2016

Pesticide Resistance Management

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NORTHEAST SARE Sustainable Agriculture Research & Education

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What is Pesticide Resistance?

An inheritable characteristic of a pest that makes it less sensitive to a pesticide

- Renders the pest able to survive exposure to that pesticide that would normally kill those without the genes
- Occurs in all pests - weeds, insects, fungi, etc.
- Reflected by failure of a product to achieve expected level of control

What is Pesticide Resistance?

- A mutation makes a pest less sensitive to a pesticide, can naturally occur in pest population before pesticide use
- Pesticide use kills susceptible individuals (those *without* the mutation/gene), and “selects” those with the mutation to survive
- Pests *with* the mutation live, reproduce, and pass on the genes, which made them less sensitive to the pesticide, to their offspring
- The pest population has increasing numbers of resistant individuals

What is tolerance?

<u>Tolerance</u> - natural ability of a species or individual member of a species to survive and reproduce after a pesticide treatment.

- This implies no selection or genetic manipulation to make the organism this way.
- Tolerance is a **natural tendency** and is not a result of selection pressure.

Example: Mature caterpillars are more tolerant to many insecticides than younger ones of the same species due to differences in body size, exoskeleton thickness, and the ability to metabolize a poison. These differences are identified as **tolerance** or **natural resistance** rather than true insecticide resistance.

In contrast to resistance, insecticide tolerance is a natural tendency and is not a result of selection pressure. Mature caterpillars are more tolerant to many insecticides than younger ones of the same species due to differences in body size, exoskeleton thickness, and the ability to metabolize a poison. These differences are identified as tolerance or natural resistance rather than true insecticide resistance.

Why do pests become resistant?

- Pre-adaptation
- High fertility
- Short generation time

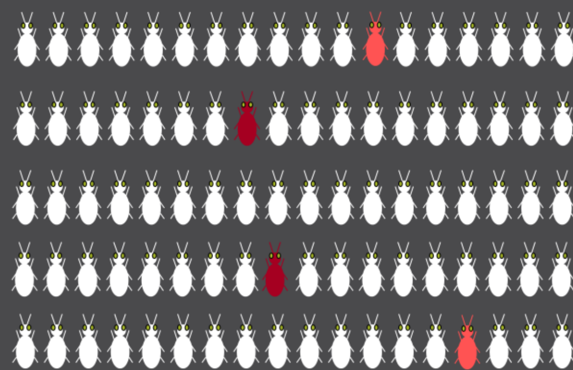
Intrinsic properties of pest species. Can't be controlled.

- Selection pressure

Under human control!

