Why weed management is important
  ▶ The importance of identification
  ▶ The ID process
  ▶ Resources for identification
  ▶ Research results
  ▶ Understanding herbicides
Why is weed control critical?

- ~$450 million in losses to Florida agriculture
- Billions spent at State, National level
- >75% of all pesticide sales are from herbicides
- Need to control weeds to reduce competition, increase safety, protect desirable plant species, protect property
Why is Identification important?

Most important part of weed control:

- Critical to always ID your pests before beginning your attack (step 1 in IPM)
- Determines what control measures are needed (and which ones will work)
  - Some herbicides are weaker/better on certain weeds – no herbicide controls all weeds
  - Systemics – perennials
  - Contacts – will work on annuals

Could help identify cultural problems at your site, predict problematic species

- Too wet = Alligator weed, torpedograss, sedges
- Dry areas – spurges, bidens, FL pusley
Identification Basics

- Plant ID usually based on flowers/fruits
  - Can’t wait this long to ID weeds; early control important
  - Try to use growth habit, color, smell, feel, season, placement (shade/sun, dry/wet, etc.) to ID
- Goal is to ID and control before seed develops/vegetative spread
Where to start....

Weed Pests

Monocots (Grass like)

Dicots (Broadleaf)

Grasses

Sedges

Primitive Weeds (No seeds)
Monocots: “Grassy weeds”

- One cotyledon or seed leaf inside seed coat
- One single leaf emerges during germination
- Hollow, rounded or flattened stems, closed/hard nodes
- Parallel veins
Sedges

- Grass “like” but not true grasses
- “Sedges got edges” – solid triangular shaped stems, leaves extend in 3 directions
- Annual & perennial; perennial are TOUGH to control
Look for:
- **Stem shape**
- Presence and shape of:
  - **Ligule** – membranous scale on inner leaf sheath at junction with blade
  - **Auricle** – “claw” appendages at base of blade
  - **Collar** – band of meristematic tissue at junction of blade and sheath
  - **Sheath** – tubular part of leaf that wraps around stem
  - **Midrib** – central vein
  - **Root structures** (bulbs, stolons, etc.)
  - **Hair**?
Monocot ID

Stem/Leaf | Leaf Arrangement
--- | ---
Grass | alternate leaf arrangement
- leaves usually flat, long and narrow
- usually round stem
- overlapping leaf sheath at base of stem

Sedge | spiral around stem
- solid stem, usually triangular
- leaves usually flat
- fused leaf sheath at base of stem
Root Structures

- Crown
- Rhizome
- Tuber
- Fibrous root system
- Stolon
- Taproot
- Bulb
- Corm
How does habit impact appearance?
Dicots: Broadleaf weeds

- Two cotyledons inside the seed coat
- Two leaves emerge when germinating
- Highly variable in appearance
- Typically “showy” flowers, net-like veins
Dicot ID

Other ways to ID:

- Root structures
- Flowers
Life Cycles

### Annuals
- Complete life cycle in 1 year
- Grasses, sedges, broadleaves
- Life cycle can begin at different times of year

### Biennials
- 2 year life cycle; germinate in fall, develop roots and leaves in first year
- Produce seed and die in second year
- Often form a basal rosette of leaves in first year, then “shoot” up and flower in the second

### Perennials
- Live more than 2 years
- Can reproduce from tubers, rhizomes, stolons, or seed
- Go dormant, lose vegetative growth, regenerate from food reserves in root systems
- Hard to control with contact/PRE herbicides
Online Good Image search

Can be used once you know the terminology
Identification Resources
Identification Resources

- USDA Plants Database: [http://plants.usda.gov/](http://plants.usda.gov/)
- UT Turf Weed ID: [http://www.tennesseeturfgrassweeds.org/Pages/Weed-ID.aspx](http://www.tennesseeturfgrassweeds.org/Pages/Weed-ID.aspx)
- Center for Aquatic and Invasive Plants [https://plants.ifas.ufl.edu/](https://plants.ifas.ufl.edu/)
Stumped?

- Collect a plant sample
- The more the better
- Flowers if possible
- Different stage of growth
- Store in plastic bag, wet paper, cool location
- Take to extension offices, REC’s
- MREC Plant Clinic – Every Tuesday, Apopka, FL
Taking Good Photos

- Overall growth habit
- Closeups:
  - Leaf shape, stems, root system
  - Seeds, flowers
  - Include information on location/site where collected
  - Possibly something in photo to show scale:
    - Quarter, keys, pencil, etc.
  - Solid background if in crowded area (truck hood, paper, notepad, etc.)
Example of Good Photos
Good Photos
Bad Photos

[Images of different types of grass and ground cover]
Selecting Control Strategies

- Perennials
  - Systemic herbicides
  - Some mechanical removal
- Annuals
  - Systemic herbicides
  - Mechanical, manual
  - Mulch, some non-chemical methods
Selectivity: Reducing Non-target Damage

- **Graminicides**
  - Fluazifop
  - Fenoxaprop
  - Sethoxydim
  - Clethodim

- **Broadleaf Selective**
  - Clopyralid
  - Aminopyralid
  - Metsulfuron
  - Triclopyr

- **Non-selective**
  - Glyphosate
  - Imazapyr
  - Diquat
  - Glufosinate
## How does it spread?

