to a herbicide, other herbicides with the same group number are also no longer effective. Therefore, resistance limits the options available for control.

Reducing the risk of developing herbicide resistant biotypes requires an integrated approach to weed control. Integrating prevention, mechanical, cultural, and biological as well as chemical control is critical to forestall herbicide resistance. When it comes to herbicides, farmers are hearing about rotating and using multiple herbicide groups.

Understanding the concept of herbicide site of action is key to effectively managing herbicide resistance. Herbicide containers and labels now display a herbicide group number that identifies the site of action. The site of action is the specific biochemical site where the herbicide interferes with plant growth. This is different than herbicide mode of action, which describes how the plant responds (or dies) when treated with a herbicide.

Herbicides are classified by their **site of action**, or biochemical site within the weed that the chemical interferes with in order to kill the plant. Each site of action has a unique **herbicide group number**, which is displayed on herbicide product containers (see https://iwilltakeaction.com/resources/herbicide-classification-chart for full list). Herbicides with the same site of action have the same group number. Resistant biotypes are defined by the **herbicide group number** for which resistance has evolved.

Herbicide resistance is defined as the inherited genetic ability of a biotype within a weed population to survive a herbicide application to which the original population was susceptible under the same dose and conditions.

Resistant biotype is a subset of plants within a weed population that are resistant to the same herbicide(s). When a biotype evolves resistance, it is not the whole weed population, but actually a small subset (**biotype**) of the population. **Multiple resistance** is the term for weed biotypes that have evolved resistance to more than one herbicide group.

Resistant biotypes evolve through **selection pressure**, in which individuals that are well adapted to certain conditions will survive and reproduce, while others die off. When repeatedly subjected to a single herbicide group, resistant biotypes often develop because resistant individuals (which occur initially due to genetic variability) survive the treatment, reproduce, and increase in the population, while susceptible individuals die and do not reproduce.

While the message has been to use herbicides with different group numbers, it is important to emphasize that the different herbicide groups must also be effective for the weeds of concern. Using two herbicides with different sites of action, where only one of those herbicides is effective at controlling the weed of concern, is not an effective resistance strategy. Using at least two **effective** sites of action for weeds greatly reduces the risk of herbicide resistance development. Effective sites of action can and should be diversified through tank mixtures or using premix products. Research has demonstrated two or more effective sites of action is a better herbicide-resistance strategy than using effective sites of action in sequence with one another. Rotating crops can help increase herbicide diversity by increasing herbicide options.

It is important to know which weed species are resistant to which herbicides in your area. This allows an effective management plan to be developed. If resistant biotypes are present, these herbicides are no longer effective and other herbicides are needed for control. Local extension educators are the best source of information for local herbicide-resistance issues.

It is not practical or economical to use a multiple effective sites of action approach for all species, but this approach needs to be implemented for species in your region with resistance or species prone to developing resistance.

WHAT IS AN EFFECTIVE SITE OF ACTION

A herbicide is considered effective when it results in 80% control or better

Example 1. Introduction to Effective Site of Action.

Herbicide	Weed Species		
	Fall panicum	Common ragweed	Palmer amaranth
	-------------	% Control	-------------
Product A (group 15)	**90**	60	**85**
Product B (group 5)	60	**85**	**90**
Number of *effective* sites of action	**1**	**1**	**2**

In this example, Product A is a group 15 herbicide and Product B is group 5, two different herbicide sites of action. Fall panicum is controlled by Product A, but not by Product B. On the other hand, common ragweed is not controlled by Product A, but is controlled with Product B. Palmer amaranth is controlled by both Product A and Product B. Based on this herbicide program only Palmer amaranth is being treated with two effective sites of action.

Consult your local weed management guide for herbicide effectiveness ratings for your weed(s) of concern, keeping in mind if your weed is resistant. Check with your local extension educator for state or regional publications.

Palmer amaranth is a weed species that is prone to developing resistance and has become one of the most troublesome species in much of the US. A large reason for the difficulty in controlling this species is the loss of effective herbicide options due to resistance. So it is very important that it is treated with at least two effective sites of action, as in this example. Taking it one step further, applying Product A and Product B together in tank mixture is a more effective herbicide-resistance strategy than applying these herbicides at two different times.

Common ragweed is only controlled with Product B (group 5). Common ragweed biotypes resistant to glyphosate (group 9), PPO-inhibiting herbicides (group 14), and ALS-inhibiting herbicides (group 2) have been reported recently and are spreading. So in this situation it is best to treat with an additional effective site of action. Additionally, fields need to be scouted regularly to identify common ragweed biotypes that escape control and could form the basis for a herbicide-resistant population.

Fall panicum is a species that to date has not developed resistant biotypes in the US. The fact that only a group 15 herbicide is used for control is not of great concern at this time.

Example 2. Evaluating Effective Sites of Action for Control of Glyphosate-Resistant Common Ragweed.

