Forces Driving the Development of Herbicide-Resistant Weeds

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Overview

• What is resistance?

• What are the critical factors that affect the occurrence of herbicide-resistant weeds?

• What are the critical factors that affect their spread?
What is resistance?

Herbicide resistance is the inherited ability of a plant to survive and reproduce following exposure to a herbicide dose normally lethal to the wild type.

(Weed Science Society of America 1998)
The chronological increase in unique cases of herbicide-resistant weeds worldwide.

Source: Dr. Ian Heap
www.weedscience.cc
Herbicide-Resistant Weeds in Wisconsin

**ALS Inhibitors**

**ACCase Inhibitors**

**Triazine Herbicides**
How Does Selection For Herbicide Resistance Occur?

Susceptible Weed

Resistant Weed

Herbicide Sprayed

Resistant Plant Survives And Sets Seed

Herbicide Is Used On Weeds With More Resistant Plants

Eventually Majority Resistant

(Adapted from Gunsolus 1993)
What are the critical factors?

- **Mutation rate for resistance traits**
- **Initial frequency of resistant weeds**
  - Fitness of resistant weeds
- **Herbicide selection intensity**
  - Herbicide effectiveness and frequency of use
  - Fitness of resistant weeds
- **Inheritance of resistance traits**
- **Gene flow**
  - Outcrossing vs. selfing weeds
  - Seed and pollen dispersal
Mutation for Resistance

• **Where does resistance come from?**
  – Genetic variation in weed populations caused by mutation

• **What is mutation?**
  – A change in the genetic code of an organism
  – A spontaneous, **natural** process
  – **Not** associated with herbicide action

• **What are typical mutation rates?**
  – Estimates range from $10^{-4}$ to $10^{-12}$
PLANTS ARE HEALTHY

Enzyme A
Amino Acid Synthesis

Enzyme F
Fatty Acid Synthesis

PLANTS ARE KILLED

Herbicide A
Amino Acid Synthesis

Herbicide F
Fatty Acid Synthesis

(Gunsolus 1993)
Effect of mutation rate and weed density on the probability of at least one resistant weed occurring in a 75-acre field

<table>
<thead>
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<th>Mutation rate</th>
<th>Weed density</th>
<th>Probability</th>
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<tbody>
<tr>
<td></td>
<td>Weeds/10 ft²</td>
<td>Weeds/75 acres</td>
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<tr>
<td>$10^{-6}$</td>
<td>1</td>
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(Adapted from Jasieniuk et al. 1996)
Frequency of Resistant Weeds

- **Initial frequency of resistant weeds**
  - Determined by mutation rate and **fitness**
    - *Fitness refers to reproductive success over time*
  - Initial frequency \( \leq \) mutation rate
  - Affects the rate of resistance development

- **Frequency of resistant weeds over time**
  - Initial frequency interacts with herbicide selection intensity to greatly affect rate of development
Herbicide Selection Intensity

• What is it?
  – An indicator of the effective kill of weeds by a herbicide

• How is it measured?
  – Reduction in weed seed yield
    • Very strong selection intensity: \( s = 99\% \)
    • Strong selection intensity: \( s = 90\% \)
    • Moderate selection intensity: \( s = 75\% \)

• How important is it?
  – Prediction models show that it is one of the most important factors that determines the rate of resistance development
Figure A: Initial Frequency of R alleles with different initial frequencies as indicated.

Figure B: Frequency of Resistant Plants over time with different selection coefficients: s=0.99 and s=0.75.
Effect of Herbicide Rotation and Selection Intensity on Frequency of Resistant Weeds

R and S weeds are equally fit
Effect of Herbicide Rotation and Selection Intensity on Frequency of Resistant Weeds

R weeds are 75% as fit as S weeds

(Jasieniuk et al. 1996)
Inheritance of Resistance Traits and Gene Flow

• **Types of Inheritance**
  – Dominant, nuclear alleles are most common
  – Recessive alleles are rare
  – Cytoplasmic alleles are typical for resistance to triazine herbicides

• **Why is this important?**
  – Nuclear alleles occur in seed and pollen

• **Gene flow**
  – The movement of resistance alleles
  – Outcrossing vs. selfing species
  – Pollen vs. seed dispersal
Glycine-Restricted Horseweed

• Why such a rapid increase in occurrence since 2000?
  – Herbicide selection intensity
    • Widespread adoption on no-tillage, glyphosate-resistant soybeans
  – Reproductive biology
    • Outcrossing can occur
      – transfer of resistance trait in pollen
    • Prolific seed production
    • Wind dispersal of seeds

(Heck et al. 2002; VanGessel 2001)
Monogenic vs. Polygenic Resistance

(Preston and Roush 1998)
Common Waterhemp: Resistant to Glyphosate?

Iowa, Illinois, Missouri

- Inconsistent control in several fields
- Individual plants within populations survive exposure to glyphosate
  - varies among experiments
  - varies with methodology
- Resistance appears to be heritable, but complex, likely polygenic
- Inheritance poorly understood
- Mechanism of resistance unknown

Hartzler et al. 2002; Owen 2002; Smeda and Schuster 2002)
Summary

• Several critical factors affect resistance
  – Mutation rate for resistance alleles
  – Initial frequency of resistance plants
  – Herbicide selection intensity
  – Inheritance of resistance alleles
  – Gene flow
  – Fitness of resistant weeds

• Accurate prediction of resistance is difficult

• Practices can be adopted to reduce the selection intensity for weed resistance to herbicides
  – Effective management, using a diversity of practices