Weed ecology and management for organic production

Erin Haramoto
Department of Horticulture
Michigan State University
Outline

• Let’s talk experiments…
• Lecture stuff
  1. Impacts of weeds
  2. Ecological weed management principles
  3. Integration ➔ Management strategies
1. Impacts of weeds

A. Yield loss!
B. Interfere with harvest
C. Pest interactions
D. Time, labor, and money spent controlling
   1. Herbicide use in our conventional farming systems
   2. Developing world
   3. Organic farms...???
1a. Impacts of weeds—yield loss

- What percentage of all pesticides used in U.S. are herbicides?
  >60%

- Estimates of average crop yield losses due to weeds range from 12-25% (Pimentel et al. 2000; Parker and Fryer 1975).

And this is WITH weed control measures!!!
1A. Impacts of weeds: Yield loss

..but results vary!!
1B. Impacts of weeds:
Harvest efficiency and indirect effects

Saginaw area; pepper harvest
1C. Impacts of weeds: Pest interactions

Tarnished plant bug on Powell amaranth (*Amaranthus powellii*) in asparagus
1D.1 Impacts of weeds: Herbicide use in the US

Total pesticide use on major crops, 1964-2001

Million pounds of ai

Source: Economic Research Service
1D.2 Impacts of weeds: Developing world

In the developing world, more human labor is expended on weeding than any other single human activity (Zimdahl 1993).
1D.3 Impacts of weeds: Organic farms

On organic farms in U.S., weeds are generally considered the worst pest problem (OFRF 1999; Bond and Grundy 2001)
Organic asparagus—Oceana County, MI
1D.3 Impacts of weeds: Costs of management

50 hrs/A in direct seeded organic carrots—what do you pay your labor?
### Amount of manual weeding needed

<table>
<thead>
<tr>
<th>Crop</th>
<th>Management</th>
<th>Hour/ha (NL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onion</td>
<td>direct-sown</td>
<td>177</td>
</tr>
<tr>
<td>Carrot</td>
<td>direct-sown</td>
<td>152</td>
</tr>
<tr>
<td>Sugarbeet</td>
<td>direct-sown</td>
<td>82</td>
</tr>
<tr>
<td>Sugarbeet</td>
<td>transplanted</td>
<td>28</td>
</tr>
<tr>
<td>Vegetables</td>
<td>transplanted</td>
<td>46</td>
</tr>
<tr>
<td>Cereals</td>
<td>direct-sown</td>
<td>7</td>
</tr>
</tbody>
</table>

- **Costs**
- **Organization**
- **Availability**
2. Ecological Weed Management

• groundwork: Characteristics of weeds
• Come up with 8-10 characteristics of weeds… what makes them “weedy”? Why are they so difficult to control? How are they similar to/different from insect pests?
2. Ecological weed management

A. **Apply knowledge of weed life cycles** to identify and target weak points

B. **Prevention** easier than treatment

C. **Thresholds**: know when a weed is likely to cause problems, and when it can be left alone.

D. **“Many little hammers”**: Use multiple tactics to maximize effectiveness and minimize risks
2A. Annual weed life cycle

- Emergence
- Seed germination
- Establishment and growth
- Seed dispersal
- Seed burial
- Seed production

"Weed seedbank"
2A. Weed life cycles

- Summer vs winter annuals
- Biennials
- Perennials
2A. Case study: Corn chamomile in peas

"Daisy"
Anthemis arvensis

Flower bud contaminant
Rejected by processor

Management in peas difficult
### Typical NY pea rotation

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Fall</td>
<td>Spring</td>
</tr>
<tr>
<td>Peas</td>
<td>Wheat</td>
<td>Sweet corn</td>
</tr>
<tr>
<td>Summer</td>
<td>Winter</td>
<td>(spring)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clover</td>
</tr>
<tr>
<td>Fall</td>
<td>Winter</td>
<td>(spring)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(fall)</td>
</tr>
<tr>
<td>Winter</td>
<td></td>
<td>(fall)</td>
</tr>
</tbody>
</table>

**Problem occurs here...**

...but when and how to best manage?
Corn chamomile in peas: Where is seed production occurring?
Results: Estimated seed production in rotational crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>1,000/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>0.0</td>
</tr>
<tr>
<td>Peas</td>
<td>0.1</td>
</tr>
<tr>
<td>Wheat</td>
<td>10.0</td>
</tr>
</tbody>
</table>