<table>
<thead>
<tr>
<th>Perennial Invasive Weeds</th>
<th>Annual Weeds/Invasives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cogongrass</strong></td>
<td><strong>Dogfennel</strong></td>
</tr>
<tr>
<td>Seed/Vegetative</td>
<td>Seed</td>
</tr>
<tr>
<td><strong>Brazilian pepper</strong></td>
<td><strong>Bidens/Spanish needles</strong></td>
</tr>
<tr>
<td>Seed</td>
<td>Seed</td>
</tr>
<tr>
<td><strong>Benghal dayflower</strong></td>
<td><strong>Ageratum</strong></td>
</tr>
<tr>
<td>Seed/Vegetative</td>
<td>Seed</td>
</tr>
<tr>
<td><strong>Torpedograss</strong></td>
<td><strong>Tasselflower</strong></td>
</tr>
<tr>
<td>Vegetative mostly</td>
<td>Seed</td>
</tr>
<tr>
<td><strong>Coral ardisia</strong></td>
<td><strong>Horseweed</strong></td>
</tr>
<tr>
<td>Seed</td>
<td>Seed</td>
</tr>
<tr>
<td><strong>Skunkvine</strong></td>
<td><strong>Spurges</strong></td>
</tr>
<tr>
<td>Seed</td>
<td>Seed</td>
</tr>
<tr>
<td><strong>Spiderwort</strong></td>
<td><strong>Parthenium</strong></td>
</tr>
<tr>
<td>Vegetative</td>
<td>Seed</td>
</tr>
<tr>
<td><strong>Chinese tallow</strong></td>
<td><strong>Praxelis</strong></td>
</tr>
<tr>
<td>Seed</td>
<td>Seed</td>
</tr>
</tbody>
</table>
Control/Management of a Few Important Weeds
**Commelina benghalensis** (Bengal Dayflower, Tropical Spiderwort)

- **Life cycle:** perennial, can act as an annual
- **Leaves:** broadly ovate to lanceolate, entire margins, parallel veins, pubescent
- **Stems:** erect or prostrate along ground and can root at nodes, pubescent
- **Flowers:** often in clusters, funnel shaped, violet to light blue in color (other day flowers often have darker flower colors); can produce subterranean flowers/seeds
- **Roots:** fibrous
- **EZ ID:** white underground stems and flowers, parallel veins, wide leaves, violet flowers
- **Control:** Prevent, eradicate, eliminate. Inspect new shipments and sources of materials for presence of BDF. Noxious weed. Glyphosate tolerant. Flumioxazin (SureGuard/Broadstar) provides good PRE control; Metolachlor (Pennant Magnum), Indaziflam (Specticle)
**Parthenium hysterophorus** (Ragweed parthenium, Whitetop)

- **Life cycle:** annual
- **Leaves:** alternate, first form basal rosette, finely lobed (pinnatifid to bipinnatifid), pubescent
- **Stems:** erect, paniculately branched and pubescent
- **Flowers:** white disk flowers on stem tips
- **Roots:** taproot
- **EZ ID:** light green/white pubescent on leaves, white flowers (“white top” name)
- **Control:** glyphosate tolerant; PREs are effective; Glufosinate (Finale), Saflufenacil (Detail), triclopyr, etc.
**Paederia foetida** (Skunk vine)

- **Life cycle:** perennial
- **Leaves:** rounded or heart-shaped, opposite or in whorls
- **Stems:** woody, reaching over 30 ft.
- **Fruit:** small, light grayish pink with red centers
- **Roots:** Fibrous
- **EZ ID:** heart-shaped leaves, distinct flowers, Sulphur smell
- **Control:** triclopyr + glyphosate; repeated applications likely needed
Introduction to *Paederia foetida*

- **Rubiaceae family**
- **No thorns**
- **Rounded to cordate leaves, opposite, entire margins**
- **Flowers on long petioles, white with red centers**
- **Small, spherical fruit, shiny brown, 2 black seeds**
Paederia in St. Augustine turf; Orlando, Florida
Introduction to *Paederia foetida*

- Can reproduce from seed, stem fragments, small stolons, rooting along nodes
- Mechanical, manual removal efforts have been unsuccessful
- Currently recommended treatments:
  - Triclopyr amine/ester, imazapic, glyphosate
  - Re-sprouting can still be observed (Langeland et al., 2006)
Methods:

- Transplanted into #1 (1 gal.) nursery containers and staked on 3 separate dates – continued to grow until treatment
  - Juvenile stage (green, softwood, immature foliage, 12 to 24 in.)
  - Mature (mostly hardwood, mature foliage, 24 to 48 in.)
  - Established (mostly hardwood, 48 to 72 in. in ht.)
  - Grouped by growth stage, blocked based upon size
### Treatments:

