Herbicide Resistance Management Decision Aid

University of Wisconsin-Extension

What is herbicide resistance?

The Weed Science Society of America (WSSA) defines herbicide resistance as "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis."

This is a sound definition with two very important elements that researchers must use experiments to confirm during resistance investigations.

1) Plants which survive a dose expected to otherwise be lethal will in fact produce off-spring proving resistant plants are 'fit' enough to be a persisting problem.

2) A genetic change has occurred which is passed on to future generations of these offspring (i.e. it is 'inherited').

In practice, for a farmer this definition means that a herbicide that could once be reliably trusted to control a certain weed species in a crop when used according to label directions is no longer an option for providing reliable control.

Unfortunately, the lack of reliable control is often not discovered until after a particular species has increased to levels detrimental to crop yield and/or quality.

To learn more, read "Herbicide resistance and herbicide tolerance definitions" published by the Weed Science Society of America (WSSA) at http://wssa.net/weed/resistance/herbicide-resistance-and-herbicide-tolerance-definitions/ (Accessed September 2014).

If a weed is herbicide-resistant, is it resistant to all herbicides?

No, the issue of herbicide resistance is more complex than that, because not all herbicides kill plants the same way. Every herbicide has an unique 'Trade Name'. The trade name is often the name farmers most easily recognize because it is the name on the herbicide container (e.g Roundup®). However, many herbicides with different trade names can have the same active ingredient, this is called the 'common name'. For example, Roundup® and Touchdown® are both trade names for the same active ingredient, glyphosate.

Glyphosate kills plants by inhibiting the production of an essential set of amino acids, and this occurs in a specific biological plant pathway (i.e. 'site') we'll simply call the 'EPSP synthase' pathway. Thus, glyphosate is called an EPSP Synthase inhibitor based on this site-of-action. Some other herbicides kill plants by targeting a completely different site-of-action, or location in the plant. There are likely a thousand herbicide trade names on the market. All of those come from over a hundred herbicide common names (i.e. active ingredients). Of the greater than 100 active ingredients, there are only 17 sites-of-action that are common in much of production agriculture. Because many of these sites-of-action are names that can be hard to remember, the International Herbicide Resistance Action Committee (HRAC) has adopted a numbering system called 'group numbers' to make the classification of herbicides easier. Glyphosate, an EPSP Synthase inhibitor, is considered a group 9 herbicide.

When a weed becomes resistant to one active ingredient, it usually means it is resistant to all herbicides that target the same site-of-action. However, herbicides that target a different site-of-action may still be effective. Herbicide resistance can be cumulative, however, meaning that after a weed becomes resistant to one site-of-action, it can still become resistant to another site-of-action through other independent selection events; this is called multiple resistance. Because resistance occurs after continuous reliance on one effective site-of-action, rotating effective sites-of-action is an important integrated tactic to avoid resistance. The way to be sure to know you're rotating effective sites-of-action starts with knowing the relationship

between herbicide trade names, common names, and sites-of-action (group numbers). To learn more about these relationships, download the TakeAction Herbicide Classification chart found at http://takeactiononweeds.com/wp-content/uploads/2014/01/herbicide-classification-chart.pdf. (Accessed September 2014).

Why does a farmer need to include strategies for managing herbicide resistance in their integrated pest management plan?

Herbicide resistance is the result of utilizing a single control tactic, repeatedly, for so long that certain species adapt to that control tactic and become more prevalent in the cropping system.

The basic principle of resistance can apply to any weed control tactic like repeated tillage or even hand weeding, but we have the greatest concern for resistance to herbicides because when used properly, herbicides are a very cost effective and efficient way to control weeds in comparison to other methods of acute (e.g. mechanical) control.

One of the most important attributes of herbicides is their ability to control undesirable plants within close proximity to desirable vegetation. Tillage and other mechanical methods of weed control can be very effective when wanted and unwanted plants are spatially isolated, but when plants are close together only hand weeding can be equally effective at eliminating the correct plant species with a cost of reduced efficiency compared to herbicides. Moreover, because herbicides reduce the need for tillage, their use helps protect soils from erosion and structural degradation from repeated tillage events.

