
Theodore M. Webster
Crop Protection & Management Research Unit
USDA-Agricultural Research Service, Tifton, GA
Weeds

• “Weeds are among the greatest contributors to production costs on American farms. The losses caused by weeds on farms in the US have now reached an estimated $4 billion annually. These losses are estimated to equal the combined losses from insects and diseases…”

  Warren Shaw, USDA-ARS, November 1954

• Herbicides are the primary means of weed control in the US
A grower’s field in Macon County, GA

Glyphosate 4X rate to 2.5 cm
Glyphosate 4X rate to 10 cm
Glyphosate 4X rate to 30 cm*
1st Herbicide Resistant Weeds

1957: 2,4-D resistance in Wild Carrot

1970: triazine resistance in Common Groundsel
Occurrence of 14 GR weeds in the US

Source: International Survey of Herbicide Resistant Weeds (www.weedscience.org)

*
Herbicide Resistance

- **Palmer amaranth**
  - Glycine (e.g. Roundup)
  - ALS-inhibitors (e.g. Staple, Cadre, Pursuit)
  - Dinitroanilines: (e.g. Prowl, Treflan)
  - Triazines (e.g. Atrazine, Simazine)

- **Waterhemp**
  - PPO-inhibitors (e.g. Reflex, Blazer, Cobra)
  - HPPD inhibitors
  - Multiple Resistance: PPO+ALS+Triazines
Why herbicide resistance?

• Dramatic Change in Selection Pressure

• Selection pressure is anything used to alter the ability of the weed to survive
  – Not Weed specific
  – Not Herbicide specific
    • Lack of tillage and perennial weeds
    • Mowing will kill many weeds, but dandelions tolerate it

• 2 Key Principles (Harper 1956)
  – Reducing the intensity of selection
  – Preventing reproduction and survival
Changes in Herbicide use patterns in GR Crops

• Adoption of GR crops often associated with:
  – Ceasing use of other herbicides
  – Reducing tillage (strip till cotton reduces preharvest labor costs 30%)
  – Relying almost exclusively on glyphosate
  – Growing more cotton (in GA)

• Glyphosate provides better, cheaper, and more flexible weed management than alternatives

“...Of much greater significance and practical importance are the changes in ecological relationships as a result of the use of herbicides.”

“In the North Central US, 2,4-D is used for the control of weeds in over 8 million acres of corn annually. The weedy grasses and many serious broadleaved weeds are not controlled by the treatments. As a result the broadleaved annual weeds are decreasing and the grasses are increasing, presenting a different and in many cases a more difficult weed problem than the original.”
Herbicide Resistant Weeds in the US

<table>
<thead>
<tr>
<th>Mechanism of action</th>
<th>Group #</th>
<th># of biotypes</th>
<th># of weed spp.</th>
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<tbody>
<tr>
<td>ACCase</td>
<td>1</td>
<td>34</td>
<td>13</td>
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<tr>
<td>ALS</td>
<td>2</td>
<td>121</td>
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<td>Auxins</td>
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<td>12</td>
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<td>Carotenoid biosynthesis</td>
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<td>Chloroacetamides</td>
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<td>1</td>
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<tr>
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<td>39</td>
<td>9</td>
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<tr>
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<td>3</td>
<td>1</td>
</tr>
<tr>
<td>PS I</td>
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<td>5</td>
<td>4</td>
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<tr>
<td>PS II (nitriles)</td>
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<tr>
<td>PS II (triazines)</td>
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<td>25</td>
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<tr>
<td>PS II (ureas)</td>
<td>7</td>
<td>11</td>
<td>7</td>
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<tr>
<td>Thiocarbamates</td>
<td>8</td>
<td>6</td>
<td>5</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>347</strong></td>
<td><strong>119</strong></td>
</tr>
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</table>
“We must protect, conserve, and use that technology wisely, or we’ll lose it...we must be good stewards of that technology and use it the right way...” (Culpepper, Cotton Farming Aug 2008)

Stewardship is the sum of the management decisions and practices that are used to preserve the utility of a weed management option (Owen 2007)
Stewardship Awareness?