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>Trade Name:</th>
<th>WSSA Group:</th>
<th>Rates:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triclopyr amine</td>
<td>Garlon 3A</td>
<td>4</td>
<td>0.75, 1.5, 3.0, &amp; 6.0 lbs. aea</td>
</tr>
<tr>
<td>Triclopyr ester</td>
<td>Garlon 4</td>
<td>4</td>
<td>0.75, 1.5, 3.0, &amp; 6.0 lbs. aea</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>Ranger Pro</td>
<td>9</td>
<td>0.75, 1.5, 3.0, &amp; 6.0 lbs. aea</td>
</tr>
<tr>
<td>Imazapic</td>
<td>Plateau</td>
<td>2</td>
<td>0.02, 0.05, 0.09, &amp; 0.19 lbs. aia</td>
</tr>
<tr>
<td>Aminopyralid</td>
<td>Milestone</td>
<td>4</td>
<td>0.014, 0.028, 0.055, &amp; 0.11 lbs aia</td>
</tr>
<tr>
<td>Fluroxypyr</td>
<td>Vista</td>
<td>4</td>
<td>0.06, 0.12, 0.24, &amp; 0.48 lbs aea</td>
</tr>
<tr>
<td>Aminocyclopyrachlor</td>
<td>Method 240SL</td>
<td>4</td>
<td>0.035, 0.07, 0.14, &amp; 0.28 lbs aea</td>
</tr>
</tbody>
</table>

*Rates generally 0.125, 0.25, 0.5, and 1.0× maximum or recommended label rate.

**Group 2 = Acetolactate synthase (ALS) inhibitor; Group 4 = synthetic auxins; Group 9 = EPSP synthesis inhibitor, amino acid synthesis inhibitor
Table 1. Effect of growth stage, herbicide, and rate for skunkvine at 5 MAT.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate (lbs./A)</th>
<th>Juvenile</th>
<th>Mature</th>
<th>Established</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triclopyr amine</td>
<td>3.0</td>
<td>100 a</td>
<td>99 a</td>
<td>95 a</td>
</tr>
<tr>
<td>Triclopyr ester</td>
<td>3.0</td>
<td>100 a</td>
<td>99 a</td>
<td>95 a</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>3.0</td>
<td>100 a</td>
<td>100 a</td>
<td>95 a</td>
</tr>
<tr>
<td>Imazapic</td>
<td>0.2</td>
<td>58 b</td>
<td>73 c</td>
<td>54 d</td>
</tr>
<tr>
<td>Aminopyralid</td>
<td>0.1</td>
<td>99 a</td>
<td>98 c</td>
<td>85 b</td>
</tr>
<tr>
<td>Fluroxypyr</td>
<td>0.2</td>
<td>99 a</td>
<td>80 b</td>
<td>76 c</td>
</tr>
<tr>
<td>Aminocyclopyrachlor</td>
<td>0.1</td>
<td>100 a</td>
<td>99 a</td>
<td>86 b</td>
</tr>
</tbody>
</table>

ANOVA

<table>
<thead>
<tr>
<th>Effect</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>stage</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>herbicide</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>rate</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>stage*herbicide</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>stage*rate</td>
<td>0.6313</td>
</tr>
<tr>
<td>herbicide*rate</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>stage<em>herbicide</em>rate</td>
<td>0.6537</td>
</tr>
</tbody>
</table>
Results: Greenhouse Trials

**XL Stage; Year 2 – 2 MAT**

*Rate increases from left to right*
## Methods:

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate needed:</th>
<th>Cost per acre:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triclopyr amine</td>
<td>3 lbs. aea</td>
<td>$83.50</td>
</tr>
<tr>
<td>Triclopyr ester</td>
<td>1.5 lbs. aea</td>
<td>$34.66</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>3 lbs. aea</td>
<td>$36.00</td>
</tr>
<tr>
<td>Imazapic</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>Aminopyralid</td>
<td>0.11 lbs. aia</td>
<td>$17.32</td>
</tr>
<tr>
<td>Fluroxypyr</td>
<td>0.48 lbs. aea</td>
<td>$32.40</td>
</tr>
<tr>
<td>Aminocyclopyrachlor</td>
<td>0.28 lbs. aea</td>
<td>$43.54</td>
</tr>
</tbody>
</table>
Results:

• Few differences noted among herbicides at labeled rates; exception was imazapic

• At 2 MAT, most economical herbicides were:
  • Fluroxypyr at 0.5× = $16.20
  • Aminopyralid at 1× = $17.32
  • Triclopyr ester at 0.5× = $17.33

• At 5 MAT, most economical herbicides were:
  • Aminopyralid at 1× = $17.32
  • Fluroxypyr at 1× = $32.40
  • Glyphosate at 0.5× = $36.00
Conclusion:

- Fluroxypyr, aminopyralid, triclopyr ester provided economical control.
- Glyphosate, triclopyr amine, and aminocyclopyrachlor also effective – may have been more economical depending on growth stage.
- Minimal re-sprouting was observed on most treatments.
- Proper choice depends on growth stage, non-target species; should be rotated.
- Future work needed on other active ingredients, various environmental conditions, and development of integrate approach.
## Preemergence Control

<table>
<thead>
<tr>
<th>Trade name</th>
<th>Barricade</th>
<th>SureGuard</th>
<th>Specticle</th>
<th>Tower</th>
<th>Gallery</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>prodiamine</td>
<td>flumioxazin</td>
<td>indaziflam</td>
<td>dimethenamid-p</td>
<td>isoxaben</td>
<td></td>
</tr>
<tr>
<td>WSSA group</td>
<td>3</td>
<td>14</td>
<td>29</td>
<td>15</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>
Preemergence control of skunkvine: 12 WAT

