UNIVERSITY OF MINNESOTA | EXTENSION

MAKING A DIFFERENCE IN MINNESOTA: ENVIRONMENT + FOOD & AGRICULTURE + COMMUNITIES + FAMILIES + YOUTH

Development and Progression of Herbicide Resistant Weeds in MN (1980's to 2013)

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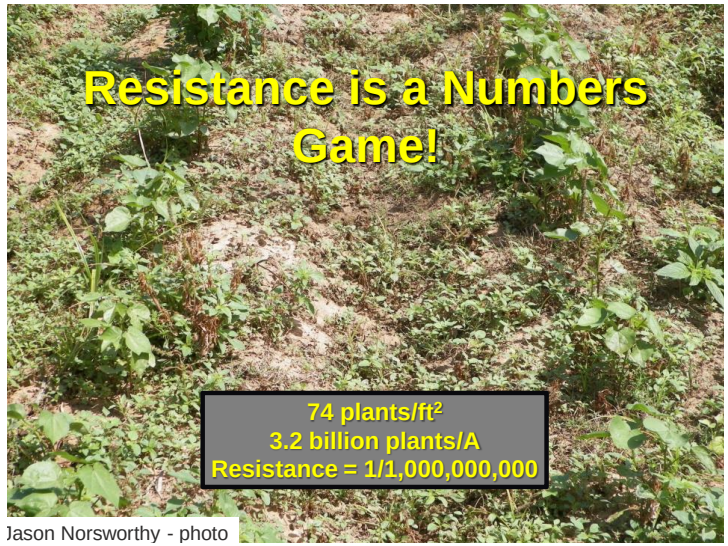
It can all start with one weed

Single waterhemp plant in 2011 (Clay County, MN)
actual seed number per plant = 142,000
Scenario: seed number on 1 plant in 1 acre = 100,000 seeds

Jeff Stachler -photo

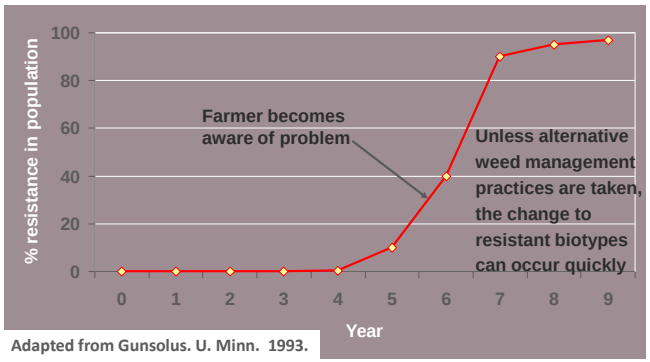
6,250,000 plants/A!! - 2 years later (2013)

Jeff Stachler - photo



Jason Norsworthy - photo

Hypothetical development of a weed population shift



Adapted from Gunsolus. U. Minn. 1993.

Jason Norsworthy - photo

Jason Norsworthy - photo

Jason Norsworthy - photo

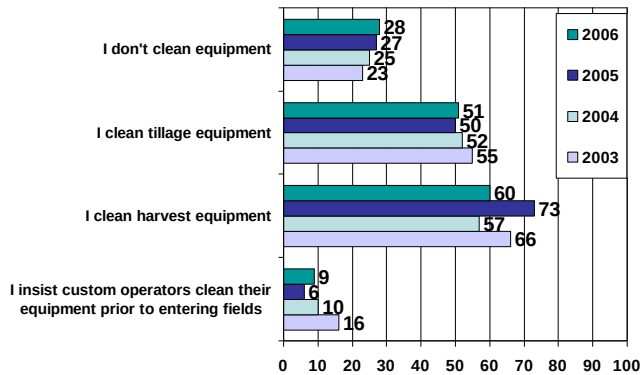
- Means of dispersal:
  - Water (especially for waterhemp)
  - Machinery
  - Wind
  - Humans
  - Animals / birds

MPR Photo/Ann Arbor Miller

Jeff Stachler - photo

Which of the following measures do you use to prevent the spread of new weed species?

IPM Assessment Survey – Breitenbach et al.



Herbicide Resistance WSSA Definitions

"**Herbicide resistance** is the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis."

"**Herbicide tolerance** is the inherent ability of a species to survive and reproduce after herbicide treatment. This implies that there was no selection or genetic manipulation to make the plant tolerant; it is naturally tolerant."

