Glyphosate Resistant Weeds: Impacts, Alternatives, and Current Research
You are.... here

- Lunch
- Weed presentation
- Coffee Break
- Wendy West – Yellow starthistle
Integrated Weed Management

- Using all available strategies to manage weed populations in a manner that is economically and environmentally sound.
  - cultural
  - mechanical
  - chemical
Goals of IWM

- Both short- and long-term goals
  - Prevent or reduce weed spread
  - Delay and/or suppress weed growth
  - Prevent or suppress weed seed production
  - Reduction of weed seed bank in soil
Developing an IWM

- Understand the problem
  - Identity and biology
- Understand the ecosystem
  - Crop biology
  - Management cost/benefit, tolerance to weeds
- Evaluate management options
  - Cultural
  - Mechanical
  - Chemical
- Refine IWM as needed (keep records)
The first step in understanding any problem is to correctly identify it.

- Dandelion
- Spiny and annual sowthistle
A number of weed books are available.
Several available.

I use a set by XID Services
- UC Davis
- WSSA
- WSWS
- others
A few online (FREE) resources are available

UC Davis Weed Research and Information Center
www.wric.ucdavis.edu
Online weed ID resources

UC Integrated Pest Management Program
http://ipm.ucdavis.edu/PMG/menu.weeds.html
Complex populations

- Rarely just one weed species present
  - Annual vs perennial vs biennial
  - Grass vs sedges vs broadleaf
- Time of emergence
  - Fall vs spring emergence vs year-round
- Reproductive strategy
  - Seed vs vegetative
Plants that are unusually persistent or pernicious often have:

- Abundant seed production
  - Also produce seed under adverse conditions
- Rapid growth and population establishment
- Seed dormancy
  - Long-term survival of buried seeds
- Self- and cross-pollinated
- Adaptations for spread
- Vegetative reproductive structures
- Capacity to occupy disturbed sites

After Baker, 1965
"Weeds" are the ones your neighbor has
"Difficult weeds" are the ones you have!
In reality, difficult weeds are species that withstand, tolerate, or are resistant to the control measures used in a particular system and have an economic impact
- Varies according to the crop, crop stage, control options, economic situation, etc
- Example:
  - In SJV, raisin grapes have more "problem" weeds than wine grapes or almonds. Why? Economics.
Difficult weeds in perennial crops

- Vineyard and orchard managers have a moderate number of chemical choices for weed control

- A few chemicals are VERY important
  - Driven by economics and “sustainability”

- This has lead to the situation where many of the difficult weeds are herbicide-resistant biotypes or populations have shifted to tolerant species
Herbicide tolerance: the inherent ability of a species to survive and reproduce after herbicide treatment; implies no selection or genetic manipulation to make the plant tolerant
  - “We’ve never gotten dependable control of this weed with this herbicide...”

Herbicide resistance: the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type
  - “We used to be able to control this weed with this treatment but it doesn’t work as well anymore...”
Current state of HRW

- World wide
  - 114 dicots and 80 monocots
  - 19 herbicide families
- USA
  - 76 dicots and 52 monocots
  - 15 herbicide families
- California
  - 7 dicots and 14 monocots
  - 7 herbicide families

www.weedscience.org
HRW in California

- Common groundsel
- Perennial ryegrass
- Smallflower umbrella sedge
- California arrowhead
- Russian thistle
- Wild oat
- Redstem
- Ricefield bulrush
- Late watergrass
- Rigid ryegrass
- Long-leaved loosestrife
- Barnyardgrass
- Early watergrass
- Small-seeded canarygrass
- Smooth crabgrass
- Horseweed
- Italian ryegrass
- Hairy fleabane
- Hairy fleabane
- Junglerice