- Barricade: 84 b
- SureGuard: 99 a
- Specticle SC: 48 c
- Tower: 60 c
- Gallery: 2 d
Praxelis clematidea
Praxelis clematidea (Praxelis)

- Asteraceae family
- Native to South America
- Australia, China, N. America
- Annual to short-lived perennial
- First verified in Florida (Orange County) in 2006
- Now verified in 6 other central Florida counties

Courtesy of EDDmaps.org
USDA-APHIS Risk Assessment

Figure 1. Predicted distribution of *Praxelis clematidea* in the United States. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

Similar species:

Ageratum houstonianum  
(A. conyzoides also similar)

Praxelis clematidea
Identification

• Both have lilac flower heads
• Ageratum flower heads more rounded, smaller
• Praxelis have flower heads high cone shaped receptacle
Species significance

• Long flowering period – high seed production
  • May through November to year-round in C. Florida
• Seeds produced in ~10 to 12 weeks
• Long distance dispersal (wind)
• Primarily found in disturbed areas
  • Agricultural production areas, roadsides, etc.
• Becoming a concern with Florida Fish and Wildlife
• Nursery production (C. Florida nurseries)
  • Issue in non-crop areas
  • Found in containers in a few instances
  • Major issue in drain holes, similar to Ageratum
Current control recommendations:

Australia

• 2,4-D
• Fluroxypyr
• Metsulfuron-methyl
• Glyphosate

Florida observations/reports:

• Glyphosate
• Glufosinate
Praxelis vs. Ageratum Biomass reduction: Apopka

- Praxelis
- Ageratum

Legend:
- A
- a
- B
- C
- D

Graph shows the comparison of Praxelis and Ageratum in Biomass reduction across different sites: Marengo SC, Biathlon, Broadstar, Gemini SC, Tower, OH2, FreeHand, Snapshot.

* indicates significant difference.
RESULTS:

Praxelis: 10 WAT
RESULTS (Praxelis):

- Biathlon, Broadstar, OH2 most consistent control (PPO inhibitors)
- Gemini (prodiamine + isoxaben) – 72 to 100% control
  - Snapshot (trifluralin + isoxaben): 65% control
- Dimethenamid-P (Tower or FreeHand): 12 to 60% control
Summary

• PPO inhibiting herbicides showed high efficacy
• More data needed for Marengo
• Differences in Ageratum and Praxelis response were evident
  • Identification important
  • Gemini, Tower/FreeHand (dimethenamid-P)
• Dormancy, germination requirements, biology largely unknown
• Preliminary data (ongoing): DNA herbicides do not appear effective applied alone [Barricade (prodiamine), Pendulum (pendimethalin)]
• Oxadiazon (Ronstar) does not appear as effective as other PPO inhibitors (oxyfluorfen, flumioxazin)
• More data needed
Postemergence Control

Ranger Pro

Finale

Vastlan

Lontrel

Check
Understanding Herbicides: Selecting and Using the Best Herbicides for your Situation
OVERVIEW:

• Major herbicide classifications
• Herbicide chemical properties, behavior
  • In the plant
  • In the environment
• Modes of action
• Herbicide applications/Formulations
• Using information to develop programs
A FEW CAVEATS.....

• Complex chemistries and interactions
• Tremendous amount of information
• Cannot discuss all possible scenarios or situations
• Broad overview, introductory information
A FEW CAVEATS.....

• Examples largely drawn from ornamental production scenarios
• Example programs are given, not recommendations
  • All situations are different
  • Speak with weed specialist in your field
• Resources for further information
HERBICIDE HIERARCHY

• Herbicide types – how they are classified
  • PREemergence
  • POSTemergence
    • Contact, systemic, selective, nonselective

• Chemical properties – how they behave
• Application methods – how they are applied
• Absorption/movement in plants – how they enter
• Mode of action – how they work
Herbicide Types

Herbicides

POST

PRE

Contact

Systemic

Selective

Nonselective

Selective

Nonselective
SELECTIVE VS. NONSELECTIVE

• Some plants can metabolize/process herbicides more quickly – no symptoms or damage

• Some herbicides only affect certain pathways, certain plants have enzymes that are insensitive to that process
  • Corn can rapidly metabolize atrazine
  • ACCase inhibitors (graminicides) work on grasses – target enzyme that is insensitive in broadleaf plants
  • Finding herbicide in plant material does not mean it caused the damage
    • Ex.: Clopyralid/aminopyralid in grasses

• Growth stage/size, leaf texture and application timing also play a role
CHEMICAL PROPERTIES

- **Solubility** – how much will dissolve in water
- **Sorption Coefficient $K_{OC}$** – adsorption potential
  - Solubility/$K_{OC}$ usually inversely related – glyphosate is a notable exception
  - Herbicides with a low sorption coefficient are usually more likely to leach
  - Affected by soil type, pH
- **Vapor pressure/volatility** – Higher vapor pressure = more volatile (change from liquid/solid to gas)
HOW HERBICIDES DEGRADE

Half-life – time for herbicide/pesticide to reach 50% of originally applied dose

1. **Microbial degradation** – soil microbes using N,C, etc.
2. **Photo-degradation** – sunlight breaking down
3. **Chemical degradation/hydrolysis** – water breaking down
WAYS HERBICIDES MOVE OFF-TARGET