• Awareness does not always lead to proactive management:
  
  – Grower awareness of herbicide resistance issues in Canada was high (90%)
  
  – Growers that altered their weed control strategies based on this knowledge was low (40%)
  
  – Weed control performance and cost are often of greater importance than site of action when selecting a herbicide (Beckie 2006)

Goodwin 1994
Constraints of Stewardship?

1. Belief that new technology will be developed to solve the resistance problem
   - Growers with this belief were less likely to adopt resistance avoidance strategies relative to those with greater uncertainty (Llewellyn et al. 2007).

   - Precedence:
     - Triazine-R weeds “solved” by new ALS and ACCase
     - ALS-R and ACCase-R weeds “solved” by glyphosate.
     - No new mode of action since 1998.
       - 1946 to 1955: 23 new herbicides
       - 1956 to 1965: 62
       - 1966 to 1975: 74
       - 1976 to 1985: 80
       - 1986 to 1995: 96
       - 1996 to 2006: <20
Constraints of Stewardship?

2. Belief that resistance strategies are futile

- Western Australia: 70% of growers surveyed believed they gained herbicide resistant weeds from neighboring farms through seed or pollen movement (Llewellyn and Allen 2006)

- Ohio farmers attributed weed introductions from natural elements, with 23% specifically citing movement from neighbors’ poorly managed fields (Wilson et al. 2008)


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Executive Summary

Herbicides are the foundation of weed control in commercial crop-production systems. However, herbicide-resistant (HR) weed populations are evolving rapidly as a natural response to selection pressure imposed by modern agricultural management activities. Mitigating the evolution of herbicide resistance depends on reducing selection through diversification of weed control techniques, minimizing the spread of resistance genes and genotypes via pollen or propagule dispersal, and eliminating additions of weed seed to the soil seedbank. Effective deployment of such a multifaceted approach will require shifting from the current concept of basing weed management on single-year economic thresholds.

Programs for herbicide-resistance management must consider the long-term strategy for weed control, including planning for the use of non-herbicide methods such as crop rotation, mechanical cultivation, and biological control. Effective management programs must also consider the economic and environmental implications of herbicide resistance on the overall sustainability of agricultural systems.

3. Plant into weed-free fields and then keep fields as weed free as possible.
4. Plant weed-free crop seed.
5. Scour fields routinely.
6. Use multiple herbicide mechanisms of action (MOAs) that are effective against the most troublesome weeds or those most prone to herbicide resistance.
7. Apply the labeled herbicide rate at recommended weed sizes.
8. Emphasize cultural practices that suppress weeds by using crop competitiveness.
9. Use mechanical and biological management practices where appropriate.
10. Prevent field-to-field and within-field movement of weed seed or vegetative propagules.
11. Manage weed seed at harvest and after harvest to prevent a buildup of the weed seedbank.
12. Prevent an influx of weeds into the field by managing field borders.
BMP 1: Understand the Biology of the Weeds Present

• Prediction of Germination/Emergence:
  – Coordinate Tactics
  – Sequence usually consistent: phenology studies
    • 25% SETFA emerged @ red chokeberry first bloom
    • 80% SETFA emerged @ multiflora rose full bloom
Emergence is relatively late in the growing season relative to most other agronomic summer annual weeds.

The Bulk of emergence occurs in July

Allowed the use of Dual Magnum applied POST to cotton, PRE to the weed.

Benghal dayflower emergence (% of total season emergence)

May-cotton 2004
May-cotton 2005
June-cotton 2004
No-crop May 2005
No-crop June 2005
BMP 1: Understand the Biology of the Weeds Present

• Germination/Emergence Requirements

• Reproductive Biology:
  – Breeding system may regulate speed of HR
  – How many seed?