Mode of Action and Mechanism of Action

Herbicide Mode of Action: The plant processes affected by the herbicide, or the entire sequence of events that results in death of susceptible plants.
- Includes absorption, translocation, metabolism & interaction at the mechanism of action

Herbicide Mechanism of Action: The biochemical site within a plant with which a herbicide directly interacts. **Site of action** is sometimes used instead of mechanism of action.

Resistance mechanisms can evolve anywhere in the mode of action sequence

The term mode of action is often incorrectly used to refer to mechanism of action.

Examples of Mechanism of Action on Labels

GROUP 9 HERBICIDE

The product with this symbol on the label contains glyphosate, an active ingredient in Group 9; the mechanism of action is binding to the EPSP synthase enzyme resulting in inhibition of aromatic amino acid formation.

GROUP 5 HERBICIDE

The product with this symbol on the label contains atrazine, an active ingredient in Group 5; the mechanism of action is binding to the Q_B-binding niche on the D1 protein of the photosystem II complex in the chloroplast thylakoid membranes resulting in inhibition of photosynthesis.

GROU 15 9 27 HERBICIDE

The product with this symbol contains s-metolachlor, glyphosate, and mesotrione, active ingredients with three different mechanisms of action, designated by Group 15 - inhibition of very long chain fatty acids resulting in inhibition of cell division; Group 9 - binding to the EPSP synthase enzyme and Group 27 – inhibition of 4-HPPD resulting in bleaching of the plants, respectively.

SITE OF ACTION OPTIONS AVAILABLE IN CORN AND SOYBEAN

Available Corn SOA #'s	Available Soybean SOA #'s
	1
2	2
	3
4	
5	5
9	9
10	10
14	14
15	15
27	

The Main Drivers of Herbicide Resistance

- Selection intensity – using the same weed management tactic again and again
  - Need for diversification of weed management tactics
- Allowing weed population size to increase in the seed bank
  - Increases probability of a R-trait
  - Need to prevent pollen and seed production

The Goal of Weed Management

- The short-term goal of weed management is to preserve yield; weed management does not increase yield
- The long-term goal of weed management is to deplete weed seed reserves and prevent additions of seed to the seed bank

PROGRESSION OF RESISTANCE IN MINNESOTA

- Resistance cases in the 1980's focused on SOA#5 (atrazine) but were not an issue due to:
  - Reduced atrazine rates and use in MN
  - Trait maternally inherited
  - Fitness penalty for resistant plants
- My first significant educational effort regarding HRW's was in 1992 – triggered by wild oat resistance to SOA#1 in 1991 and widespread use of SOA#2 in the 1990's
- Initial focus was on single SOA resistance due to single gene mutations

Progression of Resistance in Minnesota

- In the 1990's MN farmers readily adopted postemergence weed control because it decoupled planting date from spray date
  - 75% market share of Pursuit herbicide by the mid-1990's.
- The ALS (SOA #2) technology of the time (e.g. Pursuit and Accent) quickly selected for several problem weeds but the problem was "solved" with glyphosate technology starting in1996
  - Waterhemp resistance documented in 1994 www.weedscience.org
- Our problem weeds now are no different than when we left the Pursuit and Accent era of the 1990's
- We need to rethink the total postemergence approach and diversify our weed management strategies

MN Soybean Herbicide Use Data
est. 6.9 million acres in 2012

	Soybean Area Applied PPI/PRE (%)	Area Applied w/glyphosate (%)
2006	2	98
2004	15	85
2002	23	79
1999	39	48
1996	62	7
1994	71	4
	RR Soybean introduced in 1996	

In the mid-1990's ~75% of the acres were using a SOA #2 herbicide. By 2006 this was reduced to <2% of the soybean acres

WEED EMERGENCE PATTERNS AND THE EFFECT OF TIME OF WEED REMOVAL ON SOYBEAN

Roundup PowerMax 30 fl oz/a + **AMS** 8.5 lb/100gal
Applied at V1 on May 18, 2012

Roundup PowerMax 30 fl oz/a + **AMS** 8.5 lb/100gal
V3 on June 4, 2012

Roundup PowerMax 30 fl oz/a + **AMS** 8.5 lb/100gal
V5 on June 12, 2012

July 19, 2012 **Roundup PowerMax** 30 fl oz/a + **AMS** 8.5 lb/100gal July 27, 2012