Number of Species

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>Herbicide Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>Asparagus</td>
<td>triazine (atrazine)</td>
</tr>
<tr>
<td>1989</td>
<td>Roadside, railways</td>
<td>sulfonylurea</td>
</tr>
<tr>
<td>1993</td>
<td>Rice</td>
<td>sulfonylurea</td>
</tr>
<tr>
<td>1993</td>
<td>Rice</td>
<td>sulfonylurea</td>
</tr>
<tr>
<td>1994</td>
<td>Roadside</td>
<td>sulfonylurea</td>
</tr>
<tr>
<td>1996</td>
<td>Barley, wheat</td>
<td>pyrazolium (difenoquat)</td>
</tr>
<tr>
<td>1997</td>
<td>Rice</td>
<td>sulfonylurea</td>
</tr>
<tr>
<td>1997</td>
<td>Rice</td>
<td>sulfonylurea</td>
</tr>
<tr>
<td>1998</td>
<td>Rice</td>
<td>fops &amp; thiocarbamates</td>
</tr>
<tr>
<td>1998</td>
<td>Almonds, roadsides</td>
<td>glyphosate</td>
</tr>
<tr>
<td>2000</td>
<td>Rice</td>
<td>sulfonylurea</td>
</tr>
<tr>
<td>2000</td>
<td>Rice</td>
<td>fops &amp; thiocarbamates</td>
</tr>
<tr>
<td>2000</td>
<td>Rice</td>
<td>fops &amp; thiocarbamates</td>
</tr>
<tr>
<td>2001</td>
<td>Sugar beets, onions</td>
<td>fops and dims</td>
</tr>
<tr>
<td>2002</td>
<td>Rice</td>
<td>synthetic auxins</td>
</tr>
<tr>
<td>2005</td>
<td>Roadsides</td>
<td>glyphosate</td>
</tr>
<tr>
<td>2005</td>
<td>Roadsides</td>
<td>glyphosate</td>
</tr>
<tr>
<td>2007</td>
<td>Roadsides</td>
<td>glyphosate</td>
</tr>
<tr>
<td>2009</td>
<td>Roadsides, vines</td>
<td>glyphosate &amp; paraquat</td>
</tr>
<tr>
<td>2011</td>
<td>Orchard</td>
<td>glyphosate</td>
</tr>
</tbody>
</table>

www.weedscience.org
Factors affecting selection of herbicide-resistant weeds

- Agronomic production practices
- Weed biology
- Herbicide properties
Agronomic factors

- Crop rotation
- Tillage
- Crop competitiveness
- Herbicide rotation (different modes of action)
  - Changes selection pressure
HRW in field crops

- ~# resistant biotypes
- Cereals  60
- Corn     52
- Rice     28
- Soybean  24
- Canola   11
- Cotton   5
- Sugarbeet 4

Group 1 resistant wild oat treated with Fusilade
HRW in other crops

- ~# resistant biotypes
- Vegetables 16
- Orchard 37
- Pasture 23
- Forestry 8
- Other perennial 8
- Non-crop 35
Weed characteristics

- Annual growth habit
- High seed production
- Little seed dormancy
- Seed longevity in soil
- Original frequency of R trait in population
- Multiple generations per year
- Gene flow (pollen and seed)
- Fitness of R v. S biotype
- Highly susceptible to the herbicide

SU-resistant Russian thistle dispersal - Stallings et al. 1995
Some species are more prone to develop herbicide resistance

- 28 spp. with resistance to 2 MOA
- 10 to 3 MOA
- 3 to 4 MOA
- 1 to 5 MOA
- 3 to 6 MOA
- 1 to 8 MOA
  - one rigid ryegrass biotype has resistance to 8 MOA!
Worst HRW worldwide - based on # infested sites

- Rigid ryegrass
- Wild oat
- Redroot pigweed
- Common lambsquarters
- Green foxtail
- Barnyardgrass
- Goosegrass
- Kochia
- Horseweed
- Smooth pigweed

Think:
- Annual growth habit
- High seed production
- Little seed dormancy
- Seed longevity in soil
- Gene flow
- Highly susceptible to herbicide
Herbicide characteristics

- Single site of action
- High efficacy
  - selection pressure
- High use rate (relative to amount needed)
- Long soil residual activity
- High frequency of use (yearly or multiple applications per year)

Think:
- Sulfonylurea in wheat/rice
- Triazines in field and hort crops
- ACCase inhibitors in cereals
- Paraquat and glyphosate in orchards
World-wide resistance by MOA
What’s next?