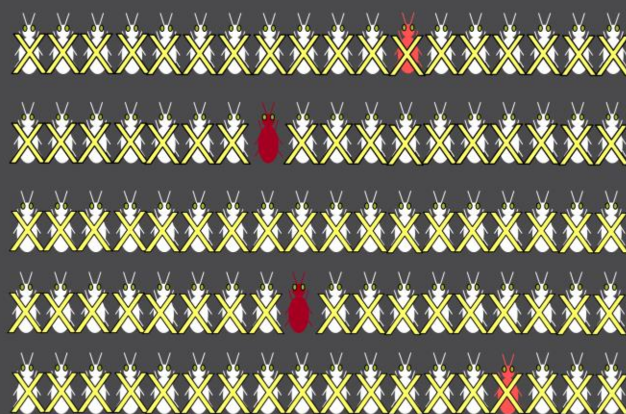
Natural pest population

- Some individuals have genes that make them less sensitive to a pesticide



Pesticide application

- Individuals that are susceptible die



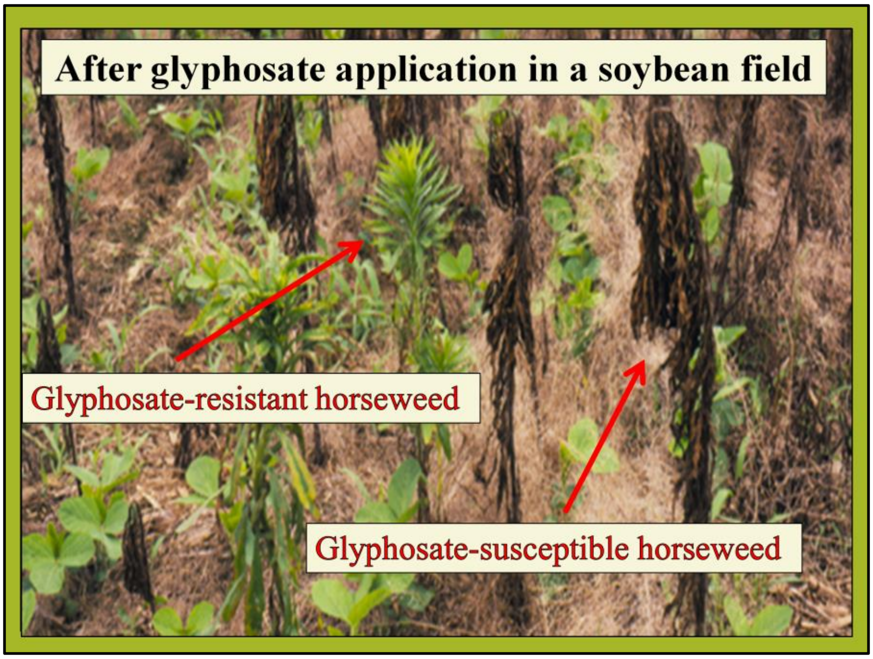
Pesticide application

- Individuals with naturally occurring genes that make them less sensitive to a pesticide survive…

After pesticide application

- Humans have applied selection pressure.
- Individuals with genes that make them less sensitive to a pesticide reproduce.
- The offspring have the genes that make them less sensitive to the pesticide.
- The new population is more resistant than a natural population

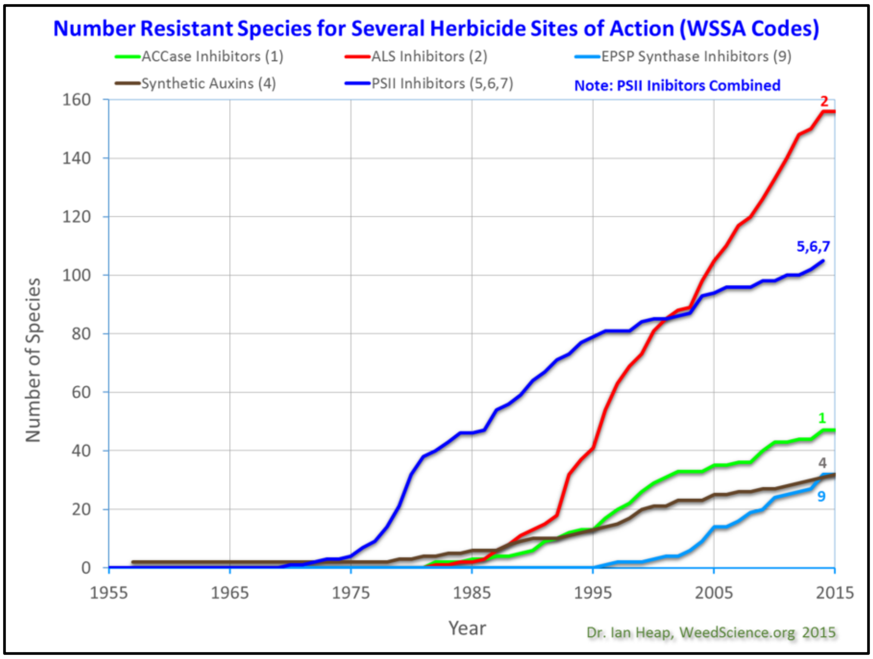
- Eventually, the population is mostly made up of resistant individuals.
- Under permanent selection pressure, resistant insects outnumber susceptible ones and the insecticide is no longer effective.