Because this described trade-off between the utility and detriment of using (or over-using) herbicides and tillage exist, farmers must incorporate effective integrated weed management (IWM) strategies to preserve the value herbicides bring to modern farming systems.

To learn more, read "Herbicide-resistant Weeds Threaten Soil Conservation Gains: Finding a Balance for Soil and Farm Sustainability" published by the Council for Agriculture Science and Technology (CAST) at http://www.cast-science.org/publications/?herbicideresistant_weeds_threaten_soil_conservation_gains_finding_a_balance_for_soil_and_farm_sustainability&show=product&productID=52723 (Accessed September 2014).

Which weeds have shown resistance to herbicides in Wisconsin?

Herbicide resistance in Wisconsin is not new. The first documented report of an herbicide-resistant weed biotype in Wisconsin was in 1979, and that was common lambsquarters with resistance to atrazine. Atrazine is a group 5 herbicide, with a site-of-action otherwise known as a photosystem II inhibitor. Since that time, the list has grown to ten herbicide-resistant weed species listed in Table 1.

How do I find out about weeds in other states and countries that have resistance to herbicides?

The most comprehensive and current source, which is used as the 'official' source, is the "International Survey of Herbicide Resistant Weeds" located online at www.weedscience.org. The database is searchable by country, state, herbicide site-of-action, crop, a weed's scientific name, or common name.

Table 1. Herbicide Resistant Weeds in Wisconsin

WEED SPECIES	SITE OF ACTION [1] ACCASE INHIBITORS	[2] ALS INHIBITORS	[5] PHOTOSYSTEM II INHIBITORS	[9] EPSP SYNTHASE INIHIBITOR
Common lambsquarters			✓	
Eastern black nightshade		✓		
Giant foxtail	✓	✓		
Green foxtail		✓		
Horseweed (Marestail)				✓
Kochia		✓	✓	
Large crabgrass	✓			
Smooth pigweed			✓	
Velvetleaf			✓	
Waterhemp		✓		✓

What weeds are the greatest threats for herbicide resistance?

Theoretically, every weed species has some probability of becoming herbicide-resistant under certain parameters. However, there are some weed species that, for a variety of reasons, are greater threats for becoming resistant to herbicides. There are 11 such species listed as the greatest threats in much of corn and soybean production based on a combination of the number and sites-of-action they are resistant to, the number of geographies and crops they have been reported resistant in, the level of difficulty associated with their control in the absence of herbicides, and their ability to compete with crops. These eleven greatest threats are:

- **Common waterhemp** (*Amaranthus rudis*)
- **Palmer amaranth** (*Amaranthus palmeri*)
- **Horseweed** (marestail) (*Conyza canadensis*)
- **Giant ragweed** (*Ambrosia trifida*)
- **Common ragweed** (*Ambrosia artemisiifolia*)
- **Common lambsquarters** (*Chenopodium album*)
- **Kochia** (*Kochia scoparia*)
- **Italian ryegrass** (*Lolium multiflorum*)
- **Barnyardgrass** (*Echinochloa crus-galli*)
- **Johnsongrass** (*Sorghum halepense*)
- **Giant foxtail** (*Setaria faberi*)

For more information on the biology and management of each weed species, visit www.takeactiononweeds.com

Why are some weed species more likely to evolve resistance to herbicides?

There are many biological, ecological, cultural, and biochemical changes that influence herbicide resistance, but the most important drivers of herbicide resistance are genetic diversity and selection pressure.

Genetic diversity is associated with processes like genetic mutation rates, outcrossing rates, pollen and seed movement, and seed production. Growers are limited in the ability to influence genetic diversity.

Selection pressure, however, is the factor that growers can most influence. Selection pressure is defined as the repeated 'exposure' from a biotic or abiotic force that influences the ability of some biotypes to survive and reproduce based on a set of 'fitness traits'.

In this case we're discussing the idea that plant biotypes that have fitness traits to tolerate or resist adverse herbicide effects will survive and increase in frequency. If this happens multiple times, eventually that fitness trait will occur at high levels allowing entire weed populations to be un-affected by the herbicide.