→ Prevention in peas requires better management in wheat
<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring Summer</td>
<td>Fall Winter</td>
<td>Spring Summer</td>
</tr>
<tr>
<td>Peas</td>
<td>Wheat</td>
<td></td>
</tr>
</tbody>
</table>

Prevention best achieved here—these individuals producing most seed

Problem occurs here….
### Corn chamomile in rotation

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Spring</td>
<td>Spring</td>
</tr>
<tr>
<td>Summer</td>
<td>Summer</td>
<td>Summer</td>
</tr>
<tr>
<td>Fall</td>
<td>Fall</td>
<td>Fall</td>
</tr>
<tr>
<td>Winter</td>
<td>Winter</td>
<td>Winter</td>
</tr>
</tbody>
</table>

- **Year 1**: Peas, Wheat
- **Year 2**: Clover
- **Year 3**: Sweet corn

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**Case where costs of cover crop outweigh benefits??**
2. Ecological weed management

A. Apply knowledge of pest life cycles to identify and target weak points

B. Prevention better than treatment

C. Thresholds: know when a weed is likely to cause problems, and when it can be left alone.

D. “Many little hammers”: Use multiple tactics to maximize effectiveness and minimize risks
Future costs of seed production

“One year’s seeding, seven years weeding”

Brainard 2002
2. Ecological weed management

A. Apply knowledge of pest life cycles to identify and target weak points

B. Prevention better than treatment

C. Thresholds: know when a weed is likely to cause problems, and when it can be left alone.

D. “Many little hammers”: Use multiple tactics to maximize effectiveness and minimize risks
2.C Thresholds
2.C Thresholds—peer-generated data!

Data from HRT 341, Spring 2013
2.C Thresholds

Weed density (#/flat)

Profit ($/acre)

Making money

Theoretical weed free profit

Losing money

Convert to economic terms—basically inverting the yield loss curve

barnyard grass

mustard

Making money

Losing money

Convert to economic terms—basically inverting the yield loss curve
2.C Thresholds

Weed density (#/flat)

Profit ($/acre)

Weed free profit - $500/acre for control measures

- barnyard grass
- mustard
2.C Thresholds

- **Profit ($/acre)** vs. **Weed density (#/flat)**

Graph showing the relationship between profit and weed density for barnyard grass and mustard.
2C. Temporal thresholds—critical weed free periods

Idea: Weeds emerging really early in a growing season may not have sufficiently negative effect to justify weeding—biomass not enough to compete with crop.

Question: How long until you need to start weeding?

Typical experiment: Keep field weedy for different durations following crop emergence and then start controlling weeds. Evaluate crop yield.
2C. Temporal thresholds—critical weed free periods

[Graph showing the relationship between time spent weed free and yield.]

Time spent weed free (until weed control stops)

yield
2C. Temporal thresholds—critical weed free periods

Idea: Weeds emerging late in a growing season may not have sufficiently negative effect to justify weeding.

Question: At what point does it make sense to let weeds go?

Typical experiment: Keep field weed-free for different durations following crop emergence and then let weeds go. Evaluate crop yield.
2C. Temporal thresholds—critical weed-free periods

Time spent weedy (until weed control starts) vs. yield
2C. Temporal thresholds—critical weed free periods

*Combine these two curves*

- **Yield (kg m\(^{-2}\))**
  - 0
  - 2
  - 4
  - 6
  - 8
  - 10
  - 12

- **Time after cabbage emergence (weeks)**
  - 0
  - 5
  - 10
  - 15

- **Critical period**

- **Weeds tolerated**
- **Weeds controlled**
2C. Problems with weed threshold concept?

– Often not host specific. 100s of weeds, more difficult to establish thresholds for all.

– Weed density can be very patchy in fields… how to sample? Different than pheremone traps for insects because weeds are not mobile.

– Density not tightly linked to competitiveness since
  • Unlike insects, one weed can be many different sizes and hence inflict different levels of damage
  • Seed production. Not controlling a weed can result in direct future yield losses via seed production

– Timing may be more important than density…
2. Ecological weed management

A. Apply knowledge of pest life cycles to identify and target weak points

B. Prevention better than treatment

C. Thresholds: know when a weed is likely to cause problems, and when it can be left alone.

D. “Many little hammers”: Use multiple tactics to maximize effectiveness and minimize risks
2D. “Many little hammers”

1. Mechanical
2. Cultural
3. Biological
4. Chemical
Most organic growers currently rely on mechanical weed management
2D.1 Cultivation

Rotary Hoe

Inter-row cultivation
2.D.1 the favorite cultivation tool of organic farmers...