Application timing	Herbicide	SOA number	Total SOA	Effective SOA
PRE	Bicep	5 + 15	2	1
POST	atrazine + glyphosate	5 + 9	2	1
	Season totals		**3**	**1**

In Example 2, glyphosate-resistant common ragweed control is a concern. The field is treated with Bicep (a combination of atrazine (group 5) plus *S*-metolachlor (group 15)) at planting and treated postemergence with a tank mixture of atrazine (group 5) and glyphosate (group 9). Bicep contains two different herbicide sites of action, but only atrazine controls common ragweed. So there is only one effective site of action used at planting. Likewise, with the postemergence application, only atrazine is providing effective control since common ragweed is resistant to glyphosate. Atrazine is the only herbicide providing effective control with both the at-planting and postemergence applications. Over the course of the season, glyphosate-resistant common ragweed is treated with only one effective herbicide, atrazine.

This situation puts a lot of selection pressure from atrazine on the common ragweed population, increasing the risk of biotypes resistant to atrazine surviving and producing seeds. Including dicamba (group 4) in the postemergence application is one option to reduce selection pressure on this population, since it is an effective site of action. Another option, although less effective, is to rotate to an alternative herbicide with an effective site of action the next season.

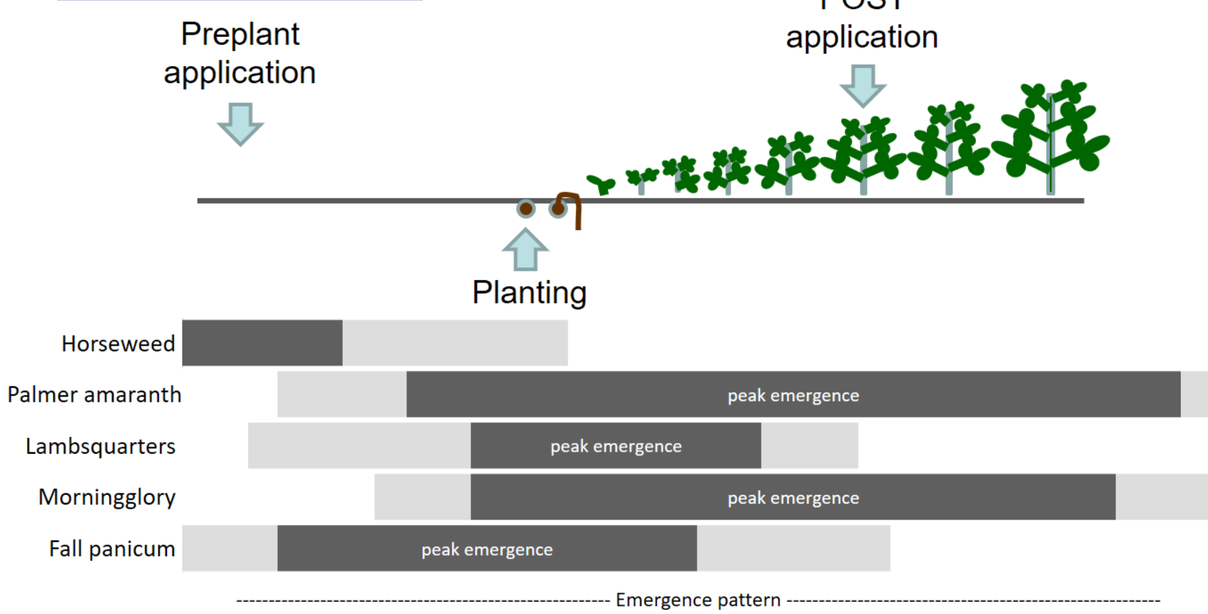
Example 3. Example of Implementing Effective Sites of Action for the Entire Season: Considering Multiple Weed Species.

In Example 3, no-till soybeans are planted in a field with a history of glyphosate- and ALS-resistant horseweed, glyphosate- and ALS-resistant Palmer amaranth, common lambsquarters, annual morningglory species, and fall panicum. A total of six different herbicide groups will be applied preplant and during the growing season. Each herbicide is included for at least one of these weeds.

In this example the field is treated with a herbicide application three weeks before planting to control winter annual weeds (including horseweed) and a postemergence herbicide. In order to reduce the number of applications, residual herbicides are included in the preplant application. In order to better manage resistance, application timing needs to be considered in relation to the weed emergence period.

Herbicide	Group Num.
Sharpen	14
glyphosate	9
Canopy[a]	2 + 5
Anthem Maxx[b]	14 + 15

Herbicide	Group Num.
Engenia	4
glyphosate	9
Warrant	15



[a]Canopy is a prepackaged mixture of metribuzin (group 5) and chlorimuron (group 2).
[b]Anthem Maxx is a prepackaged mixture of pyroxasulfone plus fluthiacet. Pyroxasulfone (group 15) provides residual control of susceptible species but provides no postemergence control; fluthiacet (group 14) provides postemergence control of a few species, but provides no residual control.