Because both selection pressure and genetic diversity is influenced by the sheer number of plants exposed, some weed species become herbicide-resistant more easily because they A) are more common across larger geographies so more weeds are routinely exposed to the same herbicide, B) have more genetic diversity including traits that allow survival following herbicide exposure, or C) both.

What information does a farmer need to know and understand to effectively manage herbicide resistance?

The key component for managing herbicide resistance is to scout for weed species before and after herbicide applications. For farmers to scout their fields effectively, they need to be able to identify the weed species on their farms.

The other component to managing herbicide resistance is to understand weed life histories, which allows farmers to correctly time herbicide applications and incorporate mechanical and cultural management tactics.

The second part of this decision aid provides information and suggests additional resources for weed identification, weed life histories, herbicide good management practices, and other integrated weed management strategies.

Know Your Weeds

Weed Identification

One of the first and most important aspects of an integrated pest management program is to accurately identify the target pest. Accurate identification enables the ability to gather more precise information about short- and long-term management strategies, and ensure the pest will be controlled according to directions on pesticide labels. Resources available for weed identification include downloadable guides and smart phone apps.

For identification of the weeds that are the biggest resistance threats, the United Soybean Board in association with weed scientists across the Midwest and South, have produced an id guide (www.takeactiononweeds.com, directly at http://digital.turn-page.com/i/279442).

There are several comprehensive online and printable guides to weed identification:

- Weed ID, University of Wisconsin-Madision, http://weedid.wisc.edu/
- Weed ID, University of Illinois http://weeds.cropsci.illinois.edu/weedid.htm
- Weeds of the North Central States, online version, http://www.aces.uiuc.edu/vista/html_pubs/WEEDS/list.html
- Early Spring Weeds of No-Till Production, University of Illinois, http://weeds.cropsci.illinois.edu/extension/Other/NCR614.pdf
- WeedID, University of Missouri, online version, http://weedid.missouri.edu/
- WeedID, University of Missouri, app for iphone and android devices (https://itunes.apple.com/us/app/id-weeds/id559906313?mt=8, https://play.google.com/store/apps/details?id=com)
- Practical Weed Science for the Field Scout, University of Missouri, http://weedscience.missouri.edu/publications/ipm1007.pdf
- Ohio Perennial and Biennial Weed Guide, The Ohio State University, http://www.oardc.ohio-state.edu/weedguide/listall.asp

Weed life history and seed characteristics

Understanding a weed species' life history is an important component of integrated weed management and herbicide resistant management because with that knowledge a producer can target their scouting trips, improve their timing of herbicide applications, and develop strategies to manage the weed seedbank to prevent future problems (see Table 2, next page).

Herbicide GMP (Good Management Practices)

For herbicide applications, remember the 3 R's.

Right rate always apply the full labeled rate

Right size apply when weeds are less than 6 inches in height or recommended size

Right time make applications when plants are actively growing for translocated herbicides

Use multiple sites of action

Combining multiple sites of action within a growing season, application, or rotation minimizes the number of weeds exposed to each site-of-action, which reduces the risk of developing a population of herbicide resistant weeds.

Use a residual herbicide

A residual herbicide, typically applied before crop emergence, with a different site-of-action from the post emergence herbicides will reduce the weed population that is exposed to the post emergence herbicides. For an in-depth discussion of reducing risk by adding a pre-emergence herbicide, see Boerboom et al.'s article in the "Additional Resources" section.

The five key pieces of weed life history information are the following:

1. **When do plants emerge?**
2. **What is the optimal growth stage for control?**
3. **How much seed does one plant produce?**
4. **How far does the seed travel?**
5. **How long does the seed persist in the soil?**

Table 2.
Weed Life History

WEED SPECIES	1. Emergence (Spring: M Ap May; Summer: Ju Jly Aug; Fall: Spt Oct Nov)	3. SEEDS PER PLANT	5. Seed Persistence: 4 YEARS OR LESS	5. Seed Persistence: 10 YEARS OR MORE	5. Seed Persistence: 30 YEARS OR MORE
Common waterhemp		250,000	✓		
Palmer amaranth		600,000	✓		
Horseweed (Marestail)		200,000			
Giant ragweed		5,100	✓		
Common ragweed		47,000		✓	
Common lambsquarters		72,500			✓
Kochia		16,000	✓		
Italian ryegrass			✓		
Barnyardgrass		7,000		✓	
Johnsongrass		80,000	✓		
Giant foxtail		1,500			✓

