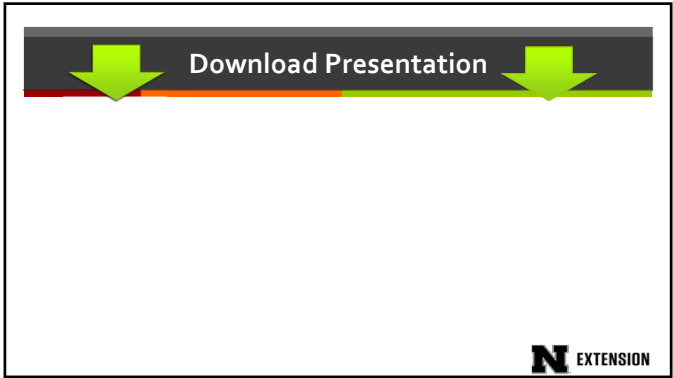
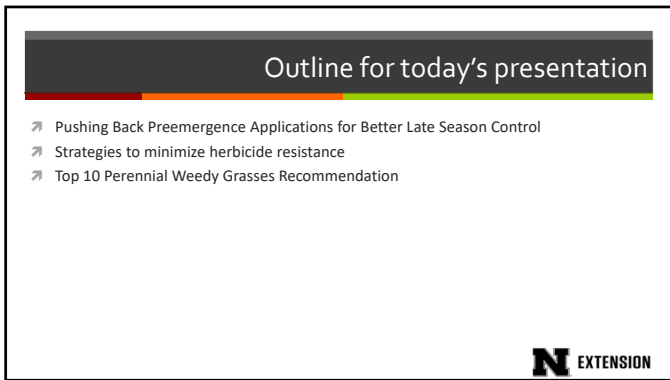




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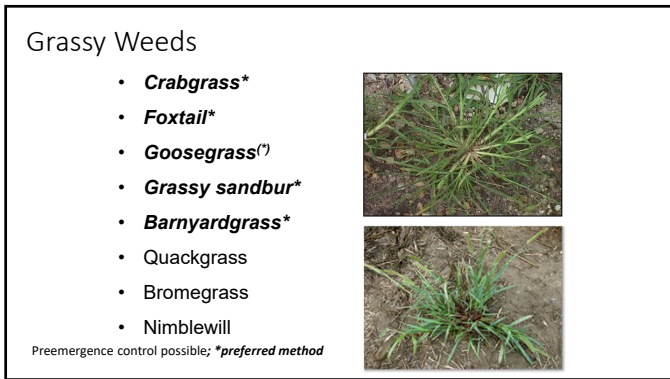
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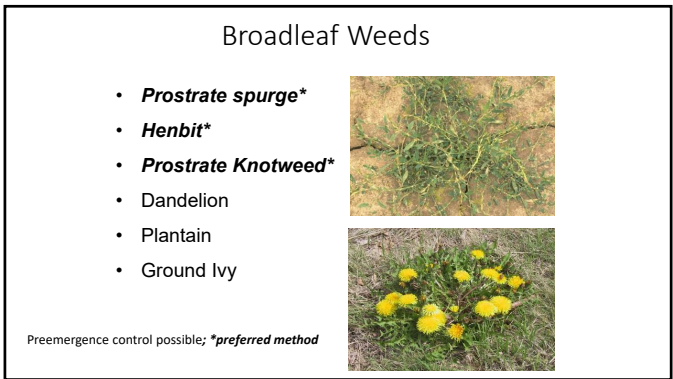
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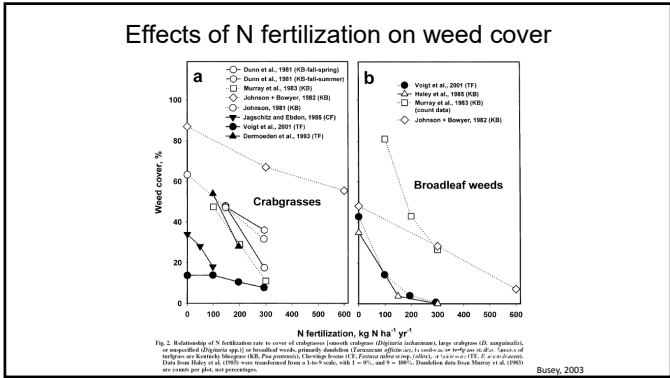
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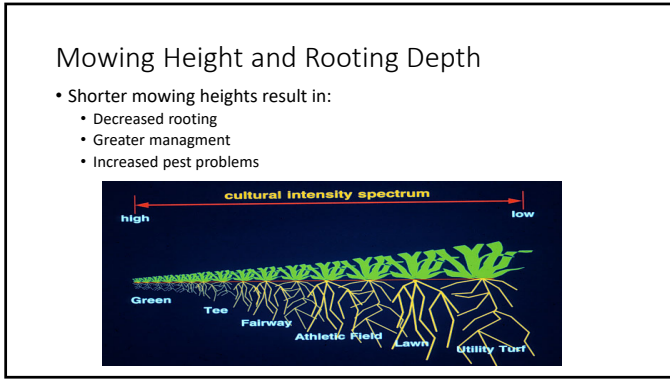
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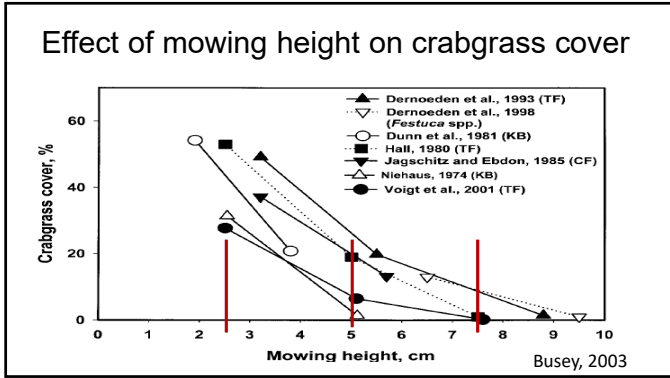
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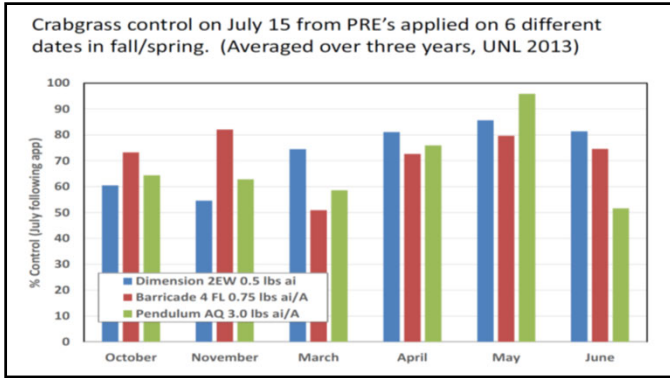