• Timing of Reproduction:
  – When does it flower?
  – Viable seed?
    • Waterhemp pollination + 10d
    • Benghal dayflower: 42 d – seedling to seed

Webster, USDA-ARS, Tifton, GA

*
Challenges: BMP 1

• Funding for this research is limited.
• Must economize through functional groups
• Requires us to identify the appropriate biological characteristics by which we can group weeds.
BMP 2: Diversified Approach to Weed Management Focused on Reducing Weed Seed Production and the Number of Weed Seeds in the Soil Seedbank

• *One year’s seeding, seven year’s weeding…Seedbanks are persistent*
Sosnoskie et al. 2013 (Weed Sci., *in press*)

**Graph:**
- **Y-axis:** Viable Palmer amaranth seed (%)
- **X-axis:** Time of burial (months)

- **Legend:**
  - GR 1 cm
  - GS 1 cm

**Key Observations:**
- At 12 months, approximately 44% of Palmer amaranth seeds remain viable.
- At 36 months, approximately 9% of Palmer amaranth seeds remain viable.

*Note:* The graph shows the percentage of viable Palmer amaranth seeds over time, with data points indicating a decrease in viability with increased burial duration.
BMP 2: Diversified Approach to Weed Management Focused on Reducing Weed Seed Production and the Number of Weed Seeds in the Soil Seedbank

- One year’s seeding, seven year’s weeding... Seedbanks are persistent
- Seedbanks reduced 95% after 5-years of weed-free management, but...
Hand weed

Slide from Stanley Culpepper, UGA
Seed Production

This is an improvement, but is it sufficient?

Intact plant: 435,000
Cut to 6 inches: 116,000
Cut to 1 inch: 28,000
Cut at Ground Level: 700

-73%  -94%  -99%
Challenges: BMP 2

• Eradication of seedbanks is difficult...a goal that growers have tried to attain throughout history.

• I question our ability to prevent seed return over large areas of land that contain diverse, long-lived, dormant soil seedbanks.
BMP 3: Plant into Weed-Free Fields and Keep Fields as Weed-Free as Possible

• Once emerged (weed and crop) the management options are dramatically reduced.

• ↑Emphasis on residual herbicides (Georgia)
  • Valor burndown
  • Warrant + Reflex PRE
  • Roundup + Staple POST1
  • Roundup + Dual Magnum POST2
  • Direx + MSMA Layby

• Get crop established ASAP; dense crop canopy will suppress weed emergence
Challenges: BMP 3

- Restrictions to ensuring a weed-free seedbed:
  - Conservation tillage programs
  - Local ordinances on burning fields
- Irrigation/Rainfall may be needed to move herbicides into germination zone
BMP 4: Plant Weed-Free Crop Seed

• Initial step in preventing the introduction of new weeds

• Utah Wheat: 14% of seed samples had wild oat contamination of 21 seed/2.2 lb sample

• Australian Wheat shipped to Japan: 4500 HR ryeagrass seed in 440 lb sample

Dewey & Whitesides 1990

Shimono et al. 2010
Challenges: BMP 4

• **Proper cleaning of grower-saved seed**

• **Convincing growers of cotton, soybean, rice, and wheat to forego saving seed (and money) and instead plant purchased seed**
BMP 5: Scout Fields Routinely

• **Timely scouting:** maintain an inventory of weed spp., location, density, & size.
  – **Before:** to determine what tools
  – **After:** to evaluate efficacy and ID problems

• **Early detection and Rapid Response to problems.**
Distribution of Glyphosate-Resistant Palmer amaranth

One field in one county in Georgia in 2004

50% of upland cotton acres (13.4 million) in the US in 2010.

Map credit: Dr. Bob L. Nichols, Cotton Incorporated
Challenges: BMP 5

- Scouting is time-consuming and costly
- Resistance management is an ever-changing process
- Proper training in weed ID is crucial
BMP 6: Use Multiple, Effective MOAs against the Most Troublesome Weeds and Those Prone to Herbicide Resistance

• Herbicides are often the strongest selection agents for weed species in a cropping system.

• Rapid increase in proportion of HR weeds with repeated use of MOA

• Models suggest diversity…
  – Tank mixes vs. sequential

Webster, USDA-ARS, Tifton, GA
Challenges: BMP 6

- **Increased short-term costs**
  - 2000-2005: Herbicide costs = $32.30/A
  - 2006-2010: Herbicide costs = $62.50/A

- Matching MOA’s of similar efficacy with weed spectrum.

