GENE DRIVES TO COMBAT OUR WORST WEEDS

Patrick J. Tranel
Overview

• Weed Science 101
• Why new weed control strategies are needed
• How gene drives could contribute to weed control
A soybean field without weed control
How do farmers control weeds?

- Cultural control
- Biological control
- Mechanical control
- Chemical control
Cultural control

30-inch row spacing

20-inch row spacing

Courtesy F. Below
Mechanical control
Chemical control
What do herbicides and antibiotics have in common?

- Contribute to human health and well-being
- Require careful risk/benefit analysis for approval
- Are expensive to discover and commercialize
- Can be misused and overused
- Lose effectiveness because of resistance
How do they differ?

• Response to antibiotic resistance:
  • Use them more wisely
  • Increase research funding and encourage development of new antibiotics

• Response to herbicide resistance:
  • Another reason why we shouldn’t use herbicides
  • Ag chemical companies created the problem, they should fund resistance research
Herbicide-resistant weeds globally

Number of cases

Year


Roundup Ready crops

I. Heap, www.weedscience.org
Weeds with multiple resistance

![Bar chart showing the number of species with multiple resistance against different numbers of herbicide groups.](image-url)
Two of the worst U.S. weeds

Palmer Amaranth
*Amaranthus palmeri*

- Ovate to Diamond Leaves (widest near the base)
- No Hair on Leaves or Stems
- Long Petioles (as long or longer than leaf)
- Spike Seedhead (very rough to the touch on female plants)

**Waterhemp**
*Amaranthus rudis*

- No Hair on Leaves or Stems
- Male Waterhemp
- Female Waterhemp
- Long lanceolate leaves
- Waxy leaf surface
Biological attributes

- Prolific seed producers
  - One million seeds per female
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL corn/soybean acres</td>
<td>22,000,000</td>
</tr>
<tr>
<td>% with waterhemp</td>
<td>75%</td>
</tr>
<tr>
<td>% with escapes in given year</td>
<td>5%</td>
</tr>
<tr>
<td>Escapes/acre</td>
<td>100</td>
</tr>
<tr>
<td>Potential seeds/escape</td>
<td>500,000</td>
</tr>
<tr>
<td>% of potential seed production</td>
<td>10%</td>
</tr>
<tr>
<td>% surviving/germinating next year</td>
<td>10%</td>
</tr>
<tr>
<td>New individuals to control each year</td>
<td>$4 	imes 10^{11}$</td>
</tr>
</tbody>
</table>
Biological attributes

- Dioecious (plants are either male or female)
Forced outcrossing promotes:

- Genetic diversity
- Evolution of herbicide resistance
- “Stacking” of multiple herbicide-resistance traits
Primary herbicides for broadleaf weed control in corn and soybean, and resistance status in waterhemp and Palmer amaranth

<table>
<thead>
<tr>
<th>Herbicide group</th>
<th>Resistance status</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALS inhibitors</td>
<td>*****</td>
</tr>
<tr>
<td>Auxins</td>
<td>*</td>
</tr>
<tr>
<td>Triazines</td>
<td>***</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>****</td>
</tr>
<tr>
<td>Glufosinate</td>
<td>?</td>
</tr>
<tr>
<td>PPO inhibitors</td>
<td>****</td>
</tr>
<tr>
<td>Chloroacetamides</td>
<td>*</td>
</tr>
<tr>
<td>HPPD inhibitors</td>
<td>**</td>
</tr>
</tbody>
</table>
$10 million spent one year in Arkansas for hand weeding Palmer amaranth

Weeding Palmer amaranth in Arkansas

Weeding waterhemp in Illinois

Courtesy J. Norsworthy

Courtesy P. Smith
How do farmers control weeds?

- Cultural control
- Biological control
- Mechanical control
- Chemical control
- Genetic control (?)
Genetic control: example from the insect world

- Sterile insect technique
  - Mass rear, sterilize with radiation, and release males

- Assisted in eradication of screwworm from the U.S.

- A great USDA success story… but it did not happen overnight
Could a similar approach be used to turn a strength of waterhemp and Palmer amaranth – being dioecious – into a weakness?

Introduce a dominant “maleness” gene

==> fewer females

==> fewer seeds produced
Modeling manipulation of gender in dioecious pigweed

Parameters:
- 20% seed bank decay
- 25% seed bank recruitment
- 0.025% seedling survival
- 14,400 seeds/female added to seed bank

No genetic control
Modeling manipulation of gender in dioecious pigweed

Single introduction
- 100 modified males/ha
- Each carrying 1 copy of male gene
Using gene drives for genetic control of weeds
What is a gene drive?

- A way to alter genetic inheritance
Inheritance of a single copy of a new gene
Inheritance with a gene drive
Gene drive mechanisms

- Based on naturally occurring “gene drives”
  - Transposable elements (i.e., “jumping genes”)
  - “Selfish” genes (genes that propagate themselves)

- Numerous gene drive systems have been proposed, primarily for insect control

- CRISPR/Cas9
  - Tool that enables targeting of specific genes
How could gene drives contribute to weed control?

• For dioecious species, a gene drive could enhance efforts to male-bias populations
Where are we at?

• Genes responsible for sex determination of waterhemp and Palmer amaranth not yet known

• Basic biology, particularly genomics, of weeds lags behind other pest disciplines
  • Genomes of waterhemp and Palmer amaranth just now becoming available

• Procedures for genetic manipulation of waterhemp and Palmer amaranth not yet available

• DNA markers specific to males in both species have been identified
  • USDA /NIFA
Other potential gene drives for weed control

• For species not dioecious, target reproduction to reduce seed or pollen production

• Reverse herbicide resistance
  • Use a gene drive to replace a herbicide-resistant version of a gene with a herbicide-sensitive version

• Create sensitivity to new, environmentally safe herbicides

• Reduce seed dormancy

• Reduce seed shattering
  • Use in conjunction with harvest-weed-seed destruction

• Reduce the negative impacts of weeds
  • Make plants shorter (less competitive)
  • Reduce allergenicity of ragweed pollen
Challenges and opportunities

• Gene drives will not work in predominantly self-pollinated species

• Gene drives will supplement, not replace, current weed control strategies

• Regulatory requirements, ecological impacts, social acceptance, etc. are important issues

• Extensive research (and funding) is needed to identify candidate genes, develop genetic transformation procedures, model outcomes, etc.
Comparison of published genomes
(From Ravet et al. (2018) Pest Manag Sci 74:2216)

- Plant pathogens: 275
- Arthropod pests of plants: >30
- Plants: 225
  - Of these, only 2 are significant U.S. weeds

Funding is needed for the basic research that will lead to novel weed control strategies... and to educate the next generation of scientists that can transcend boundaries of weed science, genomics, and bioinformatics.
Acknowledgments

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  – for inviting me

• National C-FAR
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• All of you
  – for listening!
Questions?