**Definition of Herbicide Resistance and Tolerance**

**Resistance:** Inherited ability of a weed biotype to survive a herbicide application to which the original population was susceptible.

**Tolerance:** Inherited ability of a species to survive and reproduce after herbicide application.

**Biotype:** A group of plants within a species that have biological traits that are not common to the population as a whole.
Total 311 biotypes
183 species
Over 270,000 fields

Chronological Increase of Resistant Weeds
World & USA

Occurrence of Resistant Weeds in Field Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th># Resistant Biotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td>60</td>
</tr>
<tr>
<td>Corn</td>
<td>52</td>
</tr>
<tr>
<td>Rice</td>
<td>28</td>
</tr>
<tr>
<td>Soybean</td>
<td>24</td>
</tr>
<tr>
<td>Canola</td>
<td>11</td>
</tr>
<tr>
<td>Cotton</td>
<td>5</td>
</tr>
<tr>
<td>Sugarbeet</td>
<td>4</td>
</tr>
</tbody>
</table>
Occurrence of Resistant Weeds in Other Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th># Resistant Biotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables</td>
<td>16</td>
</tr>
<tr>
<td>Orchard</td>
<td>37</td>
</tr>
<tr>
<td>Pasture</td>
<td>23</td>
</tr>
<tr>
<td>Forestry</td>
<td>8</td>
</tr>
<tr>
<td>Other Perennial</td>
<td>8</td>
</tr>
<tr>
<td>(tea, coffee, rubber, mint, etc)</td>
<td></td>
</tr>
<tr>
<td>Non Crop</td>
<td>35</td>
</tr>
<tr>
<td>(roadside, railway, industrial site)</td>
<td></td>
</tr>
</tbody>
</table>

Chronology of herbicide resistant weeds in California

Herbicide resistant weeds in California

<table>
<thead>
<tr>
<th>Species</th>
<th>Area</th>
<th>Year</th>
<th>Herbicide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common groundsel</td>
<td>Asparagus</td>
<td>1981</td>
<td>Triazine (atrazine)</td>
</tr>
<tr>
<td>Perennial ryegrass</td>
<td>Roadside</td>
<td>1989</td>
<td>Sulfonurea</td>
</tr>
<tr>
<td>Smallflower umbelina igel</td>
<td>Rice</td>
<td>1993</td>
<td>Sulfonurea</td>
</tr>
<tr>
<td>California arrowhead</td>
<td>Rice</td>
<td>1993</td>
<td>Sulfonurea</td>
</tr>
<tr>
<td>Russian thistle</td>
<td>Roadside</td>
<td>1994</td>
<td>Sulfonurea</td>
</tr>
<tr>
<td>Wild oat</td>
<td>Barley, wheat</td>
<td>1996</td>
<td>Diuron</td>
</tr>
<tr>
<td>Redstem</td>
<td>Rice</td>
<td>1997</td>
<td>Sulfonurea</td>
</tr>
<tr>
<td>Rice field balsam</td>
<td>Rice</td>
<td>1997</td>
<td>Sulfonurea</td>
</tr>
<tr>
<td>Late watergrass</td>
<td>Rice</td>
<td>1998</td>
<td>fops &amp; thiocarbamates</td>
</tr>
<tr>
<td>Rigid ryegrass</td>
<td>Almonds, roadsides</td>
<td>1998</td>
<td>Glyphosate</td>
</tr>
<tr>
<td>Barnyardgrass</td>
<td>Rice</td>
<td>2000</td>
<td>fops &amp; thiocarbamates</td>
</tr>
<tr>
<td>Early watergrass</td>
<td>Rice</td>
<td>2000</td>
<td>fops &amp; thiocarbamates</td>
</tr>
<tr>
<td>Small-seeded canarygrass</td>
<td>Sugar beets</td>
<td>2001</td>
<td>fops and dinitro</td>
</tr>
<tr>
<td>Smooth crabgrass</td>
<td>Onions</td>
<td>2002</td>
<td>Synthetic auxins</td>
</tr>
<tr>
<td>Horseweed</td>
<td>Barley, wheat</td>
<td>2005</td>
<td>Glyphosate</td>
</tr>
<tr>
<td>Cotton creasy</td>
<td>Barley, wheat</td>
<td>2005</td>
<td>Glyphosate</td>
</tr>
</tbody>
</table>

Resistant Weeds Globally

Source: Dr. Ian Hooper
www.weedsience.com
**Resistance**: Genetic Mutations that Convey

- Altered site of action
  - change in target enzyme
- Enhanced metabolism
  - ability to degrade herbicide
- Decreased translocation
  - Herbicide does not get to its site of action
- Sequestration
  - Herbicide not available to the plant – tied up.