- Herbicide antagonism

- Smaller herbicide toolbox
BMP 7: Apply the Labeled Herbicide Rate at Recommended Weed Sizes

• Contrary to the European model

• Do not reduce herbicide rates:
  – Long-established tenet of crop breeding
  – Polygenic resistance is greater risk
Multi-Drug Resistance

MRSA

Staphylococcus aureus (hospital isolates): percentage of methicillin-resistant strains, 2007, Latin America and the Caribbean

*Including countries that did not report any information or reported less than 10 isolates

Multidrug-resistant tuberculosis (MDR-TB)

Key findings:
- Proportion of TB cases with drug-resistance: about 3.7% of new tuberculosis (TB) patients in the world have multidrug-resistant strains (MDR-TB). Levels are much higher in those previously treated—about 20%. The frequency of MDR-TB varies substantially between countries.
- MDR-TB case-load: WHO estimates that between 220,000 and 400,000 MDR-TB cases occur among TB cases notified in the world in 2011. About 60% of these cases occur in Brazil, China, India, the Russian Federation and South Africa.

Percentage of patients with *P. falciparum* parasitaemia on day 3 after treatment with an artemisinin-based combination therapy (2006-2010)

Treatment failure:
- < 3%
- 3-9.9%
- 10-19.9%
- 20-39.9%
- ≥ 40%

BMP 7: Apply the Labeled Herbicide Rate at Recommended Weed Sizes

• Contrary to the European model

• Do not reduce herbicide rates:
  – Long-established tenet of crop breeding
  – Polygenic resistance is greater risk

• Treat proper weed sizes

Webster, USDA-ARS, Tifton, GA
Palmer amaranth: Glyphosate-resistance comes to Georgia

Glyphosate 1X rate, 2 d after application to 41 cm Palmer amaranth
Weed Management in Glufosinate-Tolerant Cotton

- Timing is critical!
- 3 to 4 inches for consistent Palmer control

This is not a 4-inch pigweed!

Slide from Stanley Culpepper, UGA
Challenges: BMP 7

- Perceived and real risks to using herbicides.
- Crop phytotoxicity: labels will need to reflect Extension Recommendations
- Concern with minor-use crops
- Timely applications to target specific weed sizes
- Can be difficult to ensure adequate coverage
BMP 8: Emphasize Cultural Management Techniques that Suppress Weeds by Using Crop Competitiveness (BMP’s)

- Planting time
- Competitive varieties
- Seeding rate
- Row spacing
Challenges: BMP 8

• Principles adaptable to most any cropping system…

• Not *Once Size Fits All*, but instead a part of an Integrated Pest Management system
  – Complex
  – Trial and Error

• Hurdles:
  – Equipment
  – Increased seed cost per area
BMP 9: Use Mechanical and Biological Management Practices Where Appropriate

• Tillage changed regularly to avoid dominance by any particular species:
  – Reduced tillage:
    • ↑ perennials, small seeded BL’s, annual grasses
    • ↑ in # and diversity of weed species
  – Conventional tillage:
    • ↑ large seeded-BL’s
BMP 9: Use Mechanical and Biological Management Practices Where Appropriate

• Tillage changed regularly to avoid dominance by any particular species

• Mulches: can suppress weeds, but…

Webster, USDA-ARS, Tifton, GA
Black Mulch Promotes Purple Nutsedge Growth

3440 Shoots

Purple Nutsedge
Black LDPE Mulch

18 Feet

Northing (cm)

Northing (cm)

Webster, USDA-ARS, Tifton, GA

1860 Shoots

Purple Nutsedge
Non-mulched control

24 Feet

Easting (cm)

Easting (cm)
BMP 9: Use Mechanical and Biological Management Practices Where Appropriate

• Tillage changed regularly to avoid dominance by any particular species

• Mulches

• Winter cover crops
  – Weed emergence inversely related to rates of mulch residue (Putnam & Defrank 1983; Teasdale & Mohler 2000)
Relatively small-seeded species