- **Leaching** – related to solubility – movement off target area
  
  - Related to half-life, solubility, and sorption coefficient

- **Volutility** – movement away as gas
  
  - Most herbicides volatile to some degree
  
  - Incorporated to prevent losses (rainfall/irrigation)
Herbicides must reach target site and be taken up

Ex.: Some herbicides could work by root uptake, but don’t, too much adsorption to soil particles or fast degradation

Race for efficacy/weed control before decomposition or movement

Longer half-life possibly better weed control but possibly more environmental impact
HERBICIDE BEHAVIOR

• All influenced by environment
  • Wind
  • Soil type/organic matter content/microbial population
  • Moisture
  • pH
  • Humidity
  • Temperature
HERBICIDE ENTRY AND MOVEMENT

- Must penetrate the cytoplasm – cell wall
- Cuticle > cell wall > cell membrane
- Can be foliar or through roots
- Root is easier due to no cuticle, but could also be adsorbed or degraded in soil
BASIC TERMINOLOGY

• **Xylem** – transports water and nutrients from roots to stems, leaves, etc.

• **Phloem** – transports soluble organic compounds (photosynthates, sugars) from photosynthesis to parts of the plant where it is needed
ABSORPTION/MOVEMENT

Phloem mobile (glyphosate)

Phloem and xylem (MSM)

Foliar contact (diquat)

Root/cleoptile (shoot) inhibitor (pendimethalin)

Xylem mobile (tebuthiuron)
## MODE OF ACTION

- **WSSA Group**
  - On labels
- **HRAC Group**
- **Common names**
- **Trade names**
  - Mostly for field crops

### Table 3: Mode-of-action and classification of common turfgrasses herbicide site of action according to the Weed Science Society of America (WSSA) and the Herbicide Resistance Action Committee (HRAC).

<table>
<thead>
<tr>
<th>Timing</th>
<th>Mode-of-Action</th>
<th>WSSA Group</th>
<th>HRAC Group</th>
<th>Common Name</th>
<th>Trade Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>Mitotic inhibition</td>
<td>3</td>
<td>K1</td>
<td>dithiopyr</td>
<td>Dimension</td>
</tr>
<tr>
<td>Pre</td>
<td>Mitotic inhibition</td>
<td>3</td>
<td>K1</td>
<td>pendimethalin</td>
<td>Pendulum</td>
</tr>
<tr>
<td>Pre</td>
<td>Mitotic inhibition</td>
<td>3</td>
<td>K1</td>
<td>propanil</td>
<td>Barricade</td>
</tr>
<tr>
<td>Pre</td>
<td>Lipid biosynthesis inhibition</td>
<td>8</td>
<td>N</td>
<td>benzoate</td>
<td>Benoxacrid</td>
</tr>
<tr>
<td>Pre</td>
<td>Photosystem II inhibition</td>
<td>7</td>
<td>C2</td>
<td>acetoluron</td>
<td>Turesan</td>
</tr>
<tr>
<td>Pre</td>
<td>Protoporphyrinogen oxidase (PPO) inhibition</td>
<td>14</td>
<td>E</td>
<td>oxadiazon</td>
<td>Ronstar</td>
</tr>
<tr>
<td>Pre/Post</td>
<td>Mitotic inhibition</td>
<td>15</td>
<td>K3</td>
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<td>C1</td>
<td>amicarbazone</td>
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<tr>
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<td>C1</td>
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<td>C1</td>
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<tr>
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<td>C1</td>
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<td>14</td>
<td>E</td>
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<td>Post</td>
<td>Synthetic Auxin</td>
<td>4</td>
<td>O</td>
<td>2,4-D</td>
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<tr>
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<td>Synthetic Auxin</td>
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<td>O</td>
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<td>Barvel</td>
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<tr>
<td>Post</td>
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<td>O</td>
<td>quinclorac</td>
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<td>Post</td>
<td>Inhibition of cell wall (cellulose) synthesis</td>
<td>27</td>
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<td>B</td>
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<td>Revolver</td>
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<td>B</td>
<td>imazaquin</td>
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<td>B</td>
<td>rimsulfuron</td>
<td>Trinex</td>
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<td>B</td>
<td>sulfosulfuron</td>
<td>Certainty</td>
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<td>B</td>
<td>trifloxysulfuron</td>
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<td>diclofop</td>
<td>Illexan</td>
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<tr>
<td>Post</td>
<td>Acetyl CoA Carboxylase (ACCase) Inhibitors</td>
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<td>A</td>
<td>ciethodim</td>
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<tr>
<td>Post</td>
<td>Enolpyruvyl Shikimate-3 Phosphate (EPSP) synthase inhibition</td>
<td>9</td>
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<td>glyphosate</td>
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<td>Post</td>
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<td>6</td>
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<td>22</td>
<td>D</td>
<td>diquat</td>
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<tr>
<td>Post</td>
<td>Photosystem II inhibition</td>
<td>22</td>
<td>D</td>
<td>paraquat</td>
<td>Gramoxone</td>
</tr>
</tbody>
</table>
HOW THEY WORK