- What are we “selecting” with our weed management strategies?
  - Common weeds – prone to resistance
  - Important herbicides use and reliance trends
  - Agronomic actions
    - Perennial crops, specialty crops, reduced tillage
<table>
<thead>
<tr>
<th>Weed</th>
<th>Present in CA</th>
<th>Resistance outside CA</th>
<th>Resistance reported in CA</th>
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<tbody>
<tr>
<td>Rigid ryegrass</td>
<td>✓</td>
<td>8 modes of action</td>
<td>✓ glyphosate</td>
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<tr>
<td>Wild oat</td>
<td>✓</td>
<td>6 MOA</td>
<td>✓ difenzoquat</td>
</tr>
<tr>
<td>Redroot pigweed</td>
<td>✓</td>
<td>3 MOA</td>
<td></td>
</tr>
<tr>
<td>Common lambsquarters</td>
<td>✓</td>
<td>4 MOA</td>
<td></td>
</tr>
<tr>
<td>Green foxtail</td>
<td>✓</td>
<td>4 MOA</td>
<td></td>
</tr>
<tr>
<td>Barnyardgrass</td>
<td>✓</td>
<td>7 MOA</td>
<td>✓ ACCase, thiocarbamates</td>
</tr>
<tr>
<td>Goosegrass</td>
<td>✓</td>
<td>4 MOA</td>
<td></td>
</tr>
<tr>
<td>Kochia</td>
<td>✓</td>
<td>3 MOA</td>
<td></td>
</tr>
<tr>
<td>Horseweed</td>
<td>✓</td>
<td>5 MOA</td>
<td>✓ glyphosate, paraquat</td>
</tr>
<tr>
<td>Smooth pigweed</td>
<td>✓</td>
<td>2 MOA</td>
<td></td>
</tr>
</tbody>
</table>

10 worst weeds from www.weedscience.org
Resistance trends

- PPO inhibit
- glycines

0 5 10 15 20 25 30 35 40 45 50 55 60
0 20 40 60 80 100 120
0 5 10 15 20 25 30 35 40 45 50 55 60
The future?
# Reported glyphosate resistance

<table>
<thead>
<tr>
<th>Species</th>
<th>Resistance USA</th>
<th>Resistance CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaranthus palmeri, A. rudis)</td>
<td>✔️ ✔️</td>
<td></td>
</tr>
<tr>
<td>Ambrosia artemisifolia, A. trifada</td>
<td>✔️ ✔️</td>
<td></td>
</tr>
<tr>
<td>Conyza bonariensis, C. canadensis</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>Digitaria insularis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Echinochloa colona</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Eleusine indica</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euphorbia heterophylla</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lolium multiflorum, L. rigidum</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
</tr>
<tr>
<td>Parthenium hysterophorus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantago lanceolata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum halapense</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Urochloa panicoides</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Rigid and Italian ryegrass

- Often co-exist (swarm)
- Annual grass
- Obligate outcrossers
- Throughout CA but more common weed in northern Central Valley
- 2 to 15-fold resistance
- Usually target site mutation
Figure 1. Map of California showing the geographical distribution of Italian ryegrass populations sampled for this study. Closed circles indicate populations with more than 20% seedlings surviving treatment with glyphosate t 866 g ae / ha; open circles indicate populations with 5% (two populations) or no surviving seedlings. Forty seedlings from each population were tested for glyphosate response.

Horseweed

- AKA mare’s tail
- Annual weed
- Prolific seed producer
- Wind-blown seed
- Early colonizer
- Doesn’t tolerate disturbance
- 6-fold resistance (whole plant)
- 4-8 fold resistance (in vivo)
- Mechanism not known. Suspected translocation mutation
Results
718 plants at 144 sites
-62% GR
-15% Intermediate
-23% GS

Hanson et al. 2009
Weed Sci 57:48-53
Hairy fleabane

- AKA flaxleaf fleabane
- Annual weed
- Wind-blown seed
- Early colonizer
- Doesn’t tolerate disturbance
- 3 to 10-fold resistance (whole plant screening)
- ~ 4-fold resistance in vivo
- Mechanism not known
Hairy fleabane survey - 2009

Prelim Results
75 populations
-27% GR
-52% Mixed
-21% GS

Zozaya et al. 2010
CWSS poster session
Junglerice
Selection pressure
Repeated use can select for resistant biotypes

- Any herbicide or other weed management tool

~41% of all herbicides in CA (lbs ai) are glyphosate!
Changes in glyphosate use

- Adoption of RR crops (early 90’s)
  - Corn, soybean, cotton, canola, alfalfa
  - Sugarbeet, wheat, bentgrass
- Increasing dependence on glyphosate in CA
  - RoundUp off patent in 2000 – price decrease
  - GWPA
  - Growers switching to POST weed management
    - Almond 2009: 740,000 bearing acres but 1.3 million acres treated with glyphosate!
## CA almond herbicide use