Image searching for “types of hoes” isn’t as bad as you think
2D.1 Cultivation efficacy in organic snap beans
2D.1 Problems with cultivation?
2D. “Many little hammers”

1. Mechanical

Weeds

2. Cultural

3. Biological

4. Chemical
2D.2 Cultural control

1. Grow healthy competitive crops
2. Utilize crop rotations to break weed life cycles
3. Manipulate weed seed germination
   - Stale/false seed bed
   - Delayed emergence
4. N fertility management
2D.2.1 Cultural Weed Control: Grow Healthy Competitive Crops

- Select competitive resistant varieties
- Provide optimal growing conditions
- Irrigate and fertilize crop, not weeds
- Transplant to give crop head-start
- Increase planting density and planting uniformity
2D.2.1 Crop density and spatial uniformity effects on weeds in spring wheat cultivation?
2D.2.2 Cultural Weed Control: Crop Rotation

- Life cycles of problematic weeds often match life cycles of crops
- Crop rotation can help reduce weed problems by disrupting weed life cycles
2D.2.2 Crop rotation: Downy brome in wheat

*Figure 7.2* Density of *Bromus tectorum* plants in winter wheat grown in rotation with rapeseed or in continuous monoculture, with or without tillage, in an experiment conducted in Alberta, Canada. (Adapted from Blackshaw, 1994.)
### Table 2. Persistence of common weed seeds in the soil seedbank.

<table>
<thead>
<tr>
<th>Weed species</th>
<th>Years required for 50 percent reduction in seed number</th>
<th>Years required for 99 percent reduction in seed number</th>
</tr>
</thead>
<tbody>
<tr>
<td>common lambsquarters</td>
<td>12</td>
<td>78</td>
</tr>
<tr>
<td>velvetleaf</td>
<td>8</td>
<td>56</td>
</tr>
<tr>
<td>field pennycress</td>
<td>6</td>
<td>38</td>
</tr>
<tr>
<td>common cocklebur</td>
<td>6</td>
<td>37</td>
</tr>
<tr>
<td>yellow foxtail</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>prostrate knotweed</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>Pennsylvania smartweed</td>
<td>4</td>
<td>26</td>
</tr>
<tr>
<td>redroot pigweed</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>annual bluegrass</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>shepherd's-purse</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>chickweed</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>curly dock</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>common waterhemp</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>common groundsel</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>ivy leaf morningglory</td>
<td>&lt;2</td>
<td>11</td>
</tr>
<tr>
<td>barnyardgrass</td>
<td>&lt;2</td>
<td>10</td>
</tr>
<tr>
<td>common ragweed</td>
<td>&lt;1-1/2</td>
<td>10</td>
</tr>
<tr>
<td>large crabgrass</td>
<td>&lt;1-1/2</td>
<td>8</td>
</tr>
<tr>
<td>wild mustard</td>
<td>&lt;1</td>
<td>7</td>
</tr>
<tr>
<td>giant foxtail</td>
<td>&lt;1</td>
<td>5</td>
</tr>
<tr>
<td>common sunflower</td>
<td>&lt;1/2</td>
<td>2</td>
</tr>
<tr>
<td>hemp dogbane</td>
<td>&lt;1/2</td>
<td>2</td>
</tr>
<tr>
<td>giant ragweed</td>
<td>&lt;1/2</td>
<td>2</td>
</tr>
<tr>
<td>kochia</td>
<td>&lt;1/2</td>
<td>2</td>
</tr>
</tbody>
</table>

Sources: Burnside et al. (1996), Buhler and Hartzler (2001), Dawson and Bruns (1976), Lewis (1973), and Roberts and Feast (1972).
Two general strategies

- Stimulate germination in absence of crop and kill weeds = “stale seed bed” or “bare summer fallow”
  - Tillage and irrigation can stimulate
  - Flaming, herbicides = good ways to kill weed seedlings without stimulating further emergence
- Inhibit germination during early crop growth (remember weeds might be ok if they emerge later…)
  - Irrigation best at this (trickle tape)
2D.2.3 Manipulating weed seed germination