• Alter some essential metabolic process
• Almost all work on metabolic pathways/processes specific to plants
  • Relatively low mammalian toxicity
1. Photosynthesis – energy production
2. Mitosis – cell division
3. Lipid synthesis
4. Nitrogen metabolism
5. Growth regulation
**MODE OF ACTION**

**MECHANISM OF ACTION HIERARCHY**

<table>
<thead>
<tr>
<th>Mode of action</th>
<th>Mechanism of action</th>
<th>Herbicide family/name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipid synthesis inhibitor</td>
<td>Group 1 ACCase inhibitor</td>
<td>“Dims” Sethoxydim</td>
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<tr>
<td></td>
<td></td>
<td>“Fops” Fluazifop</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Dens” Pinoxaden</td>
</tr>
</tbody>
</table>

Example from WSSA Herbicide Resistant Management Lesson 2
WSSA Group Number: 1, 15, 26
HRAC Group Number: A, K3, N

Microtubule organization
Fatty acid synthesis
Photosynthesis
Amino acid synthesis
Cell wall synthesis
Tetrahydrofolate synthesis
ATP synthesis

Hormone transport
Hormone-based gene regulation

Mitochondria
Chloroplast
Nucleus
Microtubules

Delye et al. 2013.
SOME IMPORTANT MOAs

• **Group 1** – Acetyle CoA carboxylase (ACCase inhibitors)
  • Inhibit creation of lipids in grasses
  • Clethodim, fluazifop, sethoxydim

• **Group 2** – Acetolactate synthesis inhibitors (ALS)
  • Stops production of 3 amino acids
  • Halosulfuron, metsulfuron, imazaquin

• **Group 3** – mitosis inhibitors (root pruners)
  • Inhibit cell division in germinating seedlings, stops root formation
  • Pendimethalin, oryzalin
SOME IMPORTANT MOAs

• Group 4 – growth regulators
  • Mimic auxin, a plant hormone
  • 2,4-D

• Group 9 – inhibition of enolpyruvyl shikimate-3-phosphate synthase (EPSP)
  • Inhibits EPSPS, stopping production of three amino acids produced in shikimate pathway
  • This stops production of a enzyme and other proteins that are built from those amino acids and are vital for protein synthesis and growth
  • Pathway not found in humans or animals
  • Glyphosate
SOME IMPORTANT MOAs

• **Group 10 – inhibition of glutamine synthetase**
  - Glutamine synthetase inhibitors stop conversion of ammonia to glutamine, allowing ammonia to build up to toxic levels
  - Glufosinate

• **Group 22 – Inhibition of photosystem I**
  - Herbicides accept electrons from photosynthetic pathway that leads to formation of reactive molecules that destroy lipids and then cell membranes – “cell membrane disruptors”
  - Paraquat, diquat
SOME IMPORTANT MOAs

• Group 14 – Protoporphyrinogen oxidase inhibitors (PPO inhibitors)
  • PPO inhibitors block production of chlorophyll, cause reactive molecules to form in the cell, destroys cell membranes
  • Flumioxazin, carfentrazone, oxyfluorfen
APPLICATION METHODS

• **Broadcast** – herbicide is uniformly applied over a given area

• **Over-the-top** – Herbicide is applied over a crop, usually selective herbicides, often used term in ornamental weed control

• **Directed application** – directing herbicide application towards the base on a non-target plant
Over the top or broadcast type application

Directed application
APPLICATION METHODS

• **Spot spray** – spraying herbicide to small areas, usually as foliar applications

• **Cut-stump, hack/squirt** – Methods used to control woody plants/invasive species

• **Foliar** – leaves and foliage (above ground)

• **Soil** – PRE herbicides, root uptake

• **Basal sprays** – Trunk/stem applications

• **Layby**, etc. etc.
APPLICATION TIMINGS

• Pre-plant/Pre-plant incorporated – seeded or planted crops (vegetables, fruits, etc.)
• Preemergence – before weeds emerge
• Early-postemergence – immediately after weeds emerge but are still very small
• Postemergence – after weeds emerge, may be fairly large in size
APPLICATION TIMINGS

• Preemergence, postemergence, early postemergence may also refer to the crop, not just the weeds

• Corn, beans, etc., crops that emerge

• Closely read labels – importance of using products labeled for specific uses (e.g. pendimethalin)

• Follow weed management guides for specific crops
FACTORS INFLUENCING APPLICATIONS

- Calibration/proper mixing and loading
- Equipment that is used
- Sprayer pressure and nozzle type
- Weather
- Carrier volume (rate stays same)
  - Contact higher, systemic lower
  - Coverage vs. convenience
FORMULATIONS

• Pesticides rarely applied in technical form
• Formulated to improve:
  • Handling
  • Storage
  • Application
  • Efficacy
  • Safety

+ Water, adjuvants, etc.