Weed pest resistance occurs in a similar fashion as with insect pest resistance. This slide shows what happens as resistance is developed – the resistant individuals will eventually make up the entire population.

Why is Managing Resistance Important?

- Pesticide resistance is increasing
- Currently:
  - 520 insect and mite species
    - At least 17 insect species are resistant to <u>**all**</u> major classes of insecticides
  - 273 weed species
  - 150 plant diseases
  - 10 rodent species



This graph presents the chronological increase in resistance to 5 herbicide sites of action. The letters refer to the Weed Science Society of America code (WSSA) to identify herbicide sites of action. Different herbicide sites of action have different propensities to select resistance. PSII inhibitor (Group 5, 6, 7) herbicides, primarily atrazine resistant weeds in corn, dominated in the USA and Europe in the 1970's and 80's. ALS inhibitor (Group 2) herbicides are the most prone to resistance. Note that the Y axis is the number of species (because a species is only plotted once per site of action).

Why is Managing Resistance Important?

- We want pesticides to provide effective control of pests
- It's hard to develop new products for pest control
  - If we exhaust current technology, it might be a long time until something is developed to replace it!
- Environmental stewardship
  - Pest are mobile, resistance that develops in one crop can spread
  - Minimize ineffective use?? of pesticides

All types of pesticides are at risk for resistance!

Herbicides
Herbicide Resistance Action Committee (HRAC)
http://www.hracglobal.com

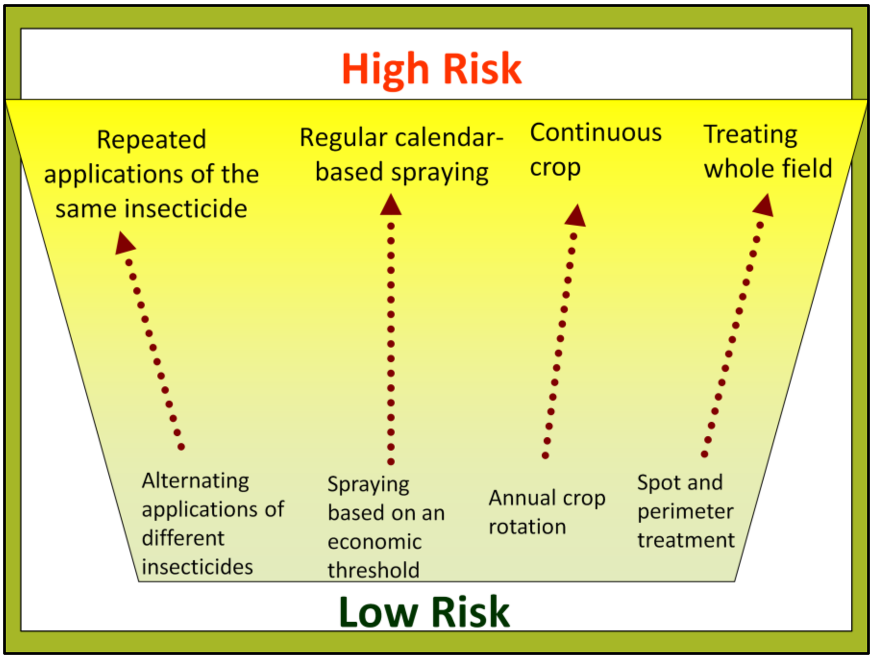
Fungicides
Fungicide Resistance Action Committee (FRAC)
http://www.frac.info

Insecticides
Insecticide Resistance Action Committee (IRAC)
http://www.irac-online.org

International groups founded by the agrochemical industry for a cooperative approach to resistance management. Sources for info and education materials.