MN Corn Herbicide Use Data

est. 8.7 million acres in 2012

Year	Corn Area Applied PRE (%)	Rate of Acetochlor lbs. ai/A	Area Applied w/ glyphosate (%)
2007	23	1.35	73
2005	49	1.27	49
2003	50	1.73	22
2002	43	1.58	11
1999	62	1.61	7
1996	73	1.72	0
		RR Corn Introduced in 1998	

WEED EMERGENCE PATTERNS AND THE EFFECT OF TIME OF WEED REMOVAL ON CORN

Lamberton, 3-4 inch weed removal date - June 18, 2005

204 bu/A

WEED EMERGENCE PATTERNS AND THE EFFECT OF TIME OF WEED REMOVAL ON CORN

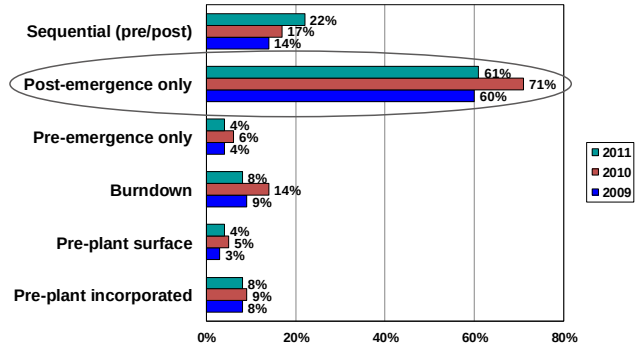
Lamberton, 9-12 inch weed removal date – July 1, 2005

170 bu/A

Which herbicide application timings do you usually use in SOYBEANS

(could select >1 answer)

IPM Assessment Survey – Breitenbach et al.



Which herbicide application timings do you usually use in CORN

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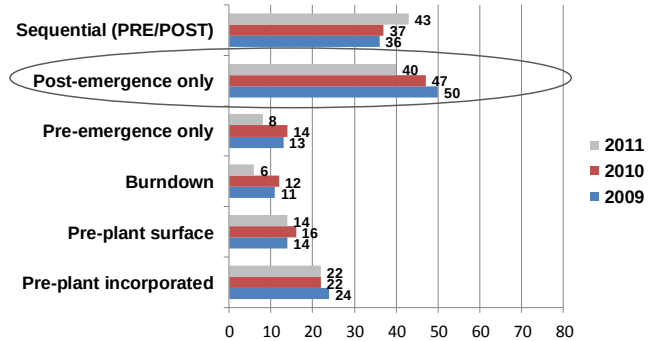
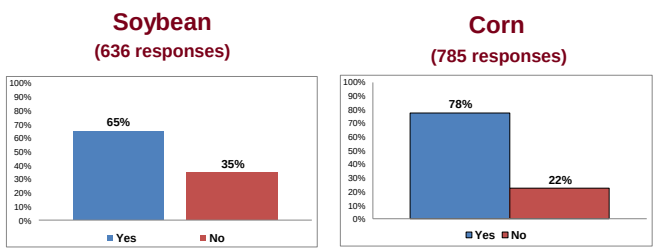


2013: Do you Plan to Use a Pre-emergence Herbicide in …….?

IPM Assessment Survey – Breitenbach et al.



Impediments to Weed Management

- Durable Weed Management Practices Also Got Sidetracked by One-Year Farming Business Cycles

Prevention vs. Remediation

  - "Farmers are loathe to institute complicated preemptive resistance management schemes, especially if they cost more. Still, the best remedial strategy is to look over one's shoulder and learn from the mistakes of others. When there is resistance somewhere to a pesticide under a similar cropping system, it is time to get scared, and not to say "it hasn't happened here, therefore it won't". When the first resistance appears, and it is not spread throughout the population, further enrichment of resistant individuals in the population can be delayed."

Jonathan Gressel et al. **1996**.
In Molecular Genetics and Evolution of Pesticide Resistance
ACS Symposium Series; American Chemical Society; Washington, DC

PROGRESSION OF RESISTANCE IN MINNESOTA

- Earlier cases focused on SOA#5 (atrazine) in the 1980's were not an issue due to:
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Factors Affecting Speed of Selection

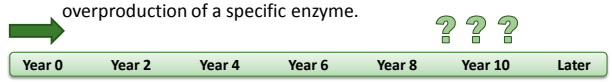
The length of time for selection of resistance varies by :

Cultural practices

Frequency of herbicide use

Herbicide mechanism of action

- Biology of weed species
- Frequency of resistant biotypes among weed species
- Mechanism of herbicide resistance
  - Differential uptake and translocation, compartmentalization and detoxification generally takes longer to evolve than altered SOA or overproduction of a specific enzyme.



