# Beyond Herbicide Mode of Action: Considering "Effective" Modes of Action

Mark VanGessel[1], Claudio Rubione[1], Michael Flessner[2], Bob Hartzler[3] and William Curran[4]
[1]University of Delaware, Georgetown DE; [2]Virginia Tech, Blacksburg, VA; [3]Iowa State University, Ames, IA, [4]Penn State University, University Park, PA

## Herbicides and Mode 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. Understanding the concept of herbicide mode of action is one of the tactics to manage herbicide use more effectively. Herbicide labels and containers now display the herbicide group number that identifies the mode of action. The herbicide site of action, or target site, is the location of the primary interruption/disruption and is often a specific plant enzyme. This is different than herbicide mode of action, which describes how the plant responds (or dies) when treated with an herbicide.

Often, when resistance develops to an herbicide, other herbicides with the same group number are also no longer effective. Therefore, resistance limits the options available for chemical 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 prevent or delay herbicide resistance. When it comes to herbicides, farmers are hearing about using multiple herbicide groups and rotating herbicides groups.

Herbicides classified by their **mode of action** describes the way an herbicide works to control weeds. In general, herbicides interrupt certain biological processes, often by disrupting enzyme activity or other plant functions. Each mode of action has a unique **herbicide group number**, which is displayed on herbicide product labels and containers (see https://iwilltakeaction.com/resources/herbicide-classification-chart for full list). Herbicides with the same mode of action have the same group number. Resistant weed biotypes are defined by the **herbicide group number** for which resistance has evolved.

**Herbicide resistance** is the naturally occurring, inheritable ability of an individual plant or population to survive an herbicide application that would kill a normal plant or population of the same species. These surviving plants can mature and produce seed, and the resistance trait is passed on to the next generation.

Resistant biotypes evolve through **selection pressure**, in which individuals that are 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

There are many ways that weeds evolve resistance to herbicides, but the mechanisms fall into two main categories, 1.) target-site and 2.) non-target site resistance. Target-site resistance occurs when there is a change in the structure of the target site/protein, so the herbicide can no longer bind to the site of action. Enhanced metabolism or metabolic resistance is the most common and concerning type of non-target site resistance and is a process within resistant (and tolerant) plants that leads to alteration and inactivation of herbicides. Using multiple effective modes of action and rotating herbicide modes of action are important for managing resistance evolution, but with non-target site resistance, the success of mixing and rotating herbicides is less clear.

treatment, reproduce, and increase in the population, while susceptible individuals die and do not reproduce.

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 modes 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.

While the message has been to use herbicides with different group numbers, it is also important to emphasize that the different herbicide groups must also be effective for the weeds of concern. Using two herbicides with different modes of action, where only one of those herbicides is effective at controlling the weed of concern, is not an effective resistance management strategy. Using at least two **effective** modes of action for weeds greatly reduces the risk in particular, for evolution of target-site resistance. Effective modes of action can and should be diversified through tank mixtures or using premix products. Research has also demonstrated that two or more effective modes of action in mixture are generally a better herbicide-resistance management strategy than using two effective modes of action in sequence and both tend to be more effective than herbicide rotation. However, rotating crops can provide many pest and soil management benefits which include helping to increase herbicide diversity by increasing herbicide options.

## What is an Effective Mode of Action?

*An herbicide is considered effective when it results in 80% control or better.*

In example 1, Product A is a group 15 herbicide and Product B is group 5, two different herbicide modes of action. Large crabgrass 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 modes of action.

**Example 1. Introduction to effective mode of action.**

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

*Effective products are equal or greater than 80% control and shown in bold.

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 particularly 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 especially important that it is treated with at least two effective modes 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 management strategy than applying these herbicides at two separate 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 in several states. So, in this situation it is best to treat with an additional effective mode of action for common ragweed. Additionally, fields need to be scouted regularly to identify common ragweed biotypes that escape control and could form the basis for an herbicide-resistant population.

Large crabgrass is a species that to date has not evolved wide-spread herbicide resistance in US field crops. The fact that only a group 15 herbicide is used for crabgrass control is not currently of great concern.

In Example 2, glyphosate-resistant common ragweed control is a concern in corn. The field is treated with Harness Xtra (a combination of atrazine (group 5) plus acetochlor (group 15) at planting and treated postemergence with a tank mixture of atrazine (group 5) and glyphosate (group 9). Harness Xtra contains two different herbicide modes of action, but only atrazine controls common ragweed. So, there is only one effective mode of action used at planting. Likewise, with the postemergence application, only atrazine provides effective control since common ragweed is resistant to glyphosate. Atrazine is the only herbicide providing effective control at both planting and postemergence. Over the course of the season, glyphosate-resistant common ragweed is treated with only one effective herbicide, atrazine.

**Example 2. Evaluating effective modes of action for control of glyphosate-resistant common ragweed in corn.**

| Application timing | Herbicide | MOA number | Total MOA | Effective MOA |
|---|---|---|---|---|
| PRE | Harness Xtra | 5 + 15 | 2 | 1 |
| POST | atrazine + glyphosate | 5 + 9 | 2 | 1 |
| | | Season total | **3** | **1** |

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 mode of action for control of common ragweed. Although less helpful than using two effective modes of action in one season, an alternative is to rotate to an different effective herbicide other than a group 5 (atrazine) for common ragweed control the next season.