- Common cocklebur
- Ipomoea morningglory
- Sicklepod

Coffee senna  Palmer amaranth  Common ragweed  Florida beggarweed

*
• Reduces population / selection pressure
• Uniform cover crop mat
• Still require herbicides
• Need herbicides that are not bound to cover crop
Challenges: BMP 9

• Mechanical control requires specialized equipment and skilled labor
• Tillage operations vs. soil conservation programs
• Synthetic mulches are $$$ (+disposal)
• Cover crops = no marketable crop
BMP 10: Prevent Field-to-Field and Within-Field Movement of Weed Seed and Vegetative Propagules

• Natural seed dispersal limited to <15 ft from the mother plant, with exceptions…

• Handweeding
2000-2005:
17% of Georgia growers hand-weeded
5% cotton acres at $2.40/A

2006-2010:
92% of Georgia growers hand-weeded
52% cotton acres at $23.70/A

Photo by Eric Prostko, UGA Extension
BMP 10: Prevent Field-to-Field and Within-Field Movement of Weed Seed and Vegetative Propagules

- Natural seed dispersal limited to less than 5 m from the mother plant
- Handweeding
- Equipment and gin trash and manure
Cotton Gin Trash
BMP 10: Prevent Field-to-Field and Within-Field Movement of Weed Seed and Vegetative Propagules

- Seed dispersal limited to less than 5 m from the mother plant
- Handweeding
- Equipment and gin trash and manure
- Animals
  - Fire ants and Common ragweed
  - Benghal dayflower
Challenges: BMP 10

• Complex and costly
• Rented land
  – 38% nationwide
  – 50% in Midwest and Mississippi Delta
  – Returns: Immediate vs. Long-term
• Sanitation between fields and farms
• Preventative tactics…I told you so!
• Ohio Farmers: sources of new weeds
  – Wind (97%)
  – Wildlife (87%)
  – Birds (80%)
BMP 11: Manage Weed Seed at Harvest and Post-Harvest to Prevent Buildup of the Weed Seedbank

- Weed seed “rain”:
  - 30 to 45% before harvest
  - 30 to 45% expelled from harvester
  - 10 to 25% retained with grain

- Seed collection and destruction @ harvest
Weeds present at harvest are good indicators of next year’s weed issues.
Photos by April Noble and Joseph Berger
(from www.Bugwood.org)
Challenges: BMP 11

• Development of technology to “consume seed”

• Predictions of “seed rain”

• What factors enhance seed herbivory?
Recommendations for Adoption of BMP’s

1. Reduce the Weed Seedbank through Diversified Programs that Minimize Weed Seed Production.
Adoption of Diverse Control Tactics is Crucial in Resistance Management

Slide from Stanley Culpepper, UGA
Recommendations for Adoption of BMP’s

1. Reduce the Weed Seedbank through Diversified Programs that Minimize Weed Seed Production.

2. Implement a Herbicide-MOA Labeling System for All Herbicide Products, and Conduct an Awareness Campaign.
Group #’s beginning to appear…but it’s not yet standard
Recommendations for Adoption of BMP’s

3. Communicate that Discovery of New, Highly Effective Herbicide MOA’s is Rare and that Existing Herbicide Resource is Exhaustible.

4. Demonstrate the Benefits and Costs of Proactive, Diversified Weed Management Systems for the Mitigation of HR Weeds.
Recommendations for Adoption of BMP’s

5. Foster the Development of Incentives by Government Agencies and Industry that Conserve Critical Herbicide MOA’s as a Means to Encourage Adoption of Best Practices.

6. Promote the Application of Full, Labeled Rates at the Appropriate Weed and Crop Growth Stage.

Webster, USDA-ARS, Tifton, GA
Recommendations for Adoption of BMP’s

7. Identify and Promote Individual BMP’s that Fit Specific Farming Segments with the Greatest Potential Impact.

8. Engage the Public and Private Sectors in the Promotion of BMP’s, Including Those Concerning Appropriate Herbicide Use.
Recommendations for Adoption of BMP’s