Herbicide Resistance Characteristics

Low-Level Resistance

- A continuum of plant responses from slightly injured to nearly dead
- The majority of plants display an intermediate response
- Susceptible plants will be present in the population, especially when herbicide resistance is determined early

Examples

Roundup, etc.	GROUP	9	HERBICIDE
Reflex, Valor, etc.	GROUP	14	HERBICIDE
Clarity, 2,4 D, etc.	GROUP	4	HERBICIDE
Gramoxone, etc.	GROUP	22	HERBICIDE

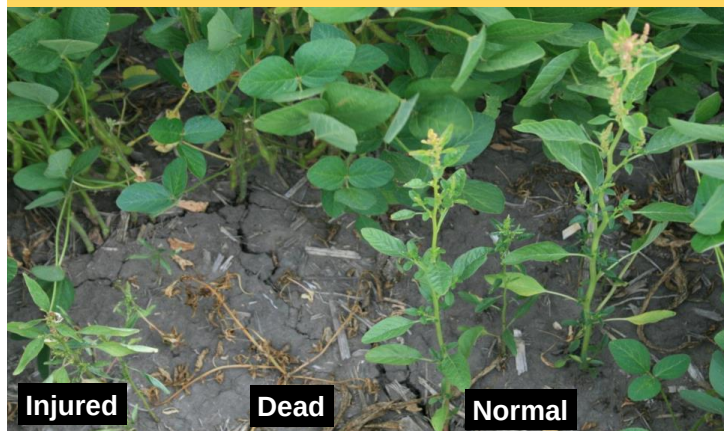
High-Level Resistance

- Plants are slightly injured to uninjured
- Few plants have an intermediate responses
- Susceptible plants can be present in the population

Examples

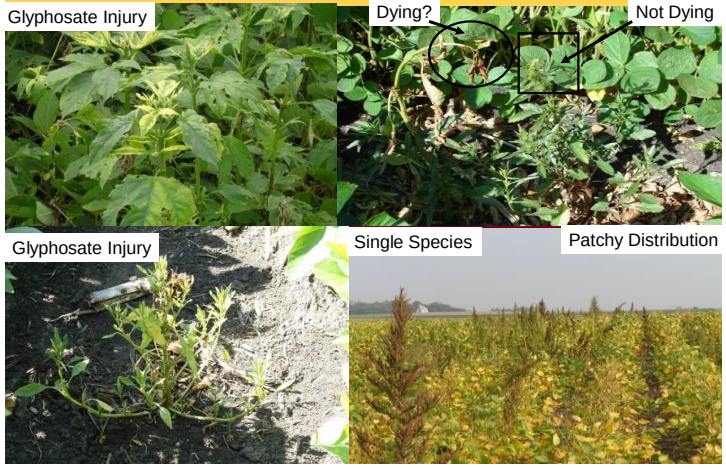
atrazine, Sencor, etc.	GROUP	5	HERBICIDE
Classic, Permit, FirstRate, etc.	GROUP	2	HERBICIDE
Select, Assure, etc.	GROUP	1	HERBICIDE

Low-Level Herbicide Resistance



What Does Glyphosate Resistance Look Like?

Photo Credits to Dave Nicolai & Jeff Stachler



PROGRESSION OF RESISTANCE IN MINNESOTA

- Rates of resistance development were greatest with SOA's #1, and 2 and longer for 9
- Debates of tolerance vs. resistance and level of resistance slowed our response to glyphosate
- Issue grew from single to multiple species of concern
- Issue grew to multiple-resistance
- Issue is now evolving to multiple mechanisms of resistance to a particular herbicide
- End result is increasing risk uncertainty of herbicide effectiveness and available options