**Control practices that have led to the rapid appearance of resistance**

- Sole reliance on herbicides for weed control
  - Particularly same mode of action for an extended period
  - Even more particularly, high risk herbicide mode of actions (ALS, ACCase etc)
- Continuous cropping or monocultures
  - Also non-crop systems with similar annual vegetation
- Minimum tillage (rapid turn over of seed bank)
- High rates of application (roadsides, orchards)

**Characteristics of herbicides that lead to the rapid appearance of resistance**

- Single site of action
- Broad spectrum control
  - Not always the case
- Degraded by common metabolic process (cytochrome P450)

**Characteristics of weeds that lead to the rapid appearance of resistance**

- Genetic variability
- Wide range of adaptation
- High seed production
- Annual growth habit

**Most Important Herbicide-Resistant Species**

1. Rigid Ryegrass  *Lolium rigidum*
2. Wild Oat  *Avena fatua*
3. Redroot Pigweed  *Amaranthus retroflexus*
4. Common Lambsquarters  *Chenopodium album*
5. Goosefoot  *Chenopodium album*
6. Echinochloa crusgalli
7. Echinochloa crusgalli
8. Kochia  *Kochia scoparia*
9. Horseweed  *Conyza canadensis*
10. Smooth Pigweed  *Amaranthus hybridus*

**Rigid Ryegrass (Lolium rigidum)**

**Global Statistics**

- Sites: 19,160
- Area Infested: 2,303,954 ha (= 5 million acres)

**11 Herbicide Modes of Action (> 70 herbicides)**

- Mainly ACCase, ALS inhibitors & dinitroaniline
- 6 Cropping regimes
Multiple Herbicide Resistance

<table>
<thead>
<tr>
<th>Chemical family</th>
<th>Number of worldwide occurrences</th>
<th>Number of multiple resistant cases</th>
<th>% multiple resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthetic inhibits (PSII; triazines and ureas)</td>
<td>306</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>ALS inhibitors (sulfuryluron and imidazolinones)</td>
<td>260</td>
<td>39</td>
<td>15</td>
</tr>
<tr>
<td>ACCase (graminicides, fops and dims)</td>
<td>118</td>
<td>26</td>
<td>22</td>
</tr>
<tr>
<td>Glycine (glyphosate)</td>
<td>37</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Synthetic auxins (phenoxys, benzoic acid, and pyridines)</td>
<td>36</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>Dinitroanilines (most pre-grass herbicides)</td>
<td>27</td>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>PPO (diphenyl ethers)</td>
<td>4</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>788</strong></td>
<td><strong>118</strong></td>
<td><strong>15</strong></td>
</tr>
</tbody>
</table>

Multiple Resistance in the US

- Of the 325 reported cases of herbicide resistance in weeds in the US:
  - 19 are multiple resistant (6% of cases)
  - Mainly resistant to ALS, Photosystem II and ACCase herbicide modes of action.

Glyphosate first used commercially in 1974.

Widespread usage in orchards and broad acre agriculture in the late 1970’s to early 1980’s

First glyphosate resistant weed selected in the field in 1996, 22 years after its first commercial use.

Glyphosate Resistance

Glyphosate Resistance in Rigid Ryegrass (*Lolium rigidum*) in California

- Glyphosate Resistant Rigid Ryegrass
  - First detected in 1998
  - First glyphosate-resistant weed in U.S.
  - Intensively treated since 1984

Glyphosate Resistance Survey (Lanini and Jasieniuk, UC Davis)

