Weed
Adaptations to
Chemical and
Non-Chemical
Control Practices

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Today’s presentation

• Why weeds are problematic
• Herbicides and herbicide resistance
• Other causes of herbicide failure
• Non-chemical selective pressures
• Best Management practices for weed control
The problems with weeds...
Weeds are problems in more than just ag and hort systems...

• Beyond competition for water and nutrients...
• Reduced biodiversity
• Adverse effects on ecosystem functions
• Hazards to human and animal health
• Reduced safety through obstructions
• Loss of aesthetic value
An example of effects on ecosystem functions

Non-native species can impact fire cycles

Five things you probably never knew about California’s wildfires

Patrick May
PUBLISHED: July 3, 2018 at 10:49 am | UPDATED: July 3, 2018 at 10:56 am
California News, Latest Headlines, News

Non-native plants are helping California to burn, baby, burn

Travis Bean writes in UC Weed Science blog that despite all the news coverage of last year’s wildfires, “almost no source has identified the actual fuels involved for this most recent fire season or any other. As a weed scientist, this is a particularly alarming omission, especially when it’s highly likely that invasive plants may have been partially responsible for exacerbating the intensity and spatial scale of many, if not most, of 2017’s fires.” Bean writes that there’s an apparent “tendency to lump fires into very broad categories (e.g., “forest” fire, “brush” fire, “wildfire”) that tell managers, the public, and policy makers little about the actual fuel. Without letting the public and policy makers know that our wildfires are being dramatically worsened by fuels from invasive plants, it’s difficult to build the political will and support for efforts to do a better job managing these fuels. As scientists and managers, simple data on the fuels involved and the antecedent weather would allow us to provide timely predictions on not just when and where these fires will strike, but also where and when we should be investing in fuel breaks, restoration, or other management actions that can save money, resources, and lives.”
Medusahead
From: Medusahead Management Guide for the Western US

- Winter annual grass
- Native to Mediterranean
- First reported in OR in 1887
- Mainly infests rangelands
- Displaces native species
- Disrupts wildlife habitat
- Poor forage
  - Silica accumulator
  - Barbed seeds
- Alters fire regimes

Map from CalFlora
Medusahead
From: Medusahead Management Guide for the Western US

• Acts as a fire promoter in the big sagebrush (*Artemesia tridentata*) steppe

• Fills in between sagebrush to create a continuous fuel corridor

• Many species of sagebrush are unable to regenerate from frequent fires
Herbicides for weed control
Herbicides are, for many, a critical component of weed control programs.
Herbicides are not always 100% effective... ...and that is sometimes due to herbicide resistance

Photo from: A.S. Culpepper
There are currently 495 unique cases (species x site of action) of herbicide resistant weeds globally, with 255 species (148 dicots and 107 monocots).

Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 163 different herbicides.
<table>
<thead>
<tr>
<th>Crop or Situation</th>
<th>Number of Herbicide Resistant Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>75</td>
</tr>
<tr>
<td>Corn (maize)</td>
<td>61</td>
</tr>
<tr>
<td>Rice</td>
<td>51</td>
</tr>
<tr>
<td>Soybean</td>
<td>48</td>
</tr>
<tr>
<td>Roadsides</td>
<td>34</td>
</tr>
<tr>
<td>Winter wheat</td>
<td>32</td>
</tr>
<tr>
<td>Spring Barley</td>
<td>30</td>
</tr>
<tr>
<td>Orchards</td>
<td>27</td>
</tr>
<tr>
<td>Canola</td>
<td>21</td>
</tr>
<tr>
<td>Cotton</td>
<td>18</td>
</tr>
<tr>
<td>Pastures</td>
<td>18</td>
</tr>
<tr>
<td>Vegetables</td>
<td>16</td>
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<tr>
<td>Railways</td>
<td>15</td>
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<tr>
<td>Peas</td>
<td>13</td>
</tr>
<tr>
<td>Fallow</td>
<td>12</td>
</tr>
</tbody>
</table>

*Dr. Ian Heap, WeedScience.org 2018*
Number of Herbicide Resistant Weed Species by Weed Family (Top 10)

- Poaceae: 81 species
- Asteraceae: 42 species
- Brassicaceae: 22 species
- Cyperaceae: 12 species
- Amaranthaceae: 11 species
- Scrophulariaceae: 9 species
- Polygonaceae: 8 species
- Alismataceae: 7 species
- Chenopodiaceae: 7 species
- Caryophyllaceae: 6 species

Dr. Ian Heap, WeedScience.org 2018
Herbicide resistant weeds in CA

• 30 species by site of action combinations, dominated by two patterns of resistance.