PROGRESSION OF RESISTANCE

OUR CURRENT SITUATION - MULTIPLE RESISTANCE

SITE OF ACTION OPTIONS AVAILABLE IN CORN AND SOYBEAN

Available Corn SOA #'s	Available Soybean SOA #'s
	1
2	2
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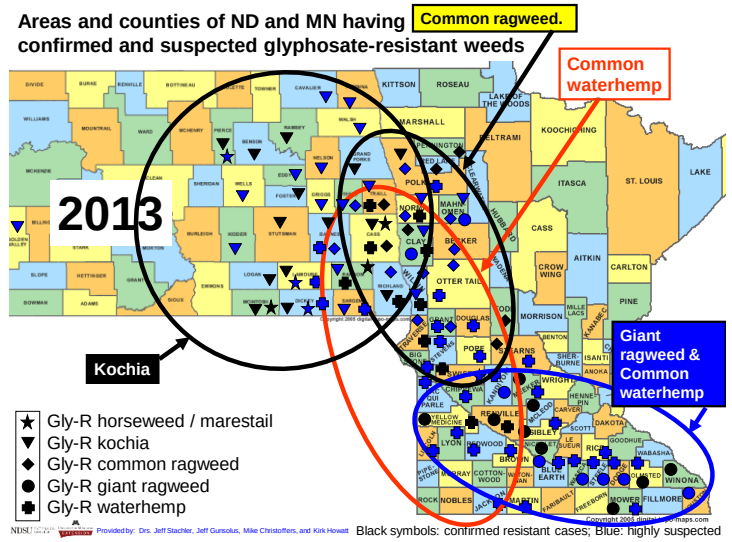
27	

Impacts of Herbicide Resistance to Weed Management Strategies

- ISU Reports waterhemp responses to labeled herbicide rates indicate:
  - 95% of the populations are resistant to SOA #2 - ALS
  - 58% of the populations are resistant to SOA #5 - Atrazine
  - 54% of the populations are resistant to SOA #9 – Glyphosate
  - 28% of the populations are resistant to SOA #27 – HPPD
  - 6% of the populations are resistant to SOA #14 – PPO
  - **30% of the populations are resistant to SOA#'s 2,5,9**

- Resistance to multiple SOA's is also not uncommon
  - Consider establishment of RR alfalfa in a field of Giant Ragweed resistant to SOA #9 and #2



TAKE ACTION

A UNITED SOYBEAN BOARD / EXTENSION WEED SCIENCE THEME

Weed Out Resistance
- **Know Your Weeds**
- Know Weed Growth
- Know Weed Seed Characteristics
- Know Herbicide Resistance

In Field Tactics
- Rotate Crops
- Rotate and Use Multiple Herbicide Sites of Action
- Increase Cultivation

Spray Attention
- **Know Herbicide Site of Action** and Herbicide Properties
- Manage Drift
  - Know environmental Conditions
  - Know Your Neighbors Crops

The Bottom Line
- Manage Risk
- Know Cost-Benefits of Practices
- Know the Cost of Poor Weed Control

MN Soybean Research & Promotion Council Funded Take Control

- ❑ **Now is the time to *Take Control***
- ❑ **Develop *Long Range Durable Plans***
- ❑ **Use *PRE/POST* Herbicide *Systems* on your farm.**
- ❑ **Integrated Weed Mgmt. is more than Integrated Herbicide Mgmt.**

Weed Biology is Important to Weed Management

Biological Parameters	 Giant Ragweed	 Lambsquarters	 Common Ragweed	 Waterhemp
Time of Emergence	**Early** 10% by 150 GDD	**Early** 10% by 150 GDD	**Moderate** 10% by 300 GDD	**Late** 5% by 150 GDD
Duration of Emergence	**Short**	**Moderate**	**Moderate**	**Prolonged**
Depth of Emergence	**< 6 inches**	**< 1 inch**	**<2 inches**	**< 1 inch**
Relative Competitiveness (0 – 10)	**10** **Our most competitive weed species**	**3**	**3**	**1.5**

Lower your risk of developing herbicide-resistant weeds

Reference Corn + Soybean Digest, Nov. 2013

- Identify your main target weeds
- Use effective, multiple SOA's (2 - 3) on target weeds
- Rotate SOA's by year (multi-year planning)
- Start with a preemergence herbicide
- Note SOA groups that have a low risk for selecting for herbicide-resistant weeds (e.g #15)
- Control weeds when they are small
- Don't let escapes produce seed