11

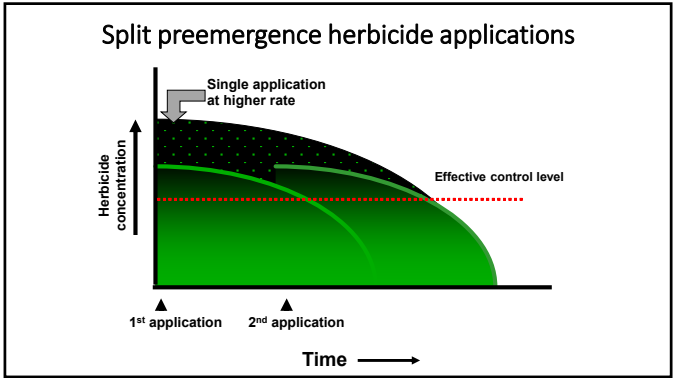
### When to apply preemergence herbicides

- Soil temperatures exceed 50° F
- Occurs first:
  - In landscape beds
  - Thinned turfgrass
  - Near sidewalks
- Better to apply early than late

12



13

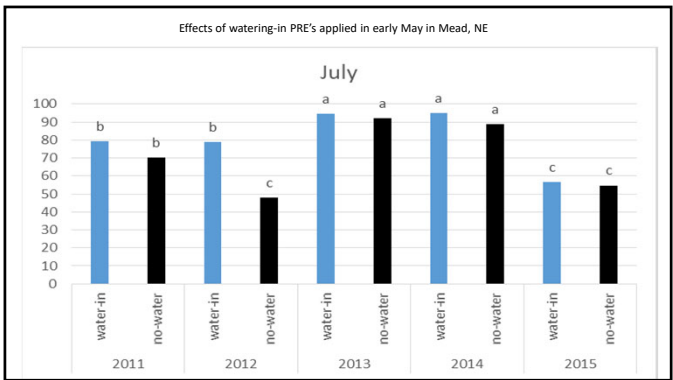


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Preemergence Herbicide "efficacy"

- Less than adequate control
- Timing and application rates are correct, so...?
- Reasons for "failure"
  - Poor turf conditions
  - Tough weeds/lots of them
  - High rainfall/irrigation
  - Non-Uniform application
  - Insufficient early irrigation/rainfall

15



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Effective Use of Preemergence Herbicides

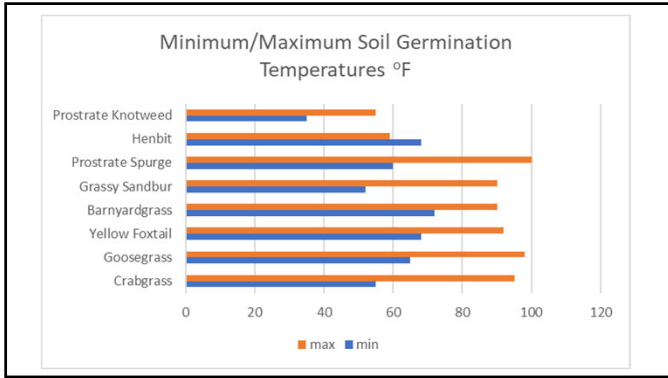
- Start with healthy turf
- Better to apply too early
- App timing is flexible within reason (earlier/split apps)
- Water in
- Uniform application is essential
- Label rates
- Split applications can provide extended season control