Emergence

Seed germination

Seed dispersal

Seed burial

Seed production

Establishment and growth

“Weed seedbank”
2D.2.3 “Stale seed bed”: stimulate germination and kill weeds BEFORE crop emergence

http://www.steamweeding.co.nz/information/index.html
2D.2.3 Flame-Weeding!!!
2D.2.4 Cultural weed control
N Fertility management

- Germination and growth of many weeds is stimulated by nitrogen
- Target fertilization both temporally and spatially to meet crop needs
2D.2.4 Reduced or split N can reduce weed emergence and growth

Brainard, DiTommaso and Mohler 2006
2D.2.4 Spatial N manipulation

- Deep fertilizer placement vs broadcast
- Strip management—legumes in, cereals out.
2D. “Many little hammers”

1. Mechanical

2. Cultural

3. Biological

4. Chemical
2D.3 Biological weed control?

Flora practical jokes

Gary Larson
2D.3 Biological weed control

- Herbivores
- Pathogens
- Cover crops
- Seed predators

“classic” biological control
Seed production

Seed germination

Seedling mortality

Seed mortality

Allelochemicals

Mulch effects

Nutrient effects

Cover crops

Seed predation

Seed decay
2D.3 Results: Buckwheat residue effects

- **Wheat**: No effect on wheat yield in greenhouse or field.

- **Corn chamomile**
  - Buckwheat: Reductions in emergence and growth in ¾ of studies
  - Bare:
2D.3 What is mechanism?

Hypotheses?

Buckwheat    Bare
2D.3 Buckwheat effects on weed emergence
Shepherd’s purse and N interactions

Kumar et al. unpublished
2D.3 Seed Predation

Ex. Red clover effects on weed seed predation

Davis & Liebman 2003
2D.3 Red clover in wheat: Effects on seed production?
2D. “Many little hammers”

1. Mechanical
2. Cultural
3. Biological
4. Chemical
2D.4 Chemical weed control

http://www.purewatergazette.net/images/weed.gif
## 2D.4 Organic herbicides?

Mustard, lambsquarters and pigweed control using natural products at 14-21 DAT in 6 states, 2006

<table>
<thead>
<tr>
<th>trt #</th>
<th>trt</th>
<th>Conc. (%)</th>
<th>GPA</th>
<th>NY</th>
<th>CA</th>
<th>DE</th>
<th>MN</th>
<th>MI</th>
<th>PA1</th>
<th>PA2</th>
<th>PA3</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vinegar</td>
<td>5</td>
<td>70</td>
<td>77.5</td>
<td>5.0</td>
<td>88.0</td>
<td>45.7</td>
<td>15.0</td>
<td>11.3</td>
<td>71.3</td>
<td>85.0</td>
<td>49.9</td>
</tr>
<tr>
<td>2</td>
<td>Vinegar</td>
<td>10</td>
<td>70</td>
<td>87.5</td>
<td>12.5</td>
<td>93.0</td>
<td>85.7</td>
<td>63.8</td>
<td>51.3</td>
<td>78.8</td>
<td>95.0</td>
<td>71.0</td>
</tr>
<tr>
<td>3</td>
<td>Vinegar</td>
<td>15</td>
<td>70</td>
<td>80.0</td>
<td>26.2</td>
<td>96.0</td>
<td>78.6</td>
<td>65.0</td>
<td>68.8</td>
<td>93.8</td>
<td>100.0</td>
<td>76.0</td>
</tr>
<tr>
<td>4</td>
<td>Vinegar</td>
<td>20</td>
<td>70</td>
<td>95.0</td>
<td>61.2</td>
<td>95.0</td>
<td>90.0</td>
<td>91.3</td>
<td>73.8</td>
<td>93.8</td>
<td>100.0</td>
<td>87.5</td>
</tr>
<tr>
<td>5</td>
<td>Matran EC</td>
<td>5</td>
<td>35</td>
<td>46.3</td>
<td>17.5</td>
<td>56.0</td>
<td>0.0</td>
<td>2.5</td>
<td>6.3</td>
<td>38.8</td>
<td>23.8</td>
<td>23.9</td>
</tr>
<tr>
<td>6</td>
<td>Matran EC</td>
<td>10</td>
<td>35</td>
<td>58.8</td>
<td>82.5</td>
<td>81.0</td>
<td>5.7</td>
<td>27.5</td>
<td>47.5</td>
<td>77.5</td>
<td>96.3</td>
<td>59.6</td>
</tr>
<tr>
<td>7</td>
<td>Matran EC</td>
<td>15</td>
<td>35</td>
<td>62.5</td>
<td>92.5</td>
<td>86.0</td>
<td>40.0</td>
<td>22.5</td>
<td>58.8</td>
<td>77.5</td>
<td>100.0</td>
<td>67.5</td>
</tr>
<tr>
<td>8</td>
<td>Matran EC</td>
<td>20</td>
<td>35</td>
<td>73.8</td>
<td>95.0</td>
<td>90.0</td>
<td>43.1</td>
<td>43.8</td>
<td>75.0</td>
<td>95.0</td>
<td>100.0</td>
<td>77.0</td>
</tr>
</tbody>
</table>

