Herbicide Resistant Weeds

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Herbicides work by disrupting biological pathways that allow plants to produce sugars and other compounds that are needed for growth. The location where a herbicide interrupts a pathway is called the site of action. For instance, the site of action for atrazine is photosystem II of the photosynthetic pathway. In some cases, different herbicides have the same site of action (e.g., 2,4-D and Banvel (dicamba) are both synthetic auxins that interfere with natural plant auxin). The Weed Science Society of America developed a classification system to group herbicides by their site of action. Grouping herbicides by site of action provides a simple tool for determining which herbicides kill plants in the same way. Table 1 lists the herbicide groups and herbicides that are registered for use in Florida.

Herbicide performance is a complex issue that is influenced by many factors. These include spray coverage, application method, herbicide rate, environmental conditions, and weed size, to name a few. Poor or incomplete control may also be due to the ability of a weed to tolerate a particular herbicide. Herbicide tolerance is the inherent ability of a species to survive following a herbicide treatment.

There was no selection to make the plant tolerant; it simply possesses a natural tolerance. For instance, most grass species are tolerant to 2,4-D. Herbicide resistance is different from tolerance and is defined as the inherited ability of a plant to survive a herbicide application to which the natural or wild-type is susceptible. For example, goosegrass is normally susceptible to paraquat, but some populations contain plants that have undergone a genetic change that makes them less susceptible. When these populations are treated with paraquat, the normal biotypes are controlled, while the resistant biotypes survive.

Extremely small numbers of herbicide-resistant individuals naturally occur in plant populations. There is no evidence that herbicides cause the genetic changes that result in herbicide resistance. Herbicides simply select for herbicide-resistant individuals that already occur in the population by controlling susceptible plants and allowing the resistant plants to survive and reproduce. Eventually, all that is left are the resistant plants, and the herbicide is no longer effective. See Figure 1 for an example. Once selected...
for, resistant plants can remain in the population for many years.

In addition to being resistant to a single herbicide, some resistant plants can be classified as having cross resistance or multiple resistance. Cross resistant plants have resistance to two or more herbicides from the same group (same site of action). For example, if you have a population of pigweed that has developed resistance to atrazine, a Group 5 herbicide, it is likely that these pigweed plants will also be resistant to the Group 5 herbicides simazine and metribuzin (Sencor). Although it is much less common, weeds can also have multiple resistance. Multiple resistant weeds are resistant to two or more herbicides with different sites of action. For example, in Indiana a biotype of horseweed/marestail is resistant to glyphosate (Group 9), 2,4-D (Group 4), and chloransulam (Group 2) (Creech et al. 2004, NCWSS 2004 Proceedings).

The first recorded herbicide-resistant weed, 2,4-D resistant spreading dayflower (*Commelina diffusa*), was identified in 1957 in a sugarcane field in Hawaii. Today an estimated 300 weed biotypes are resistant to one or more herbicides worldwide (Figure 2). Currently in Florida, only 4 resistant biotypes (American black nightshade, goosegrass, hydrilla, and dotted duckweed) have been documented. However, it is likely that other undocumented herbicide resistant weed populations occur throughout the state. Continually updated information on the status of herbicide-resistant weeds can be found at http://WeedScience.org/in.asp.

### Detecting Herbicide Resistant Weed Populations

Because weed control is rarely 100% effective, herbicide resistant populations often go undetected until they represent about 30% of the population. As the ratio of resistant to susceptible weeds increases, irregular patches of a single weed species will begin to appear. The patches may be reason to suspect herbicide resistance if:

1. Application problems can be ruled out.
2. Other weed species are controlled adequately.
3. The suspected weed species doesn’t show symptoms of herbicide treatment and is growing in close proximity to dying plants of the same species.
4. There has been a previous failure to control the same species in the same field with the same herbicide or a herbicide from the same group.
5. Records show repeated use of one herbicide or one group of herbicides.