17

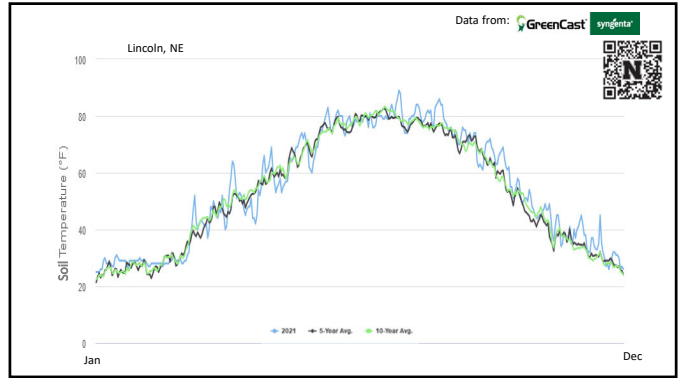
Weed Seed Germination Soil Temperatures

- Crabgrass >55° to 60°F for 7 to 10 days up to 95°F
- Goosegrass >65°F for several weeks
- Yellow Foxtail 68° to 92°F
- Barnyardgrass 72° to 90°F
- Grassy Sandbur 52 F to 75 F
- Prostrate Spurge 60°F to 100°F
- Henbit 68 and 59
- Prostrate Knotweed 35-40 cease at 50° F

18



19

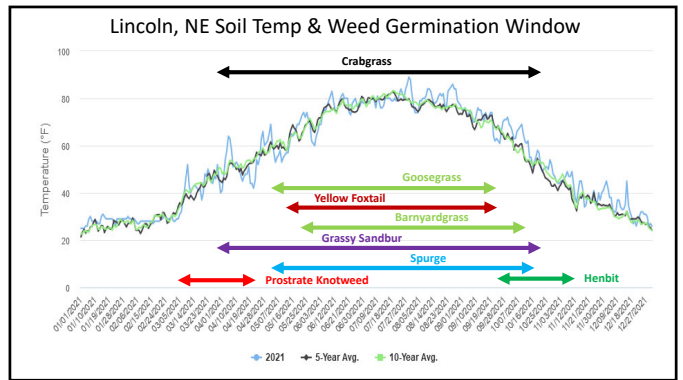


20

### Weed Seed Germination Soil Temperatures

- Crabgrass >55° to 60°F for 7 to 10 days up to 95°F
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- Prostrate Spurge 60°F to 100°F
- Henbit 68 and 59
- Prostrate Knotweed 35-40 cease at 50° F

21



22

### Show me the data!

- Barricade (prodiamine), Dimension (dithiopyr) and Pendulum (pendimethalin) applied at full rate on May 1 or June 1, 2022
- Same applied at ½ rate on May 1 FB same on June 15
- Drive XLR8 (quinclorac) applied at full rate on June 1
- Drive XLR8 applied with each pre on June 1
- 2 locations in proximity, one with heavy crabgrass and one with heavy yellow foxtail
- Data collected on cover and converted to % control based on untreated

23

-----% Control-----

	July 9, 2022		August 29, 2022	
	Crabgrass	Foxtail	Crabgrass	Foxtail
Untreated Check	0h	0g	0f	0g
Dimension 2EW	2 pt/a 1-May	100a	45cde	94a
Dimension 2EW	1 pt/a May 1-June 15	92ab	13fg	68a-d
Barricade 4FL	30 fl oz/a May 1	90ab	18efg	76abc
Barricade 4FL	15 fl oz/a May 1-June 15	44efg	25efg	37de
Pendulum Aquacap	4.2 pt/a May 1	95ab	24efg	89a
Pendulum Aquacap	2.1 pt/a May 1-June 15	89ab	21efg	78ab
Dimension 2EW	2 pt/a June 1	84abc	32def	69a-d
Barricade 4FL	30 fl oz/a June 1	31fg	23efg	20ef
Pendulum Aquacap	4.2 pt/a June 1	27g	15fg	17ef
Drive XLR8; Dimension	64; 30 oz/s, pt/a June 1	90ab	98a	45b-e
Drive XLR8; Barricade	64; 30 oz/s, pt/a June 1	85abc	88a	43cde
Drive XLR8; Pendulum	64; 4.2 oz/s, pt/ac June 1	83ab	93a	46b-e
Drive XLR8 + MSO	64 fl oz/a June 1	73bcd	78ab	34ef

24

-----% Control-----

	July 9, 2022		August 29, 2022	
	Crabgrass	Foxtail	Crabgrass	Foxtail
Untreated Check				
Dimension 2EW	1 pt/a	May 1-June 15	92ab	13fg
Barricade 4FL	15 fl oz/a	May 1	90ab	18efg
Pendulum Aquacap	4.2 pt/a	May 1	95ab	24efg