Weed Killer 75DF
COMMON FORMULATIONS

• **Emulsifiable Concentrates (E, EC)** – active ingredient + solvent + emulsifier – allows oil based products to be mixed with water

• **Solutions** – active ingredient that dissolves in carrier (usually water); don’t separate out

• **Flowables/Liquids (F/L)** – active ingredient is a solid that doesn’t dissolve in water. Impregnated on a substance like clay and ground, and then suspended in liquid
COMMON FORMULATIONS

• **Granulars (G)** – active ingredient impregnated on a solid carrier like clay, applied dry with a spreader

• **Wettable Powders (WP/W)** – dry dust like material that is put in water and sprayed, needs constant agitation

• **Water Dispersible Granules or Dry Flowable (WDG/DF)** – like wettable powder, but formulated into granules to prevent dust and increase safety

• **Soluble Powder (WSP)** – look like wettable powders but dissolve in water and form a solution
PUTTING IT ALL TOGETHER

• Herbicide types and applications chosen based on specific goals

• Chemical properties lead to labeling for specific uses and restrictions

• Plant back periods, use patterns, application volumes, nozzle selection, use sites, etc.
  • Example: Imazapyr has long residual and absorbed by roots, not going to be labeled for use around root zone of landscape plants (can use simple bioassays for these types of situations)
  • Example: glyphosate is strongly bound to soil particles (despite high solubility) so it can be used for this purpose
PUTTING IT ALL TOGETHER

• Another example: 2,4-D is volatile, not labeled for use in enclosed structures (greenhouses)
• Risk vs. reward also leads to labeling decisions
  • 1 acre corn = $500 – millions of acres
  • 1 acre roses = $100,000 > hundreds of acres
  • Pendimethalin applied at same rate to both
  • Prowl less expensive than Pendulum EC
DEVELOPING PROGRAMS

• Rotate through different MOA
  • By year, by season, by application
  • Different for different scenarios

• Nursery production examples
  • Group 3 and Group 21 – DNAs (prodiamine, etc.) and isoxaben effective on cool-season weeds
  • Group 14 (flumioxazin) effective on summer weeds
WHY ROTATE?

• Prevent/delay resistance
  • Weeds that produce many seeds
  • Applications to large areas repeatedly
  • Little to no options or use of integrated weed management

• Improved control – uncontrolled weed will take over

• Utilize a combination of curative (POST) and preventative (PRE) chemical methods
## Common Ornamental Preemergence Herbicides and Site of Action

<table>
<thead>
<tr>
<th>Active ingredient</th>
<th>Trade Name</th>
<th>WSSA Herbicide Group</th>
<th>Weeds Controlled:</th>
</tr>
</thead>
<tbody>
<tr>
<td>dithiopyr</td>
<td>Dimension 2EW</td>
<td>3</td>
<td>Grasses and a few broadleaves</td>
</tr>
<tr>
<td>oryzalin</td>
<td>Oryzalin Pro, Surflan</td>
<td>3</td>
<td>Grasses and a few broadleaves</td>
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<tr>
<td>pendimethalin</td>
<td>Corral, Pendulum 2G, Pendulum AquaCap, Pin-dee, etc.</td>
<td>3</td>
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<td>prodiamine</td>
<td>Barricade, Prodimine, RegalKade</td>
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<td>Grasses and a few broadleaves</td>
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<tr>
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<td>Treflan, Trifluralin, Preen</td>
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<tr>
<td>flumioxazin</td>
<td>Broadstar, SureGuard</td>
<td>14</td>
<td>Broadleaves and grasses</td>
</tr>
<tr>
<td>oxadiazon</td>
<td>Oxadiazon, Ronstar</td>
<td>14</td>
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</tr>
<tr>
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<td>Galigan, Goal</td>
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<tr>
<td>dimethenamid-p</td>
<td>Tower</td>
<td>15</td>
<td>Grasses, sedge suppression, and some broadleaves</td>
</tr>
<tr>
<td>s-metolachlor</td>
<td>Pennant Magnum</td>
<td>15</td>
<td>Grasses, sedge suppression, some broadleaves</td>
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<tr>
<td>isoxaben</td>
<td>Gallery</td>
<td>21</td>
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<tr>
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<td>Marengo SC, Marengo G</td>
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<td>benefin + oryzalin</td>
<td>XL 2G</td>
<td>3 + 3</td>
<td>Grasses and some broadleaves</td>
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<td>FreeHand</td>
<td>3 + 15</td>
<td>Grasses and broadleaves</td>
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<tr>
<td>trifluralin + isoxaben</td>
<td>Quali-Pro TI, Snapshot</td>
<td>3 + 21</td>
<td>Grasses and broadleaves</td>
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<tr>
<td>prodiamine + isoxaben</td>
<td>Gemini</td>
<td>3 + 21</td>
<td>Grasses and broadleaves</td>
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<td>dithiopyr + isoxaben</td>
<td>Fortress G</td>
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<td>oxadiazon + prodiamine</td>
<td>RegalStar II</td>
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<td>oxyfluorfen + oryzalin</td>
<td>Rout</td>
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<td>oxyfluorfen + pendimethalin</td>
<td>OH2</td>
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<td>oxyfluorfen + prodiamine</td>
<td>Biathlon</td>
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<td>Grasses and broadleaves</td>
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<td>oxyfluorfen + trifluralin</td>
<td>Granular Herbicide 75 (Harrells)</td>
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<tr>
<td>oxyfluorfen + oxadiazon</td>
<td>OO-Herbicide, Two OX E-Pro, Regal OO</td>
<td>14 + 14</td>
<td>Grasses and broadleaves</td>
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*Product labels contain information on specific weeds controlled.
### Example Rotation: Granulars