### Preventing Herbicide Resistant Weeds

The appearance of herbicide-resistant weeds is usually linked to repeated use of the same herbicide or several herbicides from the same group (same site of action). For example, continuously applying only glyphosate for weed control in Roundup Ready cotton has resulted in the selection of glyphosate (Group 9) resistant Palmer amaranth. Weed management programs that use herbicides from different groups will delay or prevent the selection of herbicide resistant weed populations. When developing a herbicide rotation plan, it is critical to make sure that the herbicides you wish to use are in different groups. For instance, you might consider rotating the herbicides Assure II, Select, and Beacon for johnsongrass control; however, if you referred to Table 1 you would find that Assure II and Select are both Group 1 herbicides. A more ideal herbicide rotation for johnsongrass control might include Assure II or Select (Group 1), Beacon (Group 2), and glyphosate (Group 9).

When it allows for increased herbicide flexibility, crop rotation can be an effective resistance management strategy. However some herbicides or herbicide groups are used in many different crops. For example, Group 2 herbicides are labeled for use in pastures, wheat, barley, corn, soybeans, cotton, peanuts, rice, vegetables, and other crops. Consequently, crop rotation does not automatically result in herbicide rotation. When planning a herbicide program, refer to Table 1 to verify that the herbicides you are using are in different groups.

Tank mixes generally are not an effective resistance management strategy and should only be
used when the herbicide combination is needed to control the weed spectrum or herbicide rates can be reduced. Tank mixing for other reasons is not economically or ecologically sound.

Cultivation and spot spraying can be used to remove weed escapes that may be a result of herbicide resistance. Assuming that herbicide resistant and non-resistant plants germinate at the same time, tillage can control both equally well. In chemical fallow situations, use a herbicide from a different group than the herbicide used for weed control in the crop.

Accurate record-keeping is essential to effectively manage the development of herbicide-resistant weed populations. In order to have an effective herbicide rotation or tank-mix system to prevent resistance, you must know which herbicides have been used in the past, at what rate, and how often.

The use of an integrated weed management program that incorporates all the tools available to control weeds, including cultural, mechanical, and chemical methods, will slow or prevent the development of herbicide resistant weed populations.

For detailed information on properly managing herbicides for the preventing herbicide resistant weeds in specific cropping systems or pastures refer to: UF/IFAS publication SS-AGR- Managing Against the Development of Herbicide Resistant Weeds: Sugarcane; others to follow.
Figure 1. A possible progression of selection for resistant weed biotypes when a single herbicide or site of action is used continuously or without adding a herbicide with a different site of action to the tankmixture. Initially, good control would be observed providing application factors were optimal for herbicide activity (A). After several applications, a single plant may survive, grow and reproduce seed (B). That seed would germinate the following year and as a result, more plants would not be controlled the following year (C). As selection pressure continues, one would begin noticing a reduction in herbicide performance when the resistant population in the field approaches approximately 30% of the weed population (D). Providing the same selection pressure is applied to the field, the resistant weed population will continue to increase until nearly 100% of the population is resistant (E).

Figure 2. World-wide occurrence of herbicide-resistant weed biotypes. Addition of all biotypes resistant to each of the sites of action totals to greater than 300 different biotypes as of 2000.
Table 1. Group number and site of action of herbicides registered for use in Florida (compiled Fall 2005).

<table>
<thead>
<tr>
<th>Group number and site of action</th>
<th>Chemical Family</th>
<th>Common Name</th>
<th>Trade Name(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1</strong></td>
<td>arylloxyphenoxy-propanoates</td>
<td>cyhalofop, diclofop, fenoxaprop, fluazifop, quizalofop</td>
<td>Clincher, Illoxan, Acclaim Extra, Fusion¹, Fusilade, Fusion¹, Ornamec, Assure II</td>
</tr>
<tr>
<td>Acetyl CoA carboxylase (ACCase) inhibitors</td>
<td>cyclohexanediones</td>
<td>clethodim, sethoxydim, tralkoxydim</td>
<td>Envoy, Select, Volunteer, Poast, Poast Plus, Achieve</td>
</tr>
<tr>
<td><strong>Group 2</strong></td>
<td>benzoate</td>
<td>pyrithiobac</td>
<td>Staple</td>
</tr>
<tr>
<td>Acetolactate synthase (ALS) inhibitors</td>
<td>imidazolinones</td>
<td>imazapic, imazapyr, imazamox, imazaquin, imazethapyr</td>
<td>Cadre, Arsenal, Lightning², Stalker, Scepter, Lightning³, Pursuit, Pursuit Plus³</td>
</tr>
<tr>
<td>pyrimidinylloxylbenzoic</td>
<td>bispyribac-sodium</td>
<td></td>
<td>Regiment, Velocity</td>
</tr>
<tr>
<td>sulfonylureas</td>
<td>bensulfuron, chlorosulfuron, halosulfuron, nicosulfuron, trifloxysulfuron, chlorimuron, metisulfuron, tribenuron, sulfometuron, sulfosulfuron, thifensulfuron, rimsulfuron</td>
<td></td>
<td>Due⁴, Londax, Corsair, Landmark⁵, Telar, Permit, Sempra, Sandea, Sedgehammer, Yukon⁵, Accent, Envoke, Synchrony⁷, Ally, Escort, Oust Extra⁸, Express, Harmony Extra⁹, Landmark⁶, Oust, Oust Extra⁸, Oustar¹⁰, Westar¹⁰, Outrider, Harmony GT, Harmony Extra⁹, Synchrony⁷, Matrix, Tranxit</td>
</tr>
<tr>
<td>triazolopyrimidine</td>
<td>cloransulam, flumetsulam</td>
<td></td>
<td>Firstrate, Frontrow, Frontrow</td>
</tr>
</tbody>
</table>
**Table 1.** Group number and site of action of herbicides registered for use in Florida (compiled Fall 2005).