25

-----% Control-----

	July 9, 2022		August 29, 2022	
	Crabgrass	Foxtail	Crabgrass	Foxtail
Untreated Check				
Dimension 2EW	1 pt/a	May 1-June 15	92ab	13fg
Barricade 4FL	15 fl oz/a	May 1	90ab	18efg
Pendulum Aquacap	4.2 pt/a	May 1	95ab	24efg
Dimension 2EW	1 pt/a	June 1	84abc	32def
Barricade 4FL	30 fl oz/a	June 1	31fg	23efg
Pendulum Aquacap	4.2 pt/a	June 1	27g	15fg

26

-----% Control-----

	July 9, 2022		August 29, 2022	
	Crabgrass	Foxtail	Crabgrass	Foxtail
Untreated Check				
Dimension 2EW	1 pt/a	May 1-June 15	92ab	13fg
Barricade 4FL	15 fl oz/a	May 1	90ab	18efg
Pendulum Aquacap	4.2 pt/a	May 1	95ab	24efg
Drive XLR8; Dimension	64; 2 oz/a; pt/a	June 1	90ab	98a
Drive XLR8; Barricade	64; 30 oz/ac	June 1	85abc	88a
Drive XLR8; Pendulum	64; 4.2 oz/a; pt/ac	June 1	83ab	93a
Drive XLR8 + MSO	64 fl oz/a	June 1	73bcd	78ab

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### Summary

- Apply early rather than later
- Split apps with lower rates were problematic
- Foxtail populations were near 100% resulting in poor control and questionable data for objective
- Use of post emergence annual grass herbicides (quinclorac (Drive); mesotrione (Tenacity); topramezone (Pylex) provides added benefit in timing flexibility and broadleaf activity

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### Herbicide Resistance - Definition

➤ Genetic characteristic of a weed or plant biotype to survive a herbicide application

*Biotype = a group of plants within a species that has biological traits that are not common to the population as a whole.*

➤ Interestingly, plants also have a genetic capacity to develop resistance to many abiotic stresses like drought, heat, cold etc. based on exposure and subsequent selection pressure

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### Herbicide-resistance Mechanisms in Weeds

**Target Site**

- Altered site of action
  - Mutation in gene coding for herbicide target site; prevents herbicide binding.
  - Overproduction of the site of action.

**Non-Target Site**

- Reduced translocation - decreased absorption and translocation.
- Enhanced metabolism - converts herbicide to a form no longer toxic.
- Sequestration - isolation of herbicide in vacuoles or intracellular spaces.





Image from Herbicide Resistance: Development and Management, New Mexico State University.

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### Herbicide Resistance

- **Cross resistance**
  - Weed biotype that has gained resistance to more than one herbicide with the same mode/mechanism of action. Same or different families.
    - Group 4 – synthetic auxins, i.e. 2,4-D, MCPA, dicamba, triclopyr
- **Multiple resistance**
  - Weed biotype that has developed tolerance to more than one herbicide (or stress) brought about by different selection pressures (*different modes/mechanism of action*).
    - Annual bluegrass (9 MOAs) and goosegrass (8 MOAs)




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### Herbicide Resistance - Around the World (2020)

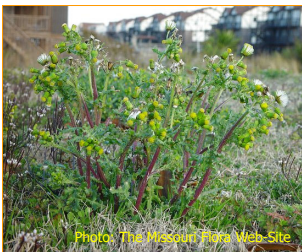


- 509 Resistant Biotypes
- Resistance identified in 21 of the 31 herbicide sites of action: 164 different herbicides
- 266 Species (153 dicots and 113 monocots)
- More than 270,000 locations in 71 countries




32

### The Beginning of Documented Weed Resistance

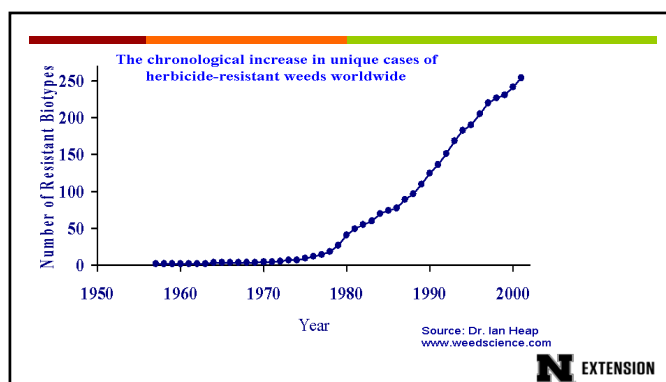


- 1968 (Washington)
- nursery crops
- common groundsel
- atrazine and simazine

Photo: The Weed Science Web Site



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### Weed Characteristics That Favor Resistance

- **Reproductive capability**
  - High seed production
  - High germination rate
- **Seed dispersal mechanisms**
  - Method(s) by which plant spread seeds.
  - Wind, animals, equipment


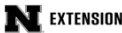


Image from Annual Bluegrass, Purdue University.