LSD (P=.05) | 14.2 | 15.8 | 14.0 | 27.7

**Weather Data**

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp</td>
<td>72.0</td>
<td>45.0</td>
<td>80?</td>
<td>84.0</td>
<td>65.0</td>
<td>81.0</td>
</tr>
<tr>
<td>RH</td>
<td>57.0</td>
<td>66.0</td>
<td>88.0</td>
<td>41.0</td>
<td>56.0</td>
<td>60.0</td>
</tr>
<tr>
<td>cloud</td>
<td>60.0</td>
<td>30.0</td>
<td>0.0</td>
<td>95.0</td>
<td>15.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Leaf Stage**

|        | 3-4  | 3    | <=3  | 4    | 4    | 4    | 4    |

1. Based on biomass data
2. Three separate trials were conducted in PA.

Brainard et al, unpublished
What do you think about organic herbicides?

• Advantages?

• Disadvantages?
3. Integration of “many little hammers”

1. Mechanical

2. Cultural

Weeds

3. Biological

4. Chemical
3. Integration—management strategies

"Many little hammers": Synergistic effects of cultural tactics on weed biomass production in corn and sunflower. Tactics included increased seeding rates, narrower row spacing, fertilizer placement, and delayed planting. Treatments were compared with conventional systems used by producers. Anderson (2005), Agron. J. 97: 1579-1583.
3. Integration of tactics: Nordell Example
3. Nordell’s “bioextensive” vegetable crop rotation

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Spring</td>
<td>Spring</td>
<td>Spring</td>
</tr>
<tr>
<td>Summer</td>
<td>Summer</td>
<td>Summer</td>
<td>Summer</td>
</tr>
<tr>
<td>Fall</td>
<td>Fall</td>
<td>Fall</td>
<td>Fall</td>
</tr>
<tr>
<td>Clover</td>
<td>Bare</td>
<td>Late crop</td>
<td>Early crop</td>
</tr>
<tr>
<td>fallow</td>
<td>Rye/</td>
<td>Rye</td>
<td>Clover</td>
</tr>
<tr>
<td>Vetch</td>
<td>(Broccoli)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bare</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oats/</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>peas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Onions)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Look at ratio of cover crop:cash crop…

Key features:
- Prevention
- Stale seed beds/Bare summer fallow
- Rotation: Alternating early, late crops
- Cover crops
- Cultivation

Nordell and Nordell, 1996
3. Combining cultivation and cover crops—inter-seeding
Late July

August

September

Following spring
3. Interseeding—early canopy closure

Brainard and Bellinder, 2002
3. Interseeding yields, 2000

Broccoli yield (T/ha)

Weed dry weight (g/m²)

Timing of last cultivation (DAT)

Broccoli yield (T/ha)

Weed dry weight (g/m²)

Timing of last cultivation (DAT)

Brainard and Bellinder 2004
3. Interseeding yields, 2001

Brainard and Bellinder 2004
Some key points

Prevention is critical. Easier to avoid seed production than to promote seed predation and decay.

Knowledge of the biology and ecology of weeds is useful for determining optimal management strategy.

Mechanical control (cultivation) has been foundation of organic weed management, but has limitations.

Cultural practices like crop rotation, planting density etc have great potential.

“Many little hammers” necessary for successful management.
Exercise:

• What have we talked about today that might conflict with managing insect pests?
• When you design your farm, what tactics would you include? Why? What would you not include? Why not?