<p>| Group 3 | Microtubule assembly inhibitors | dinitroanilines | ethalfluralin | Curbit, Sonalan | Oryza, Oryzalin, Snapshot, Surflan, Prowl, Pursuit Plus3, others&lt;br&gt; pendimethalin | propanil&lt;br&gt; trifluralin | Barricade, Endurance | Treflan, Trifluralin&lt;br&gt; no family name | DCPA | Dacthal, Dagger&lt;br&gt; pyridine | thiazopyr | Mandate&lt;br&gt; Group 4 | Synthetic auxins | phenoxy acetic acids | 2,4-D | many, Outlaw11, Trimec11&lt;br&gt; 2,4-DB | many | Power Zone19&lt;br&gt; MCPA | MCPP (mecoprop) | Outlaw11, Trimec11, Power Zone19&lt;br&gt; benzoic acid | dicamba | Banvel, Distinct, Outlaw11, Trimec11, Yukon5, Power Zone19&lt;br&gt; carboxylic acids | clopyralid | Confront12, Lontrel, Redeem12, Transline&lt;br&gt; fluroxypyr | Pasturegard13, Spotlight&lt;br&gt; trifluralin | Confront12, Garlon, Grandstand, Pasturegard13, Pathfinder, Redeem12, Remedy&lt;br&gt; quinoline carboxylic acids | quinclorac | Drive&lt;br&gt; Group 5 | Photosystem II inhibitors | triazines | ametryn | Evik&lt;br&gt; atrazine | Aatrex, Atrazine, Bicep II Magnum14, Lexar15&lt;br&gt; hexazinone | K416, Oustar10, Velpar, Westar10&lt;br&gt; metribuzin | Sencor, Lexone, Metribuzin&lt;br&gt; prometryn | Caparol, Cotton Pro, Prometryn, others&lt;br&gt; simazine | Princep, Simazine&lt;br&gt; phenylcarbamate | phenmedipham | Spin-Aid&lt;br&gt; uracils | bromacil | Hyvar, Krovar17&lt;br&gt; Group 6 | Photosystem II inhibitors (same site as group 5, but different binding characteristics) | benzothiadiazoles | bentazon | Basagran, Storm18&lt;br&gt; Group 7 | Photosystem II inhibitors (same site as group 5 and 6, but different binding characteristics) | ureas | diuron | Direx, Diuron, Karmex, K416, Krovar17&lt;br&gt; floumeturon | Cotoran&lt;br&gt; linuron | Linex, Lorox&lt;br&gt; tebuthiuron | Spike |</p>
<table>
<thead>
<tr>
<th>Group</th>
<th>Site of Action</th>
<th>Herbicides</th>
</tr>
</thead>
</table>
| Group 8 | Lipid synthesis inhibition (not ACCase inhibition) | amide
- propanil
- napropamide
- Duet*, Stam Devrinol |
| Group 9 | EPSP synthase inhibitors              | thiocarbamates
- butylate
- EPTC
- thiobencarb
- Sutan
- Eptam, Eradicane Bolero |
| Group 10| Glutamine synthase inhibitors         | no family name
- glyphosate
- many |
| Group 11| Carotenoid biosynthesis inhibitors at phytoene desaturase | pyridazinone
- norflurazon
- Predict, Solicam, Zorial |
| Group 12| Protoporphyrinogen oxidase (PPO) inhibitors | isoxazolidinone
- clomazone
- Command 3ME |
| Group 13| Bleaching: diterpene inhibitors       | ary triazinone
- carfentrazone
- Aim, Power Zone^{19} |
| Group 14| Protoporphyrinogen oxidase (PPO) inhibitors | diphenylethers
- acifluorfen
- Storm^{16}, Ultra Blazer
- Cobra, Phoenix
- Galligan, Goal, Oxiflo |
| Group 15| unknown site of action                | N-phenylpyltaimides
- flumioxazin
- flumiclorac
- Chateau, Sureguard, Valor SX
- Resource |
| Group 16| unknown site of action                | oxadiazole
- oxadiazone
- Authority, Ronstar |
| Group 17| unknown site of action                | pyrazole
- Pyraflufen
- Edict IVM, ET |
|         | unknown site of action                | acetamides
- napropamide
- Devrinol |
|         | unknown site of action                | chloroacetamides
- acetochlor
- Volley
- Bicep II Magnum^{14}, Dual Magnum, Lexar^{15}, Pennant Magnum
- Kerb |
|         | unknown site of action                | oxyacetamides
- flufenacat
- Axiom |
|         | unknown site of action                | benzofuran
- ethofumesate
- Prograss |
|         | unknown site of action                | organoarsenicals
- MSMS
- MSMA |
Table 1. Group number and site of action of herbicides registered for use in Florida (compiled Fall 2005).