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### Herbicide Characteristics/Strategies Impacting Weed Resistance

- Single site of action
- Used multiple times during the growing season
- Used for consecutive growing seasons
  - Resistance can be developed within 2 years depending on species and/or herbicide
- Used without other control strategies

**Single site of action herbicides**

Several herbicide families only interfere with a single site of action. They include the following:

- ALS inhibitors (Group 2)
- ESPS synthase inhibitors (glyphosate) (Group 9)
- AACase inhibitors (Group 1)
- Seedling root inhibitors (Group 3)
- Photosynthesis inhibitors (Groups 5-7)
- Cell membrane disrupters (Groups 14 and 22)
- Pigment inhibitors (Groups 12, 13 and 27)



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### Herbicide Resistance Should Only Be Suspected When ...

- Other causes of herbicide failure have been ruled out.
- The same herbicide or herbicides with the same mode of action have been used year after year.
- Weeds normally controlled are not, while others weeds of the same species are.
- Healthy weeds are mixed with controlled weeds (same species).
- Patch of uncontrolled weeds is spreading, following multiple applications of the same herbicide.

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### Causes of Herbicide Failures

➤ Weed size	➤ Rate
➤ Moisture	➤ Application method
➤ Temperature	➤ Calibration
➤ Humidity	➤ Others

*All possible reasons for reduced control which should be investigated before considering the possibility of resistance.*





Image from Annual Bluegrass, Purdue University.

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### Strategies for Control/Prevention of Resistance




Light green annual bluegrass in trafficked, compacted soil. Image from Annual Bluegrass, Purdue University.

- Proactive vs. reactive
- Use other weed management tactics (healthy turf, mowing, compaction control, deficit irrigation)
- Rotate herbicides with different MOA
- Prevent seed production
- Clean mowing and cultivation equipment

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**Ross Braun** (@ross\_braun)

These two lawns were established with the same sod at the same time (2017). Both lawns have never received a pesticide application. However, one is fertilized twice a year (mainly fall) and mowed higher all year. [pic.twitter.com/2k4Hy0nEYp](https://pic.twitter.com/2k4Hy0nEYp)

7/31/20, 7:24 AM

Note: both receive similar amounts of water (rain only with no in-ground irrigation) with the one on the right receiving hose sprinkler watering when minimal rain has occurred for 3+ weeks.


**Management matters (KB in Indiana)**

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### Herbicide-resistant weeds in turfgrass: Current status & emerging threats (Brosnan et al, 2020)

Documented cases:

- smooth crabgrass (NJ)
- goosegrass (SE-US; cross resistance)
- annual bluegrass (world; cross resistance)
- annual sedge (*Cyperus* sp; SE-US)
- spotted spurge (SE-US)
- yellow nutsedge (in rice; halosulfuron)
- buckhorn plantain (IN, PA)
- barnyard grass
- green foxtail



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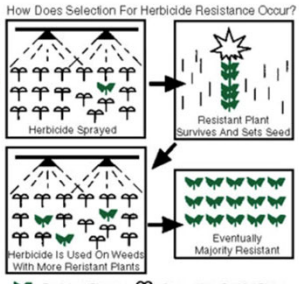
### How does it happen? Two possibilities.

➤ Survival of the fittest (*I did everything right!*)

- Selects for naturally occurring resistance in pest population.
- Selection pressure.

➤ What happened to my genes (*mutagenesis*)?

- Induced physiological changes in plant.
- Extremely rare in plants, confined mostly to virus and other "simple" organisms.



**How Does Selection For Herbicide Resistance Occur?**

Herbicide Sprayed → Resistant Plant Survives And Sets Seed → Eventually Majority Resistant

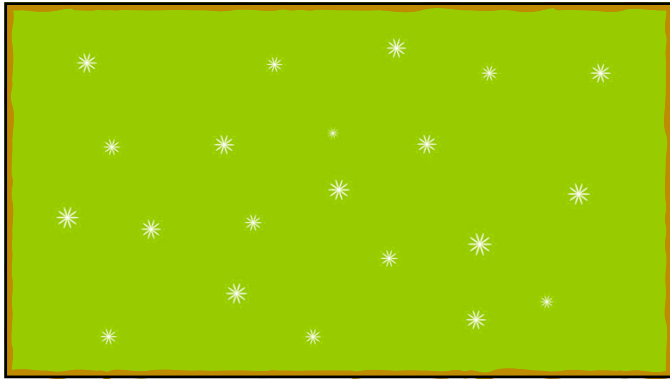
Herbicide Is Used On Weeds With More Resistant Plants

☐ = Resistant Biotype    ☐ = Susceptible Or Wild Biotype

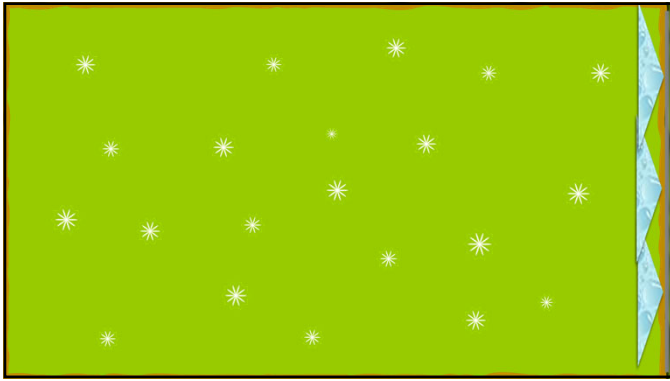
Figure 4: Selection begins when an herbicide-resistant biotype survives an herbicide application. The resistant biotype survives, matures and sets seed. Eventually, the majority could be resistant.