• The first major category is multiple-resistance in a number of sedge and grass weeds of the rice production region of the Sacramento Valley.
  • ALS inhibitors
  • ACCase inhibitors

• The second broad category is glyphosate-resistant weeds in orchards, vineyards, and associated non-crop areas such as roadsides, canal banks, and field margins and roundup-ready crops.
  • Glyphosate
<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>Site of Action</th>
</tr>
</thead>
</table>
| 1981 | *Senecio vulgaris*  
*Common Groundsel* | Photosystem II inhibitors (C1/S) |
| 1989 | *Lolium perenne*  
*Perennial Ryegrass* | ALS inhibitors (B/2) |
| 1993 | *Sagittaria montevidensis*  
*California Arrowhead* | ALS inhibitors (B/2) |
| 1993 | *Cyperus difformis*  
*Smallflower Umbrella Sedge* | ALS inhibitors (B/2) |
| 1994 | *Salsola tragus*  
*Russian thistle* | ALS inhibitors (B/2) |
| 1996 | *Avena fatua*  
*Wild Oat* | Cell elongation inhibitors (Z/0) |
| 1997 | *Ammania auricula*  
*Ered Redstem* | ALS inhibitors (B/2) |
| 1997 | *Schoenoplectus mucronatus*  
(*Scirpus mucronatus*)  
*Ricefield Bulrush* | ALS inhibitors (B/2) |
| 1998 | *Echinochloa phyllopogon*  
(*E. oryzicola*)  
*Late Watergrass* | ACCase inhibitors (A/1) |
| 1998 | *Lolium rigidum*  
*Rigid Ryegrass* | EPSP synthase inhibitors (G/9) |
| 1998 | *Echinochloa phyllopogon*  
(*E. oryzicola*)  
*Late Watergrass* | Lipid Inhibitors (N/3) |
| 2000 | *Echinochloa oryzoides*  
*Ear Watergrass* | Lipid Inhibitors (N/3) |
| 2000 | *Ammannia coccinea*  
*Redstem* | ALS inhibitors (B/2) |
| 2000 | *Echinochloa crus-galli* var. crus-galli  
*Barleygrass* | Multiple Resistance 2 Sites of Action |
| 2000 | *Echinochloa phyllopogon*  
(*E. oryzicola*)  
*Late Watergrass* | ACCase inhibitors (A/1)  
Lipid Inhibitors (N/3) |
| 2001 | *Phalaris minor*  
*Little seed Canary grass* | ACCase inhibitors (A/1) |
| 2002 | *Digitaria ischaemum*  
*Smooth Crabgrass* | Synthetic Auxins (O/4) |
| 2005 | *Conyza canadensis*  
*Horseweed* | EPSP synthase inhibitors (G/9) |
| 2007 | *Conyza bonariensis*  
*Hairy Reabane* | EPSP synthase inhibitors (G/9)  
PSI Electron Divertor (D/22) |
| 2008 | *Echinochloa coloni*  
*Juncigenic* | EPSP synthase inhibitors (G/9)  
PSI Electron Divertor (D/22) |
| 2008 | *Lolium perenne ssp.*  
multiflorum  
*Italian Ryegrass* | EPSP synthase inhibitors (G/9)  
PSI Electron Divertor (D/22) |
| 2009 | *Conyza bonariensis* | Multiple Resistance 2 Sites of Action  
Hairy Reabane  
EPSP synthase inhibitors (G/9)  
PSI Electron Divertor (D/22) |
| 2013 | *Cyperus difformis*  
*Smallflower Umbrella Sedge* | PSII inhibitor (Ureas and amides) (C/7) |
| 2013 | *Poa annua*  
*Annual Bluegrass* | EPSP synthase inhibitors (G/9) |
| 2014 | *Schoenoplectus mucronatus*  
(*Scirpus mucronatus*)  
*Ricefield Bulrush* | PSII inhibitor (Ureas and amides) (C/7) |
| 2014 | *Conyza canadensis*  
*Horseweed* | Multiple Resistance 2 Sites of Action  
EPSP synthase inhibitors (G/9)  
PSI Electron Divertor (D/22) |
| 2015 | *Amaranthus palmeri*  
*Palmer Amaranth* | EPSP synthase inhibitors (G/9) |
| 2015 | *Lolium perenne ssp.*  
multiflorum  
*Italian Ryegrass* | Glutamine synthase inhibitors (H/13) |
| 2015 | *Lolium perenne ssp.*  
multiflorum  
*Italian Ryegrass* | Multiple Resistance 3 Sites of Action  
EPSP synthase inhibitors (G/9)  
PSI Electron Divertor (D/22) |
| 2016 | *Lolium perenne ssp.*  
multiflorum  
*Italian Ryegrass* | Multiple Resistance 4 Sites of Action  
EPSP synthase inhibitors (G/9)  
PSI Electron Divertor (D/22) |
Species in CA with suspected glyphosate resistant populations