Weed Biology is Important to Weed Management

Biological Parameters	 Giant Ragweed	 Lambsquarters	 Common Ragweed	 Waterhemp
Seed Production Potential (w/o competition)	10,300 per plant	72,500 per plant	3,500 per plant	35,000 per plant
Seed Dormancy	Requires over wintering	Increases as burial depth increases	Requires over wintering	Increases as burial depth increases
Seed Longevity	**99% depletion in 2 years**	**50% depletion in 12 years**	**50% depletion in 1 year**	**50% depletion in 3 years**
Rate of Decay	Greatest predation on soil surface	Approx. 20% in first winter at 1-4 inch depths	Greatest predation on soil surface	No information found

WHEN PLANNING A HERBICIDE RESISTANCE MANAGEMENT STRATEGY CONSIDER:

This approach requires some planning and isn't as easy as the multiple application, glyphosate approach to weed management but it is still

A LOT EASIER THAN……

Hand Weeding

Watch for Hidden Impacts of Herbicide Resistance

Hidden Impacts of Herbicide Resistance

- As the frequency of herbicide resistant traits increase the likelihood of migration increases
  - Palmer Amaranth in MI, IN, WI via cotton seed for dairy and CRP
  - Movement via forage
  - Movement via manure
  - Movement via combine
  - Movement via pollen (yards not miles)
  - Movement via water (runoff and flooding)
  - Movement from ditch banks and field margins

Palmer amaranth

Credit – Christy Sprague Mich. State University

- *Amaranthus palmeri* - "Palmer pigweed"
- Native to the desert Southwest
  - Thrives in hot climatic conditions
  - Tolerant to drought
- One of 10 common pigweed species in the great plains and southeast U.S.
- Not common in the upper Midwest
  - No reports of Palmer amaranth found in U of M herbarium

NOTE PALMER'S RAPID GROWTH RATE

Waterhemp on left, Palmer amaranth on right, both planted on the same day

Time of postemergence weed control is a function of timing The Difference of 2 Days!

The Cost of Reactive Weed Management Strategies

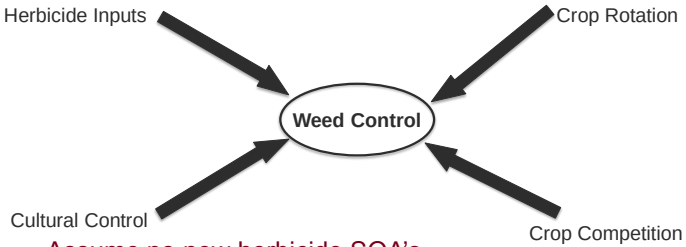
- Remediation requires the need to deplete weed seed reserves
  - Published net increases in production costs
    - $19.40/A for glyphosate R palmer amaranth in GA/AR
    - $19.40/A for glyphosate R waterhemp in MO
    - To attain zero seed production of Palmer amaranth in AK now requires 5-8 herbicides + hoeing
  - Translating net increases in soybean production costs to MN farmers
    - $133,860,000 increase in production costs and this estimate does not include losses due to weed competition

If Herbicide Resistant Weeds Continue to Increase, What is at Risk in MN Corn and Soybean Cropping Systems?

- **Loss of:**
  - **Yield and Profit**
  - **Loss of Technology**
- **Multiple resistance**
- **Replenished weed seed banks**
- **Applicator stress**
- **Loss of simplified weed control and flexibility in choosing your cropping system**

Photo by Liz Stahl – Regional Extension Educator Minnesota Extension Service

Rethink our weed management strategies



- Assume no new herbicide SOA's
- What non-chemical weed management tactics should we encourage farmers to adopt over the next couple of years?

Rethink our weed management strategies

Herbicide Inputs
- Move away from Total Post & One-Pass Post with delayed PRE
- Start with a PRE
- Post – target max. of 3-inch weeds

Crop Rotation
- Goal is to reduce the seed bank

Weed Control

Cultural Control
- Inter-row cultivation
- Increase crop seeding rate
- Work fields closer to planting date
- Delay planting if targeting early-emerging weeds
- Develop weed maps

Crop Competition
- Via Crop Rotation
- Focus on early-season weed control
- Narrow rows

Delaying weed emergence by just one week can make an enormous difference in weed growth and competition with the crop. (Courtney is 6 feet, 3 inches tall.)

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Final Points – Weeds reflect management practices

Herbicide resistance can start with just one weed