Image from Herbicide-resistant Weeds, University of Minnesota Extension.

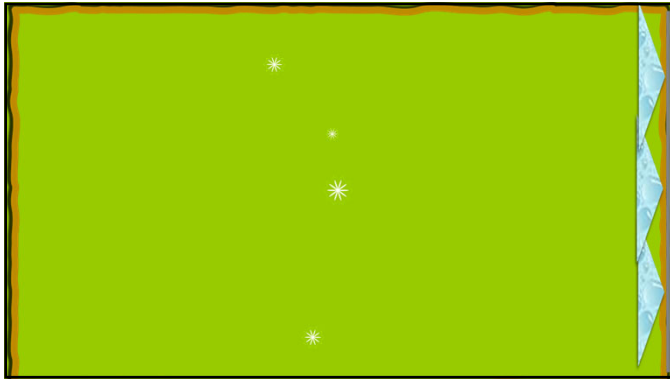
42



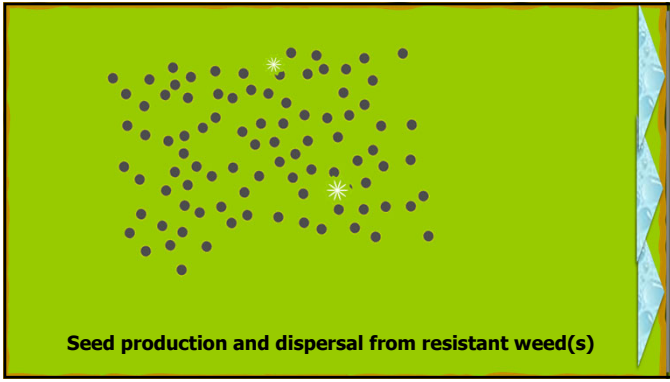
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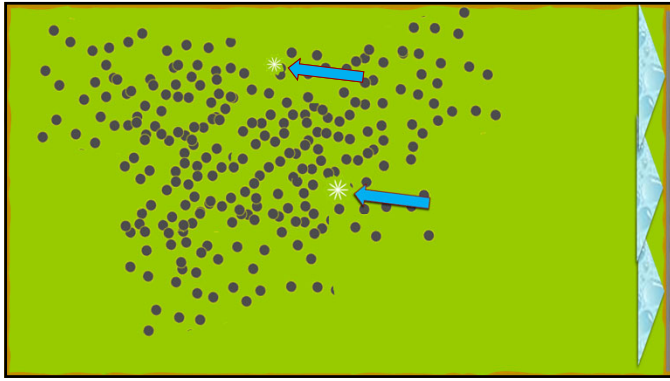
44



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Summary of Herbicide Mechanism of Action  
Weed Science Society of America (WSSA)

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 A slide with a dark grey header containing the text "Summary of Herbicide Mechanism of Action" and "Weed Science Society of America (WSSA)". Below the header is a large QR code with a large white letter 'N' in the center. In the bottom right corner, there is a logo consisting of a large 'N' followed by the word "EXTENSION".

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### Summary of Herbicide Mechanism of Action According to the Weed Science Society of America (WSSA)

- 1 Acetyl CoA Carboxylase (ACCase) Inhibitors**  
 Aryloxyphenoxypropionate (OPP) cyclohexanedione (DHMA) and phenylpyrazolin (OENAs) herbicides inhibit the enzyme acetyl-coA carboxylase (ACCCase), the enzyme catalyzing the first committed step in the fatty acid synthesis pathway (Burton 1989; Ficks and Schramm 1987). Inhibition of fatty acid synthesis practically blocks the production of phospholipids used in building new membranes required for cell growth. Broadleaf species are naturally resistant to cyclohexanedione and aryloxyphenoxy propionate herbicides because of an insensitive ACCCase enzyme. Similarly, natural tolerance of some grasses appears to be due to a less sensitive ACCCase (Stoltzberg 1989). An alternative mechanism of action has been proposed involving destruction of the electrochemical potential of the cell membrane, but the contribution of this hypothesis remains in question.
- 2 Acetolactate Synthase (ALS) or Acetylhydroxy Acid Synthase (AHAS) Inhibitors**  
 Imidazolinones, pyrimidinylthiohiozates, sulfonaminoacetylthiazolidinones, sulfonureas, and steviolglycosides are herbicides that inhibit acetolactate synthase (ALS), also called acetylhydroxyacid synthase (AHAS), a key enzyme in the biosynthesis of the branched-chain amino acids isoleucine, leucine, and valine (Lafosse and Schloess 1984). Plant death results from events occurring in response to ALS inhibition and low branched-chain amino acid production, but the actual sequence of phytotoxic processes is unclear.
- 3 Mitoisa Inhibitors**  
 Benzamide, benzoic acid (DCPA), dinitroanilines, phosphoramidate, and pyridine herbicides (Group 3) are examples of herbicides that bind to tubulin, the major microtubule protein. The herbicide-tubulin complex inhibits polymerization of microtubules at the assembly end of the protein-based microtubule but has no effect on reorganization of the tubule on the other end (Vaughn and Johnson 1981). Inactive to a loss of