- Threespike goosegrass (spring emerging)
- Feather fingergrass (summer emerging)
- Windmillgrass (summer emerging)
- Sprangletop (summer emerging)
- Witchgrass (summer emerging)
# Multiple HR weeds in CA

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>Herbicides</th>
<th>Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Barnyardgrass</td>
<td>ACCase and lipid bionsynthesis inhibitors</td>
<td>Rice</td>
</tr>
<tr>
<td>2000</td>
<td>Late watergrass</td>
<td>ACCase and lipid bionsynthesis inhibitors</td>
<td>Rice</td>
</tr>
<tr>
<td>2009</td>
<td>Hairy fleabane</td>
<td>Glyphosate, paraquat</td>
<td>Orchards</td>
</tr>
<tr>
<td>2014</td>
<td>Horseweed</td>
<td>Glyphosate, paraquat</td>
<td>Orchards</td>
</tr>
<tr>
<td>2015</td>
<td>Italian ryegrass</td>
<td>ACCase inhibitors, glyphosate, paraquat</td>
<td>Orchards, alfalfa</td>
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<tr>
<td>2016</td>
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<td>ACCase and ALS inhibitors, glyphosate, paraquat</td>
<td>Orchards, alfalfa</td>
</tr>
</tbody>
</table>
Herbicide resistance is the result of evolution of weed populations in response to the selection pressure exerted by herbicides.
Resistance before herbicides

734 dried plant specimens

Collected between 1788 – 1975

1 from 1888 with a mutation that can confer resistance to ACC-ase (WSSA 1) herbicides
Not every instance of weed control failure is due to herbicide resistance
Herbicides

Carrier Quality
Spray Solutions

- Water quality (spray solutions are >95% water)

- What goes in can affect what comes out

- Glyphosate is one of the best examples
  - pH – high pH causes glyphosate to dissociate
  - Cations – Mg, Ca, Na can bind to glyphosate
  - Turbidity – glyphosate tightly bound to soil and OM
Ammonium sulfate and glyphosate

• Glyphosate is antagonized by salts in hard water such as calcium, sodium, magnesium, and iron
  • These salts will preferentially bind to glyphosate

• Both ammonium (NH$_3^{1+}$) and sulfate (SO$_4^{2-}$) active
  • Free sulfate binds with Ca$^{2+}$, Na$^{1+}$, Mg$^{2+}$, or Fe$^{2+}$ ions in the spray water
  • Glyphosate binds to the ammonium
  • Glyphosate is more readily absorbed into foliage when combined with ammonium than when combined with Ca$^{2+}$, Na$^{1+}$, Mg$^{2+}$, or Fe$^{2+}$ ions
The Influence of Spray Water Quality on Herbicide Efficacy

What is Water Quality?

Water is a universal solvent, and it is used as a primary carrier for crop protection products applications, constituting more than 95% of the spray volume. The properties of water used for carrier in spray solutions can greatly influence the performance of herbicides including glyphosate, Ignite, Clarity, 2,4-D, Sharpen, Pursuit, Poast, Accent, and many other herbicides. Therefore, defining the role of water quality on herbicide efficacy is very important. Unlike pure water, water quality of groundwater is variable between sources. Water quality of groundwater is determined by several factors such as pH, hardness, alkalinity, turbidity, and temperature. Presence of dissolved cations like calcium, magnesium, iron, aluminum, zinc, manganese, sodium, potassium, cesium, and lithium can influence herbicide efficacy. The presence of calcium and magnesium carbonate makes water hard whereas carbonate and bicarbonate concentration determine the alkalinity of the water. The presence of soil and/or organic matter particulate leads to the turbidity in water.
Environmental factors

Dust
Temperature
Dust that accumulates on leaves can bind to glyphosate and prevent uptake.