Weeds	Number of effective sites of action (and group number)		
	Preplant application		Postemergence application
emerged horseweed plants	1 (group 14)		1 (group 4)
emerged Palmer amaranth plants	2 (groups 5, 14)		1 (group 4)
residual control of Palmer amaranth	2 (groups 5, 15)		1 (group 15)

Comments for each species:
Horseweed emerges in the fall and throughout the spring until early-summer; some fields experience populations that emerge after soybean planting. This field has horseweed biotypes resistant to glyphosate (group 9) and ALS-inhibiting herbicides (group 2). Anthem Maxx and metribuzin do not provide control of emerged horseweed plants. Control of emerged weeds with the preplant application is only from Sharpen (group 14). Sharpen and metribuzin (group 5) will control seedlings that germinate in the spring, but seedlings emerging 3-4 weeks after the preplant application probably would not be controlled due to herbicide degradation. Engenia (group 4) in the postemergence application will control these late-emerging plants. For season-long resistance management of horseweed, this example is fair to good. The herbicide program has two effective sites of action for control of emerged horseweed plants, but they are applied in sequence rather than as a tank mixture. Residual control is provided by two effective sites of action.

Palmer amaranth begins emerging in the spring and continues throughout the summer. The preplant application of Sharpen (group 14), fluthiacet (group 14) (portion of Anthem Maxx), and metribuzin (group 5) will control Palmer amaranth seedlings that have emerged at time of application. Metribuzin (group 5) and pyroxasulfone (group 15 portion of Anthem Maxx) provide control of seedlings germinating up to 4 weeks after application, but after that Palmer amaranth seedlings would begin to emerge. Engenia (group 4) controls Palmer amaranth plants that had emerged at time of postemergence application, but does not provide adequate residual control. Warrant (group 15) provides residual control but will not control emerged plants.
For season-long resistance management of Palmer amaranth, this example is poor to fair. The preplant application is applied when only a small percentage of the Palmer amaranth seedlings have emerged and will have limited utility as part of a season-long approach. The residual herbicides have two effective sites of action, but since application is made so early, the benefits of the two effective sites of action are minimized. This program would be much stronger if the residual herbicides were applied at planting rather than three weeks prior. The postemergence herbicide relies on only one effective site of action which increases the selection pressure for dicamba resistance.

Common lambsquarters begin to emerge in the early spring and continues to early summer. Sharpen (group 14), glyphosate (group 9), and fluthiacet (group 14 portion of Anthem Maxx)

provide control of lambsquarters seedlings that have emerged by the time of preplant application, and Anthem Maxx (pyroxasulfone portion only (group 15)) provides residual control. Postemergence application of Engenia (group 4) and glyphosate (group 9) also provide common lambsquarters control.
For season-long resistance management of common lambsquarters, this example is good. Three effective sites of action are used in the preplant application, an effective residual herbicide is used, and then two effective sites of action are used postemergence. Common lambsquarters is treated twice with glyphosate but both times it is used in combination with another effective herbicide group.

Annual morningglory emerges from spring to mid-summer. Annual morningglory have not begun to emerge prior to the preplant application and so chlorimuron (group 2 portion of Canopy) would provide an effective level of residual control. Effective control from postemergence application is provided by glyphosate (group 9) and Engenia (group 4), but Warrant does not provide residual morningglory control.
For season-long resistance management of annual morningglory, this example is good. Only one effective site of action is used with the preplant application (chlorimuron), but the postemergence application includes two effective sites of action. The effective sites of action are different for both applications and applying the residual herbicide closer to planting would improve the resistance management of this program.

Fall panicum emerges in the spring and early summer so glyphosate (group 9) portion of the preplant application has some effect. Pyroxasulfone (group 15 portion of Anthem Maxx) is the only effective herbicide applied prior to planting. Effective control from postemergence application is provided only by glyphosate (group 9).
For season-long resistance management of fall panicum, this example is poor. Glyphosate used in the preplant application will control emerged seedlings and the residual herbicide will provide control over most of the peak emergence period. Glyphosate is the only herbicide to control emerged fall panicum plants in the postemergence application. While Warrant (group 15) does provide residual control of fall panicum, it is not applied until after the fall panicum emergence period. Thus there is only one effective site of action used at either application timing. However, there have been no reports of herbicide resistance in fall panicum so incorporating additional sites of action may not be justified at this time.

Summary

These examples were developed to demonstrate considerations when evaluating effective sites of action. Herbicide resistance is less likely to develop when multiple effective sites of action are applied as a tank mixture, at the appropriate time, and at full rates. Understanding weed emergence timing and the likelihood of the species to develop resistance can help to refine the herbicide program and ensure herbicide programs are targeting resistant biotypes and species with a tendency to develop resistance.