Sample Partial Page

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**Mechanism/Mode of Action**

**Be Aware: Generic pesticides may not have the designation on the label**

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**4 active ingredients;**  
 3 are Group 4  
 1 is Group 14

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### Examples

- Rotate halosulfuron (**Group 2**) with mesotrione (**Group 27**) or sulfentrazone (**Group 14**) or bentazon (**Group 8**) for postemergence yellow nutsedge control
- Rotate pendimethalin, proflaminate, dacthal, dithopyr, benefin, oryzalin (**Group 3**) with mesotrione (**Group 27**) or oxadiazon (**Group 14**) or bensulfide (**Group 8**) or siduron (**Group 7**) for pre-emergence annual grass control
- Rotate 2,4-D, dicamba, MCPA, clopyralid, fluroxypyr (**Group 4**) with carfentrazone (**Group 14**) or mesotrione (**Group 27**) or quinclorac (**Group 26; Group 4?**) for postemergence broadleaf weed control

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### Pesticide resistance can be reduced by:

1. Using a pesticide until resistance develops than switch to another one.
2. Rotate different pesticides.
3. Rotate pesticides with different mode/mechanism of action (MOA) along with appropriate weed management practices.

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### Perennial Grass Control

*“The best way to control undesirable perennial grasses in the lawn is to spot treat with glyphosate.” (1994)*

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### Perennial Grass Control Top 10

- Windmillgrass
- Nimblewill
- Tall Fescue
- Orchardgrass
- Quackgrass
- Creeping Bentgrass
- Rough Bluegrass
- Smooth Brome
- Bermudagrass
- Zoysiagrass

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### Windmillgrass – *Chloris verticillata*

- Warm-season, native perennial
- Topramezone (Pylex) plus triclopyr provide the best control
- Mesotrione (Tenacity) and Acclaim Extra (fenoxaprop) less expensive option
- Adding triclopyr (Turflon Ester Ultra or Triclopyr 4) at 1 qt/A to either topramezone, fenoxaprop, or mesotrione will significantly improve control.
- Apply at least 2 times, target applications in the late spring and early summer





Image from Midwest Weeds and Wildflowers, Missouri State University.

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### Nimblewill – *Muhlenbergia schreberi*

- Warm-season, perennial
- Mesotrione (Tenacity) applied in the spring (with NIS), two or three applications.
  - For three applications, use the 5 fl oz/A rate (or 6, 6 and 4 fl oz/A) due to label restrictions.
  - Late summer and fall applications will work but start by August for best results.
- Topramezone (Pylex) at 1-1.5 fl oz/A at 21- to 28-day intervals starting in late April; include a methylated seed oil.



Above image from Midwest Weeds and Wildflowers, Missouri State University.

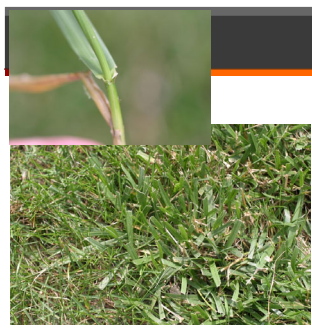
Above and right image from Purdue University.

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### Tall Fescue – *Schedonorus arundinaceus*

- Cool-season, perennial
- Chlorsulfuron (Telar XP and Chlorsulfuron 75DF) is a selective herbicide registered for tall fescue control, previously sold as Corsair, which is now off market.
- Telar XP and Chlorsulfuron 75DF contain the same active ingredient as Corsair, *only labelled for industrial sites and roadsides*



Above images from University of Missouri Plant Sciences.

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### Orchardgrass – *Dactylis glomerata*

- Perennial, cool season grass
- Bluish-green foliage
- Upright, hollow, flattened stems
- Fibrous root system, rarely with short rhizomes.



Left and below images from University of Missouri Plant Sciences.

Right image from PennState Plant Science.

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### Quackgrass – *Elymus repens*

- Cool-season, perennial
- Lax blue-green leaves
- Extensive rhizomes and a fibrous root system



Images above and immediate left from PennState Plant Science.


Images far left from Aaron J. Patton, Purdue University.

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### Creeping Bentgrass – *Agrostis stolonifera*

- Cool season, perennial
- Mesotrione (Tenacity) is safe for use in Kentucky bluegrass (5-8 fl oz/A), perennial ryegrass (5 fl oz/A), tall fescue (5-8 fl oz/A), and fine fescue (5 fl oz/A) and will control creeping bentgrass
- Timing is critical. Begin applying in early September. Three or four applications at two-week intervals. At least three applications are required for best results. Loses effectiveness later in the fall.
- Spring and summer applications provide less consistent control.