<table>
<thead>
<tr>
<th>MARCH</th>
<th>APRIL</th>
<th>MAY</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUGUST</th>
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**Oxyfluorfen Combo (OH2, Biathlon, OO Etc.)**

- *FreeHand* 
  - 3 + 15

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<tr>
<th>SEPTMBER</th>
<th>OCTOBER</th>
<th>NOVEMBER</th>
<th>DECEMBER</th>
<th>JANUARY</th>
<th>FEBRUARY</th>
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</table>

**Gemini G Snapshot**

- *Fortress* 
  - 3 + 21

**Oxyfluorfen Combo (OH2, Biathlon, OO, Etc.)**

- *Broadstar Marengo G* 
  - 14

**Broadstar/Gemini G, Snapshot, Fortress**

- *Broadstar* 
  - 14 + 3

- *Gemini G* 
  - 29

- *Snapshot* 
  - 29
ROTATION CHALLENGES

• Labeling restrictions or crop safety issues
  • Few MOA available for some crops, situations
  • May not know efficacy of all available MOA
  • Use site/crop safety issues

• Could require use of less effective options

• Adoption

• Cost concerns
OVERCOMING ROTATION CHALLENGES

• Use of integrated weed management programs
  • Combining chemical and non-chemical methods

• Tank-mixes, combination products

• Utilize different timings and strategies
  • Combination of PRE and POST herbicides
  • Combining both in single tank
REASONS HERBICIDES FAIL

• **Poor application/calibration/incorrect rate**

• Bad choice for that weed

• Environmental issues
  • Rainfall, weed health, temperature, timing, movement (drift), leaching, etc.

• Water issues – pH, ions (hard water)

• Resistance – single, cross, multiple

• Antagonism (can also be synergistic, which is good)

• Label prevents 95% of issues
FUTURE AND ONGOING CHALLENGES AND TRENDS

• Limited new products coming to market – long time away for some crops
• Major commodities > other field crops > turf > specialty crops > ornamentals > niche situations
• More combination products – these are not new herbicides
• Increased/hyper environmental awareness and dislike of pesticides, loss of some products
• More resistance
FIGURING OUT OPTIONS FOR YOUR AREA

• Limited efficacy information may be available for a particular use site or situation

• Example: Bittercress (*Cardamine* spp.) not a major concern in citrus, so recommendations probably not available

• It is a major concern in nursery crops, tons of information available

• Indaziflam is highly efficacious; used in nursery crops as Marengo. Alion (indaziflam) labeled for use in citrus

• Cross reference active ingredients
IMPORTANT CONSIDERATIONS

• The product itself must be labeled, not just the active ingredient (i.e. flumioxazin, pendimethalin, etc. etc.)

• Many herbicide failures due to poor calibration or application – check this first

• Identify before application!

• Some postemergence herbicides have some residual, can create plant-back issues or similar problems
IMPORTANT CONSIDERATIONS

• Some herbicides are highly affected by spray water pH level and water quality
• Higher sprayer pressure usually causes greater chances of physical drift
• Ensure clients look at cost per acre for treatments, not cost per product in the package. Efficacy must also be considered
IMPORTANT CONSIDERATIONS

• Adjuvants can have a significant influence on herbicide performance
  • Use adjuvants specifically recommended on the label (non-ionic surfactants, crop oil concentrates, methylated seed oil, etc.).

• Not all pesticides can be tank-mixed:
  • Physical incompatibilities
  • Chemical incompatibilities
  • Synergism and antagonism – not all tank-mixes have been evaluated
  • Consider where the target is (plant, soil, etc.)
## ADDITIONAL RESOURCES

<table>
<thead>
<tr>
<th>Article/Resource</th>
<th>Web address</th>
<th>Notes:</th>
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</thead>
<tbody>
<tr>
<td>Herbicide Resistance Action Committee</td>
<td><a href="https://www.hracglobal.com/">https://www.hracglobal.com/</a></td>
<td>Website devoted to herbicide resistance management</td>
</tr>
<tr>
<td>WSSA Herbicide Resistant Weeds Lessons</td>
<td><a href="http://wssa.net/wssa/weed/resistance/">http://wssa.net/wssa/weed/resistance/</a></td>
<td>Collection of 3 learning modules on resistance development and management. Includes links to specific crop areas and more information</td>
</tr>
<tr>
<td>Herbicide injury factsheets</td>
<td><a href="https://content.ces.ncsu.edu/catalog/series/184/herbicide-injury">https://content.ces.ncsu.edu/catalog/series/184/herbicide-injury</a></td>
<td>Information on specific herbicide damage symptoms and factsheets on each herbicide</td>
</tr>
<tr>
<td>Herbicide injury diagnosis</td>
<td><a href="http://herbicidesymptoms.ipm.ucanr.edu/">http://herbicidesymptoms.ipm.ucanr.edu/</a></td>
<td>Searchable database for diagnosing herbicide injury</td>
</tr>
</tbody>
</table>
ADDITIONAL RESOURCES

The IR-4 Program

“Aids growers by facilitating registrations of pesticides and biopesticides on specialty food crops (fruits, vegetables, nuts, herbs, spices) and environmental horticulture crops (trees, shrubs, flowers).”

- Submit potential trials (agents and growers!)
- Use the database
- Look up efficacy or crop safety reports

ir4project.org
QUESTIONS?

Chris Marble

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