<table>
<thead>
<tr>
<th>Counties</th>
<th>Cropping Systems</th>
<th>Sampling Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monterey</td>
<td>Almond orchards</td>
<td>2004: &gt;80 locations</td>
</tr>
<tr>
<td>Fresno</td>
<td>Walnut orchards</td>
<td></td>
</tr>
<tr>
<td>Madera</td>
<td>Prune orchards</td>
<td></td>
</tr>
<tr>
<td>Merced</td>
<td>Olive orchards</td>
<td>2005: &gt;100 locations</td>
</tr>
<tr>
<td>Stanislaus</td>
<td>Vineyards</td>
<td></td>
</tr>
<tr>
<td>San Joaquin</td>
<td>Winter wheat fields</td>
<td></td>
</tr>
<tr>
<td>Solano</td>
<td>Cotton fields</td>
<td></td>
</tr>
<tr>
<td>Sacramento</td>
<td>Alfalfa fields</td>
<td></td>
</tr>
<tr>
<td>Yolo</td>
<td>Tomato fields</td>
<td></td>
</tr>
<tr>
<td>Colusa</td>
<td>Sunflower fields</td>
<td></td>
</tr>
<tr>
<td>Sutter</td>
<td>Roadside</td>
<td></td>
</tr>
<tr>
<td>Butte</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glenn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tehama</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Glyphosate Resistance Survey

**Counties**
- Monterey
- R-Fresno
- RR-Madera
- Merced
- Stanislaus
- San Joaquin
- Solano
- Sacramento
- RR-Yolo
- RR-Colusa
- Sutter
- RR-Butte
- R-Glenn
- R-Tehama

**Cropping Systems**
- Almond orchards
- Walnut orchards
- Prune orchards
- Olive orchards
- Vineyards
- Winter wheat fields
- Cotton fields
- Alfalfa fields
- Tomato fields
- Sunflower fields
- Roadsides

\[ R = R \text{ to } 870 \text{ g/ha} = 0.75 \text{ lb/acre} = 1X \]
\[ RR = R \text{ to } 1720 \text{ g/ha} = 1.5 \text{ lb/acre} = 2X \]

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Taxonomy of *Lolium rigidum* (rigid ryegrass)

- Rigid ryegrass in California is not genetically distinct from Italian ryegrass (*Lolium multiflorum*).
- Italian ryegrass is much more common in California.
- Rigid ryegrass, Italian ryegrass, and perennial ryegrass (*Lolium perenne*) all hybridize.
- Can be weeds of crops (annual or perennial), non-crop areas, landscapes, and turf.
- Widespread glyphosate resistance in California is probably mainly Italian ryegrass.

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Glyphosate Resistant Horseweed
*Conyza canadensis*

First reported in USA, Delaware in 2000.

Rapidly spread—estimated over 500,000 acres infested.

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Glyphosate resistant horseweed in the US

- DE (2000)
- KY (2001)
- TN (2001)
- IN (2002)
- MO (2002)
- MD (2002)
- NJ (2002)
- AK (2003)
- MS (2003)
- NC (2003)
- PA (2003)
- CA (2005)

Source: www.weedscience.org
Lateral branching symptoms

Study by Anil Shrestha at the UC Kearney Ag Center

Prevention and Management

- Use of certified seed
- Sanitize equipment
- Use of short residual herbicides
- Rotating herbicides with different modes of action
- Integrating other non-chemical options into program
- Crop rotation
- Early detection of resistant weeds
**Selection Pressure**

Scientific Guesstimates
- ALS – 1 in 100,000?
- ACCase – 1 in 1,000,000?
- Many herbicides – 1 in 10,000,000?
- 2,4-D, glyphosate – 1 in 100,000,000?

Weed Seeds in Soil often > 100 million seeds/acre
Weed Seedling Populations often > 1 million seedlings/acre

**Survivors**

Set Seed

Resistant
Wrong Stage
Also Seed Bank

**Resistant Proportion increases**

Proportion of resistant to susceptible still quite low for many years (between 5 and 50 years depending on many factors) – resistance not suspected but may be evolving

**Herbicide Failure due to Resistance**

Resistance detected when a high proportion (usually > 30%) of the population are resistant to the herbicide

**Patterns to look for**

Very possibly

These two are not typical patterns associated with resistance

Could be, but may just be escapes too

**Key Points on Herbicide Resistance**

1. Once resistance occurs you lose the use of the herbicide and probably other herbicides that have the same mode of action for the foreseeable future for control of the resistant weed species
2. The supply of new herbicide modes of action is now coming to a standstill – companies have reduced investment in the discovery of new modes of action
3. Resistance management requires a multi-year plan, based on scientific management strategies that include resistance monitoring and rotation and/or mixtures of herbicide modes of action.
4. Herbicide resistance is a real and increasing threat to continued economic weed control along roadsides, and in rice and orchards.
Further Information

WeedScience.com
http://www.weedscience.com