<table>
<thead>
<tr>
<th>Group 18</th>
<th>Group 19</th>
<th>Group 21</th>
<th>Group 22</th>
<th>Group 27</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHP (dihydropteroate synthase step) inhibitors</td>
<td>pthalamate</td>
<td>benzamide</td>
<td>bipyridyliums</td>
<td>triketone</td>
</tr>
<tr>
<td>carbamate</td>
<td>naptalam</td>
<td>isoxaben</td>
<td>paraquat</td>
<td>mesotrione</td>
</tr>
<tr>
<td>asulam</td>
<td></td>
<td></td>
<td></td>
<td>Callisto, Lexar&lt;sup&gt;15&lt;/sup&gt;</td>
</tr>
<tr>
<td>Asulox, Asulam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>Fusion is a commercial premix of fenoxaprop and fluazifop.
<sup>2</sup>Lightning is a commercial premix of imazapyr and imazethapyr.
<sup>3</sup>Pursuit Plus is a commercial premix of imazethapyr and pendimethalin.
<sup>4</sup>Duet is a commercial premix of bensulfuron and propanil.
<sup>5</sup>Yukon is a commercial premix of halosulfuron and dicamba.
<sup>6</sup>Landmark is a commercial premix of chlorosulfuron and sulfometuron.
<sup>7</sup>Synchrony is a commercial premix of chlorimuron and thifensulfuron.
<sup>8</sup>Oust Extra is a commercial premix of metsulfuron and sulfometuron.
<sup>9</sup>Harmony Extra is a commercial premix of thifensulfuron and tribenuron.
<sup>10</sup>Oustar and Westar are commercial premixes of sulfometuron and hexazinone.
<sup>11</sup>Outlaw and Trimec are commercial premixes of 2,4-D, dicamba, and MCCP.
<sup>12</sup>Confront and Redeem are commercial premixes of clopyralid and triclopyr.
<sup>13</sup>Pasturegard is a commercial premix of triclopyr and fluroxapy.
<sup>14</sup>Bicep II Magnum is a commercial premix of atrazine and metolachlor.
<sup>15</sup>Lexar is a commercial premix of atrazine, metolachlor, and mesotrione.
<sup>16</sup>K4 is a commercial premix of hexazinone and diuron.
<sup>17</sup>Krovar is a commercial premix of bromacil and diuron.
<sup>18</sup>Storm is a commercial premix of bentazon and acifluorfen.
<sup>19</sup>Power Zone is a commercial premix of carfentrazone, dicamba, MCPA, and mecoprop.