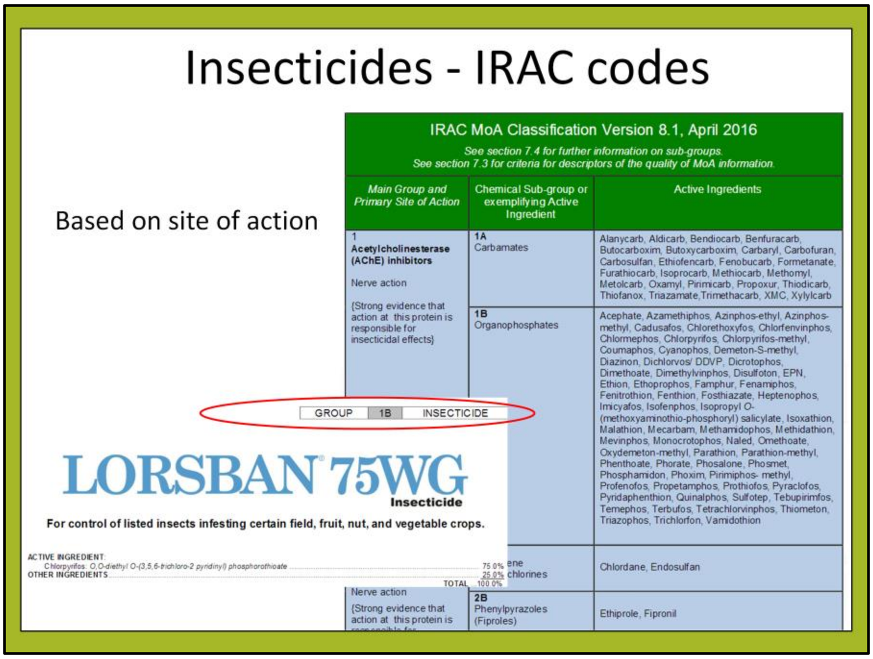
What Products are Resistant Prone?

- All pesticides have some risk, BUT not to the same extent
- Those with **single-site** mode of action, **targeted** and **narrow-spectrum** more at risk

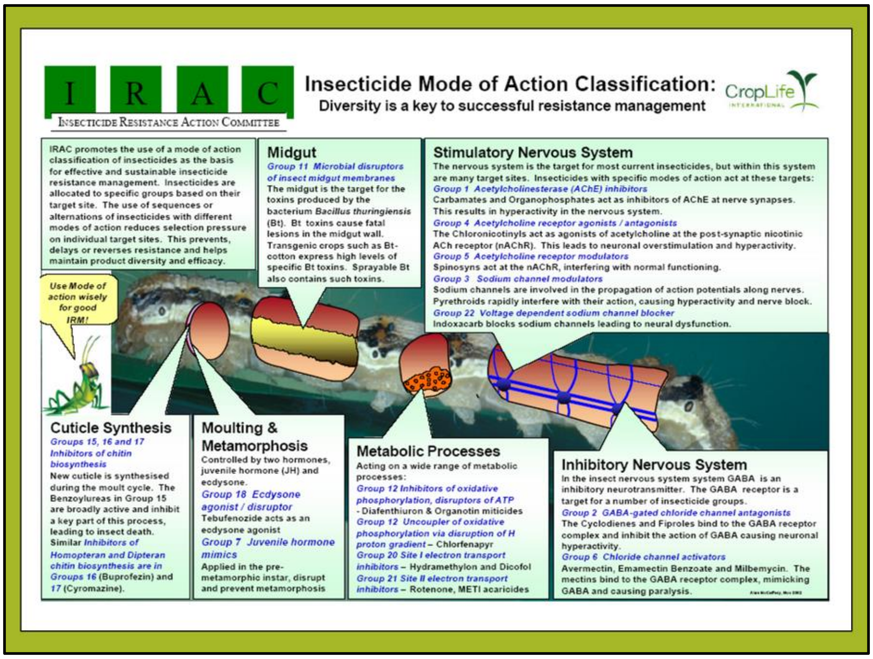

High Risk
Repeated applications of the same insecticide
Regular calendar-based spraying
Continuous crop
Treating whole field
Alternating applications of different insecticides
Spraying based on an economic threshold
Annual crop rotation
Spot and perimeter treatment
Low Risk