Photo by Andrew Kniss PhD
Soil dust reduces glyphosate efficacy

Y-axis represents REDUCTIONS in herbicide efficacy

Taller bars mean less weed control with increased dust deposits

Temperature effects on herbicide performance

- Herbicide efficacy can be adversely affected by very low and very high temperatures.

- At temperature extremes, translocation and physiological activities may be reduced (which can primarily affect the efficacy of systemic herbicides).

- Plant growth, leaf area, leaf shape, and cuticle development can be impacted.

- High temperatures can affect the deposition, volatility and breakdown of many products.
Temperature and glyphosate

• Glyphosate translocation and distribution in plants can be inhibited at low temperatures

• Conversely, resistance to glyphosate is actually reduced in some species

• Horseweed
• Marestail
• Perennial ryegrass
• Rigid ryegrass
• Johnsongrass
• Junglerice
• Barnyardgrass

• Mechanisms are still under investigation
Weed Biology and Ecology

Identity
Because weed management strategies are not equally effective against all weeds

Selectivity

- Herbicides that target grasses vs broadleaf species
- Mowing that can differentially affect erect vs prostrate plants
- Cultivation that can control annuals but not perennials
- Timing of operations to target summer vs winter annuals
Herbicides and nutsedge control

- **Metolachlor = <20%**
  - **Glyphosate = 70%**
- **Metolachlor = 55-75%**
  - **Glyphosate = 55%**
Black polyethylene mulch is used as a weed barrier in many vegetable production systems.

YELLOW nutsedge shoot production was reduced in a mulched, as compared to bareground, system; PURPLE nutsedge shoot production increased under black plastic.
A successful identification provides you with the basic knowledge that you need to develop a successful management plan.

Ideally, control strategies will be adopted based on the sensitivity of a target species to control measures.
TRADITIONAL TOOLS
WEEDS OF THE WEST

Tom D. Whitson, et al.
Western Society of Weed Science


Descriptions of >350 species
Species comprise 51 plant families

“Truck Book”

NO LONGER IN PRINT
NO UPDATES
NO ADDITIONAL SPECIES ADDED
NO CHANGES IN TAXONOMY
WEEDS OF CALIFORNIA AND OTHER WESTERN STATES

- Joseph M. DiTomaso and Evelyn A. Healy
- UC ANR Publication 3488

- Volume 1: Aizoaceae - Fabaceae
- Volume 2: Geraniaceae - Zygophyllaceae
>700 species (>60 plant families) are described, photographed

Specific subjects of interest or else as a comparative species

~60% non-native species, ~40% native species

Photographs are provided on an included CD and are available use copyright free for educational purposes
2 identification keys for the grass species

13 ‘shortcut’ tables describing the differences between species that share unique or uncommon traits
- Species with prickles, spines, or thorns
- Parasitic plants

67 tables summarizing the differences between difficult-to-distinguish species
- *Amaranthus* (pigweed) species
- *Lepidium* (pepperweed) species

“Office book”
PHONE APPS
Centromadia parryi

`Centromadia parryi` (pappose tarweed) is a species of North American plants in the tarweed tribe within the sunflower family. It is native to California and, northern Baja California. [3][4]

**Scientific classification**

- **Kingdom:** Plantae
- **(unranked):** Angiosperms
PL@NTNET uses visual recognition software to compare your uploaded picture to a database of images.
AFTER SCANNING AND COMPARING YOUR IMAGE, PL@NTNET RETURNS A LIST OF POTENTIAL SPECIES

**Centromadia parryi**

*Centromadia parryi* (pappose *tarweed*)[^2] is a species of North American plants in the tarweed tribe within the sunflower family. It is native to California and, northern Baja California.[^3][^4]

[^2]: *Tarweed* is a common name for plants in the genus *Tragopogon*.
[^3]: California is a state on the west coast of the United States.
[^4]: Baja California is a state in Mexico located along the Pacific coast of the Baja Peninsula.
YOU CAN GET FURTHER INFORMATION ABOUT EACH SPECIES VIA A LINK THAT TAKES YOU TO ITS WIKIPEDIA PAGE

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**Centromadia parryi**

*Centromadia parryi* (pappose tarweed) is a species of North American plants in the tarweed tribe within the sunflower family. It is native to California and, northern Baja California.}

**Scientific classification**

- **Kingdom:** Plantae
- **(unranked):** Angiosperms
The Pl@ntNet app has multiple databases (projects) that a user can draw upon to evaluate a specimen depending on where they are in the world.
HOW DO YOU IMPROVE YOUR CHANCES?