In Example 3, no-till soybean 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 large crabgrass. In this scenario, herbicide-resistant horseweed and Palmer amaranth are of greatest concern. If possible, the herbicide program should target these weeds with multiple effective modes of action. The herbicide program should also control the remaining species, but selecting for resistance is less of a concern. A total of six different herbicide groups will be applied preplant and during the growing season (Example 3a). Each herbicide is included for at least one of these weeds.

**Example 3a. Example of implementing effective modes of action in soybean for the entire season: considering multiple weed species.**

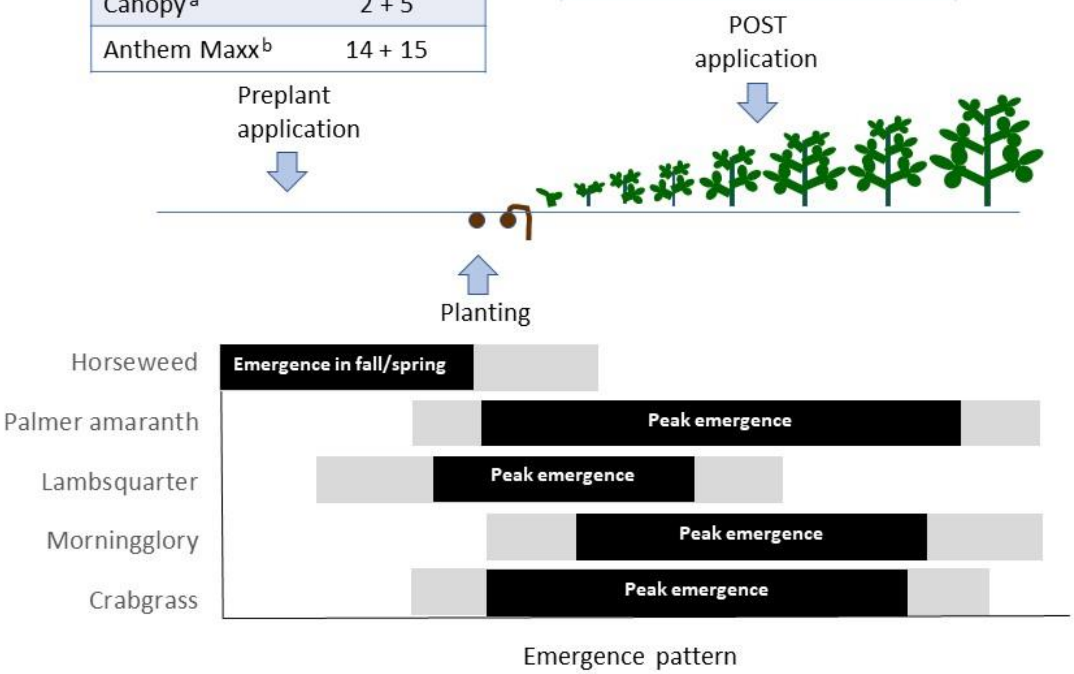
| | Number of effective modes of action (and group number) | |
|---|---|---|
| Weeds | Preplant application | Postemergence application |
| Emerged horseweed plants | 1 (group 14) | 1 (group 4) |
| Emerged Palmer amaranth plants | 2 (group 5, 14) | 1 (group 4) |
| Residual control of Palmer amaranth | 2 (group 5, 15) | 1 (group 15) |

In this example the field is treated with herbicides three weeks before planting to control winter annual weeds (including horseweed) followed by a postemergence herbicide after soybean and weed emergence (Example 3b). To reduce the number of applications, residual herbicides are included in the preplant application. To better manage resistance, application timing needs to be considered in relation to the weed emergence period (Example 3b).

**Example 3b. Illustration of two-pass program targeting five weed species in soybean.**

| 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.

Comments for each species:

**Horseweed** can emerge in the fall and 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 dissipation. Engenia (group 4) in the postemergence application will control these late-emerging weeds.

For season-long resistance management of horseweed, this example is fair to good. The herbicide program has two effective modes of action for control of emerged horseweed plants (group 14 + group 4), but they are applied in sequence rather than as a tank mixture. Residual control is provided by one effective mode of action (group 5), although both the group 14 and group 4 herbicides contribute for a short time.

**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.
<u>For season-long resistance management of Palmer amaranth, this example is poor to fair</u>. 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 modes of action, but since application is made so early, the benefits of the two effective modes 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 mode 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.
<u>For season-long resistance management of common lambsquarters, this example is good</u>. Three effective modes of action are used in the preplant application, an effective residual herbicide is used, and then two effective modes 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. Group 5 herbicide-resistant common lambsquarters is commonly found in some regions of the US, so alternative effective herbicide modes of action must be considered in those areas.

**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.
<u>For season-long resistance management of annual morningglory, this example is good</u>. Only one effective mode of action is used with the preplant application (chlorimuron), but the postemergence application includes two effective modes of action. The effective modes of action are different for both applications and applying the residual herbicide closer to planting would improve the resistance management of this program. Herbicide-resistant annual morningglorry is currently not common in US crop production.

**Large crabgrass** emerges in the spring and early-to mid-summer so the 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 crabgrass, this example is poor. Glyphosate used in the preplant application would 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 crabgrass in the postemergence application. While Warrant (group 15) does provide residual control of crabgrass, it is not applied until after the crabgrass emergence period. Thus, there is only one effective mode of action used at either application timing. However, there have been no reports of herbicide resistance in large crabgrass in field crops, so incorporating additional modes of action may not be justified at this time.

## SUMMARY

These examples were developed to demonstrate considerations when evaluating effective modes of action. Herbicide resistance is less likely to develop when multiple effective modes 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 at greater risk for resistance evolution.

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