Images at right from University of Minnesota Extension.

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### Rough Bluegrass – *Poa trivialis*



- Cool-season, perennial
- Bispyribac-sodium (Velocity SG) is registered on golf courses and sod farms, but no other turf sites.
- Availability is limited.
- Raising the mowing height (3 inches tall or greater) will help to reduce rough bluegrass over time.
- Extremely shade tolerant.

Images above from Rutgers Turf Blog, turfblog.Rutgers.edu.

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### Smooth Brome – *Bromus enermis*

- Cool-season, perennial
- Research conducted at Nebraska with Mesotrione (Tenacity) + NIS
  - 5.3 fl. oz./acre three times 10 days apart or
  - 8 fl. oz./acre applied two times 10 days apart,
  - applied in July resulted in about 85% control by Sept. 15.
- Spring applications had <30% control.




Image above from Katy Chayka, Minnesota Wildflowers.

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### Bermudagrass, *Cynodon spp.*



- Warm-season, perennial
- No "efficient" selective herbicides in cool-season turf.
- Three applications of topramezone (Pylex) at 1.33 fl oz/A at 21-day intervals starting in late summer to **suppress** bermudagrass. For best results, tank-mix Triclopyr at 1 qt/A and include a MSO.
- Repeat applications of fenoxaprop (Acclaim Extra) 28 fl oz/A during late spring and late-summer/fall provide suppression. Adding triclopyr improve turfgrass safety and suppression.
- Use with with an overseeding of a desirable cool-season turfgrass post last application; repeat for 2-3 consecutive years.

Images from Aaron J. Patton, Purdue Extension Turf Tips.

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### Zoysiagrass – *Zoysia spp.*

- Warm-season, perennial
- No "efficient" selective herbicides in cool-season turf.
- Like bermudagrass, three applications of topramezone (Pylex) at 1.33 fl oz/A with MSO at 21-day intervals starting in late summer will **suppress** zoysiagrass (no triclopyr).
- Use with an overseeding of a desirable cool-season turfgrass after the last application; repeat for 2-3 consecutive years.
- Expect 50-75% zoysiagrass removal per year with this topramezone, plus overseeding strategy.




Image above from Missouri Botanical Garden.  
Image right North Carolina State Extension.

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"The best way to control undesirable perennial grasses in the lawn is to spot treat with glyphosate."

- ~~Windmillgrass~~
- ~~Nimblewill~~
- ~~Tall Fescue~~
- ~~Orchardgrass~~
- ~~Creeping Bentgrass~~
- Rough Bluegrass**
- Quackgrass**
- ~~Smoothbrome~~
- ~~Bermudagrass~~
- ~~Zoysiagrass~~

Options now exist for 60% of the top ten!

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**Additional Resources**

**PURDUE EXTENSION education STORE**

Turfgrass Weed Control for Professionals 2018 edition - Single copy

PRICE: \$20.00 each

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**Hard copy \$20; Digital PDF \$12**

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**Weed Control Ratings for Postemergence Grass Herbicides**

Herbicide	annual bluegrass	barrygrass	bermudagrass	crabgrass	creeping bentgrass	cutting grass	field paspalum	fourtail grass	goosegrass	Japanese stiltgrass	johnsongrass	mintbush	quackgrass	rough bluegrass	ryegrass	sandbar	tall fescue	yellow foxtail	wintergrass	zoysiagrass	
2,4-D + MCPP + dicamba + carfentrazone (SpeeZone)				P					G			G					P				
2,4-D + quinclorac + dicamba (Momentum Q, Quincept)	P	G	P	G		P	P	G	P							P	P	P	G		
amicarbazone (Xonerate 25C)	F			P		P									P						
asulam (Asulox)				G					G								G				
atrazine (Atrax)	E			P		P	P	P								G	F	F			
bispyribac-sodium (Velocity SG)	F														G			P			
chlorisulfuron (Telar XP)	F				P											E		G			P
ethofumesate (Prograss)	G	P	P		P	P	P	P								P	P	P			P
fenoxaprop (Acclaim Extra)	P	F	G	P	P	G	G	E	G							P	E	P	G	F	
fenoxaprop + fluroxypyr + dicamba (Last Call)	P	F	G	P	P	G	G		G							P	E	P	G	F	
flazasulfuron (Katana)	G	G	F	G	P	P	P					E	E	E		E	E				P
fluzilop (Fusilade II, Ornamec)	P	G	F	G	G	G	G	G	G			F			F	G	F	G			P
loransulfuron (Revolver)	E	P	F	F	F	G	G		G			G	E	P	G						P
glyphosate	E	E	F	E	F	F	F	G	E	G	F	F	F	F	E	E	E	E	F	F	G

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**Other resources:**

<http://www.mobileweedmanual.com/> Jim Brosnan, Ph.D.

**N EXTENSION**

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**Thanks!**

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