<table>
<thead>
<tr>
<th>Top 10 active ingredients</th>
<th>2009 treated acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 glyphosate</td>
<td>1,300,394</td>
</tr>
<tr>
<td>2 oxyfluorfen (Goal, Goaltender)</td>
<td>723,524</td>
</tr>
<tr>
<td>3 glufosinate (Rely)</td>
<td>271,135</td>
</tr>
<tr>
<td>4 paraquat (Gramoxone Inteon)</td>
<td>250,156</td>
</tr>
<tr>
<td>5 pendimethalin (Prowl)</td>
<td>167,689</td>
</tr>
<tr>
<td>6 2,4-D</td>
<td>152,455</td>
</tr>
<tr>
<td>7 oryzalin (Surflan, etc)</td>
<td>99,220</td>
</tr>
<tr>
<td>8 simazine (Princep, etc)</td>
<td>92,220</td>
</tr>
<tr>
<td>9 flumioxazin (Chateau)</td>
<td>90,718</td>
</tr>
<tr>
<td>10 carfentrazone (Shark)</td>
<td>68,360</td>
</tr>
<tr>
<td>11 rimsulfuron (Matrix)</td>
<td>52,577</td>
</tr>
</tbody>
</table>

* Mostly strip treatments!

740,000 A bearing almond (2010)
# CA walnut herbicide use

<table>
<thead>
<tr>
<th>Top 10 active ingredients</th>
<th>2009 treated acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. glyphosate</td>
<td>212,270</td>
</tr>
<tr>
<td>2. oxyfluorfen (Goal, Goaltender)</td>
<td>113,113</td>
</tr>
<tr>
<td>3. glufosinate (Rely)</td>
<td>46,773</td>
</tr>
<tr>
<td>4. paraquat (Gramoxone Inteon)</td>
<td>30,495</td>
</tr>
<tr>
<td>5. pendimethalin (Prowl)</td>
<td>24,329</td>
</tr>
<tr>
<td>6. 2,4-D</td>
<td>23,351</td>
</tr>
<tr>
<td>7. simazine (Princep, etc)</td>
<td>23,243</td>
</tr>
<tr>
<td>8. carfentrazone (Shark)</td>
<td>17,708</td>
</tr>
<tr>
<td>9. diuron (Karmex, etc)</td>
<td>16,887</td>
</tr>
<tr>
<td>10. oryzalin (Surflan, etc)</td>
<td>16,862</td>
</tr>
</tbody>
</table>

223,000 A bearing walnut
<table>
<thead>
<tr>
<th>Rank</th>
<th>Active Ingredient</th>
<th>2009 Treated Acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>glyphosate</td>
<td>203,808</td>
</tr>
<tr>
<td>2</td>
<td>glufosinate (Rely)</td>
<td>147,387</td>
</tr>
<tr>
<td>3</td>
<td>oxyfluorfen (Goal, Goaltender)</td>
<td>59,289</td>
</tr>
<tr>
<td>4</td>
<td>paraquat (Gramoxone Inteon)</td>
<td>49,012</td>
</tr>
<tr>
<td>5</td>
<td>pendimethalin (Prowl)</td>
<td>48,286</td>
</tr>
<tr>
<td>6</td>
<td>flumioxazin (Chateau)</td>
<td>44,232</td>
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<tr>
<td>7</td>
<td>2,4-D</td>
<td>24,736</td>
</tr>
<tr>
<td>8</td>
<td>oryzalin (Surflan, etc)</td>
<td>22,766</td>
</tr>
<tr>
<td>9</td>
<td>rimsulfuron (Matrix, Mana, etc)</td>
<td>21,267</td>
</tr>
<tr>
<td>10</td>
<td>trifluralin (Treflan, etc)</td>
<td>10,763</td>
</tr>
</tbody>
</table>

482,000 A wine grapes
83,000 A table grapes
221,000 A raisin grapes
Consider the cost

- Many residual herbicides cost more than burndown herbicides
  - But do they?
- Consider the full cost of repeated burndown applications?
  - active + adjuvants + machine costs + time
  - More mowing or tillage?
  - Timely weed control (wet winter/spring)
- Consider weed costs over several years
Cooperative research project recently initiated
  - UCD, UCCE, CSUF
Focus on screening, quantifying, and mapping, and identifying mechanisms of resistance in:
  - Junglerice (Echinochloa colona)
  - Barnyardgrass (Echinochloa crus-galli)
  - Common lambquarters (Chenopodium album)
  - Johnsongrass (Sorghum halepense)
  - Pigweeds (Amaranthus spp.)
    - 11 pigweed species with resistance, 7 different MOA
Preserving glyphosate