2. For optimal control, an herbicide's effectiveness will be maximized if a weed is targeted prior to emergence or less than 4 inches in height.
4. Data for dispersal mechanisms are still lacking for many weed species. However, kochia, horsweed, barnyardgrass, and johnsongrass dispersal routes are known. Kochia (tumbleweed), horsweed (wind), barnyardgrass (birds, surface water run-off), johnsongrass (underground rhizomes in addition to seed dispersal)
5. Seed persistence categories, 4 years or less, 10 years or more, or 30 years or more are for 99% reduction in the seedbank.

Strategies to Manage Herbicide Resistance

A strategy to manage herbicide resistance incorporates multiple practices to provide effective weed management and herbicide technology stewardship. For instance, a single practice, such as crop rotation, will not prevent selection for herbicide resistant weeds.

Crop rotation can help to reduce certain weed species. For example, planting a forage, e.g. alfalfa, can help to suppress giant ragweed populations because it does not tolerate repeated mowing events. If a growers' fields are infested with spring emerging weed species such as common lambsquarters, then using small grains in the rotation to provide a dense canopy early in the growing season may be advantageous. The other rationale for using crop rotation as part of an herbicide resistance management plan is that by rotating crops, a grower will also use different sites-of-action in different crops. However, sites-of-action overlap between corn, soybean, and small grain herbicides.

Tillage when used appropriately can help to reduce weed populations. When should a grower consider using tillage? For infestations of weed species that do not tolerate seed burial, deep tillage can be very effective at reducing the weed seedbank.

Horseweed (Marestail) seed germinates at the soil surface and does not tolerate seed burial. Common waterhemp and Palmer amaranth prefer the top one inch of soil for germination. Tillage that adequately buries the seed below three inches can reduce their seed in the seedbank. In contrast, to reduce common ragweed seed long-term no-till is the best option because it can emerge from as deep as five inches in soil. It is important to keep in mind that using deep tillage comes with soil health concerns and may need to be supplemented with soil-building practices.

Crop rotation, tillage, and herbicide GMPs require long-term planning and implementation. During the growing season, the process of managing herbicide resistance involves three steps with repeated scouting trips to monitor weed populations and evaluate herbicide efficacy.

IPM (IWM) Growing Season Checklist

- ✓ **Start Clean.**
- ✓ **Stay Clean.**
- ✓ **Scout.**

Start the season off right and reduce weed populations before crop establishment by incorporating tillage, if necessary, and a pre-emergence herbicide application.

Keep those fields clean by returning after your early-season management to scout the remaining weed population and plan your post-emergence weed management strategy.

If you apply a post-emergence herbicide, then make sure to scout seven to fourteen days after the application to determine if there are any weed escapes.

If there are weed escapes, it is time to implement a strategy for removing those weeds before they produce seed and cause a larger, more serious problem.

Additional Resources:

Weed Science Society of America Herbicide Resistance educational resources available at: http://wssa.net/weed/resistance/

Boerboom, C.; Stoltenberg, D.; Jeschke, M.; Proost, R. "An Equation for Trouble? Glyphosate x Weeds = Resistance" Available at http://wp.me/a3n0Mi-gG

For weed control efficacy ratings consult University of Wisconsin Extension publications A3646 Pest Management in Wisconsin Field Crops, available at http://learningstore.uwex.edu

Pesticide labels and material safety data sheets (MSDS) can be viewed at http://www.cdms.net/LabelsMsds/LMDefault.aspx

Is it legal to use a cover crop as a forage crop? Maybe not . . . http://ipcm.wisc.edu/download/pubsPM/9-19-12-Cover-Crops-used-for-forages.pdf

Wisconsin Crop Weed Science Research Report http://wcws.cals.wisc.edu/documents

TakeAction Herbicide Classification chart http://wcws.cals.wisc.edu/documents

Take Action on Weeds website, sponsored by the United Soybean Board, http://takeactiononweeds.com

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