Take clear and focused pictures

Minimize the background

Try submitting multiple images of different structures
  - leaves
  - flowers
  - spines or bracts

Photos by Lynn M Sosnoskie
Selective pressure isn’t limited to herbicide resistance

Lynn’s first rule of weed science:

“For every weed control action there is an adaptive weed reaction.”
Selective pressure isn’t limited to herbicide resistance

• Mowing:


• Impact of mowing and weed control on broadleaf weed population dynamics in turf

• Mowing to a height of 3-5 cm (1-2”) over two seasons increased broadleaf plantain (*Plantago major*) and dandelion (*Taraxacum officinale*), mouseear chickweed (*cerastium fontanum*) and prostrate knotweed (*Polygonum arviculare*) densities in turfgrass
Selective pressure isn’t limited to herbicide resistance

• Mowing:


• Impact of mowing and weed control on broadleaf weed population dynamics in turf

• Why?

• Close mowing favors naturally prostrate habits, shorter ecotypes, and perennials that have root reserves to re-grow.
Prostrate habit, root reserves, plastic responses
Selective pressure isn’t limited to herbicide resistance

• Mowing:

• Pirchio et al. (2018) Agronomy 8:15

• Autonomous mower vs. rotary mower: effects on turf quality and weed control in tall fescue lawn

• Use of a Husqvarna Automower 420 (turf mowing Roomba) resulted in lower turf height and higher densities of clovers (*Trifolium* *spp.*), a daisy (*Bellis* *perennis*), and a trefoil (*Lotus* *corniculatus*)
Selected for species that escaped mowing or expanded sideways in responses to the continuous and consistent short mowing heights
Selective pressure isn’t limited to herbicide resistance

• Irrigation:
  

• Field Bindweed Management in Drip-Irrigated Processing Tomatoes

• The adoption of drip-irrigation in processing tomatoes resulted in reduced numbers of annual weed species (due to reduced surface wetting that stimulated germination)

• However, the adoption facilitated the spread of field bindweed (*Convolvulus arvensis*).
Field bindweed is a perennial vine in the morning glory family.
Field bindweed below-ground

- Extensive root system
  - Vertical roots
  - Lateral roots
- Nutrient reserves to facilitate regrowth
- The species can take advantage of moisture that is deeper in the soil profile (such as that produced by buried drip irrigation)
Selective pressure isn’t limited to herbicide resistance

• Handweeding:


• Vavilovian Mimicry: Nikolai Vavilov and his Little-Known Impact of Weed Science

• Barnyardgrass (*Echinochloa crus-galli*) is incredibly diverse in form and habit and is often referred to as a complex of subspecies

• *Echinochloa crus-galli* subsp. *oryzicola* is a form that physically looks like rice and even flowers and sets seed at the same time as rice

• Consequently, it is often escapes hand-weeding attempts
Because of the similarity in appearance, barnyardgrass subsp oryzicola can be difficult to distinguish from actual rice in a field.

In this situation, barnyardgrass is left to grow and reproduce and further infest a field.
Why is this so complicated!

Picture by metaphysikhall
The ultimate point...

Understand how disturbance can select for deleterious species

Weeds possess characteristics that allow them to become established and persist in many different environments.

Disruptive forces (chemical, physical, environmental) select for species with traits that can survive those conditions.

Sometimes the forces are controlled by us (i.e. herbicides) and sometimes the forces are out of our control (i.e. drought).

Be aware of shifts towards difficult to control species in the wake of control events and diversify tools as much as possible.
THANK YOU

I CHANGED MY MIND... I DECIDED I DON'T WANT A GARDEN...
WHAT ABOUT ALL THE WEEDS I DUG UP?
PUT 'EM BACK WHERE THEY WERE...
I SHOULD HAVE NUMBERED THEM...

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