- Need to diversify weed management to preserve glyphosate as a tool
  - Genetics? Probably not soon in tree/vine crops
  - New herbicides? A few new products coming in tree/vine markets
  - Use PRE products in addition to POST
  - Alternate or combine POST materials
  - Use full rates
  - Mechanical (tillage, mowing, mulches?)
Creeping resistance

High level of target site resistance – not affected by dose
Weed shifts

- Glyphosate is BROAD spectrum but not COMPLETE spectrum
  - Some species not well controlled
    - Pigweeds, lambsquarters, morningglory, etc
- Dependence on glyphosate has resulted in many crops changing to a POST only program
  - Especially in RoundUp Ready crops
  - Also in tree and vine crops
Other “local” problem weeds

- Johnsongrass
- Bristly mallow
- Cutleaf evening primrose
- Witchgrass
- Sharp-point fluevellin
- Tall willowherb
- Others?
Current research program

- Methyl bromide alternatives
  - Alt. fumigants and non-fumigant solutions
- Orchard/vineyard weed management
  - Herbicide testing
  - Application technology
- Herbicide resistance
  - Management
  - Weed surveys, grower/PCA surveys
- Herbicide issues
  - Fate, drift, non-target effects
Current: resistance screening

- Collected weed seed from several perennial crop production areas and treat in the greenhouse

0X .25X .5X 1X 2X 4X 8X 16X
Resistance management
Drift management

- Prevent off-target movement of herbicides
  - Within and outside of the orchard
- Make sure your equipment is set up correctly
  - Nozzle choice
    - Size, design, drift reduction?
  - Operating pressure
  - Ground speed
  - Boom height
- Environment
  - Breeze, wind gusts, temperature, humidity
Some mistakes are minor...
...but some can be costly!
...some are REALLY costly!
Nozzle choice affects droplet size

- Directly affects:
  - Application uniformity
  - Spray coverage
  - Drift potential
- Which impacts:
  - Weed control efficacy
  - Economics
  - Environmental quality
Spray nozzles are a small but critical part of a spray system
  ▪ Highly engineered components for high performance
  ▪ Over-, under-, and variable-applications cost time, money, and efficacy
  ▪ Better quality nozzles may cost more initially but should last much longer
    ▪ Nozzle replacement is cheap compared to the investment in chemicals and application equipment!
# 2011 tree and vine crops herbicide registration chart

**Herbicide Registration on Horticultural Tree and Vine Crops—Oct. 2010**

<table>
<thead>
<tr>
<th>Herbicide/Common Name (example trade name)</th>
<th>Apricot</th>
<th>Peach</th>
<th>Plum</th>
<th>Prune</th>
<th>Pepper</th>
<th>Plum</th>
<th>Raspberry</th>
<th>Rasperry</th>
<th>Apricot</th>
<th>Cherry</th>
<th>Grape</th>
<th>Kiwi</th>
<th>Olive</th>
<th>Pomegranate</th>
</tr>
</thead>
<tbody>
<tr>
<td>diclobutis (Fusilade)</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
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<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>dinitro (Norda)</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
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<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>duron (Karmex, Duron)</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
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<td>EPTC (Eptam)</td>
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<td>N</td>
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<td>N</td>
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<td>N</td>
<td>N</td>
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</tr>
<tr>
<td>fenuron (Chateau)</td>
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<td>N</td>
<td>N</td>
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<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>flumioxazin (Opitab)</td>
<td>R</td>
<td>N</td>
<td>N</td>
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**Note:** This is a general guide to perennial crop herbicide registrations in California. Labels change frequently and often contain special restrictions; therefore you should always consult a current label before applying any herbicide.

- **N**: Not registered
- **NB**: nonbearing
- **R**: Registered
- *****: Several herbicides listed under preemergence also have some postemergence activity.
- **** Simazine is registered on only sour cherry in CA. Thiazygly is registered on orange and grapefruit only.

Weed susceptibility information can be found at the Weed Research and Information Center ([http://wric.ucdavis.edu/](http://wric.ucdavis.edu/))
“Wow – that IS pretty simple!”

Brad Hanson
bhanson@ucdavis.edu
530 752 8115

UC Davis Weed Research and Information Center
http://wric.ucdavis.edu/
http://ucanr.org/blogs/UCDWeedScience/

UC Davis Statewide Integrated Pest Management Program
http://www.ipm.ucdavis.edu/
Thanks