Mode of action (MoA)

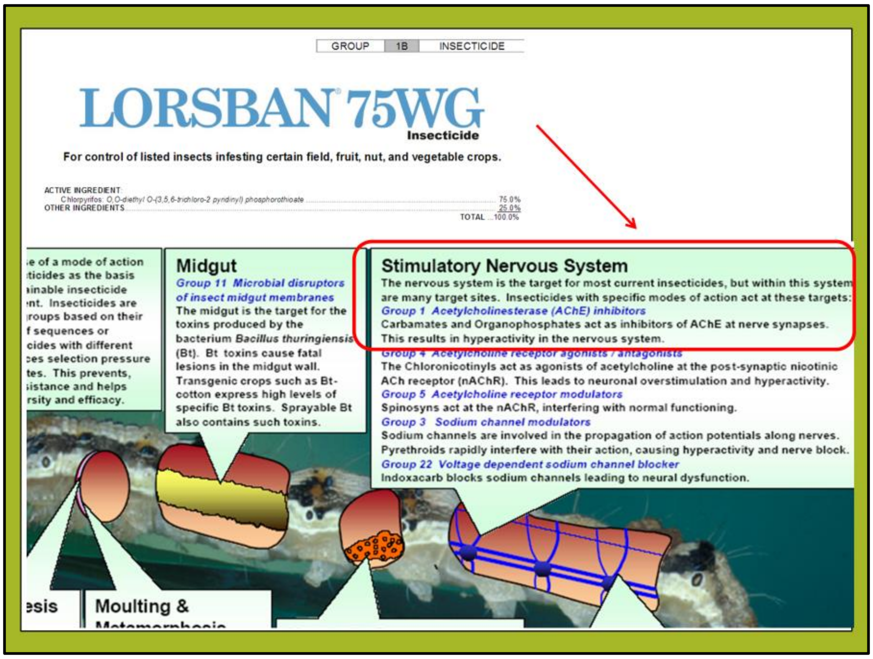
- The chemical structure of a pesticide generally defines its target site and its mode of action at that target site.
  - **Target site** - the physical location within an organism where the pesticide acts
  - **Mode of action** - the action of a pesticide at its target site. The way in which it causes physiological disruption at the target site.
- Each pesticide has a **Group Number** to help growers make resistance management decisions
- Group number is clearly marked on all labels



Educators are encouraged to show farmers how to find IRAC group codes in the pesticide guideline that they use routinely.



IRAC
INSECTICIDE RESISTANCE ACTION COMMITTEE
Insecticide Mode of Action Classification:
Diversity is a key to successful resistance management
CropLife
IRAC promotes the use of a mode of action classification of insecticides as the basis for effective and sustainable insecticide resistance management. Insecticides are allocated to specific groups based on their target site. The use of sequences or alternations of insecticides with different modes of action reduces selection pressure on individual target sites. This prevents, delays or reverses resistance and helps maintain product diversity and efficacy.
Midgut
Group 11 Microbial disruptors of insect midgut membranes
The midgut is the target for the toxins produced by the bacterium Bacillus thuringiensis (Bt). Bt toxins cause fatal lesions in the midgut wall. Transgenic crops such as Bt-cotton express high levels of specific Bt toxins. Sprayable Bt also contains such toxins.
Stimulatory Nervous System
The nervous system is the target for most current insecticides, but within this system are many target sites. Insecticides with specific modes of action act at these targets:
Group 1 Acetylcholinesterase (AChE) inhibitors
Carbamates and Organophosphates act as inhibitors of AChE at nerve synapses. This results in hyperactivity in the nervous system.
Group 4 Acetylcholine receptor agonists / antagonists
The Chloronicotinyls act as agonists of acetylcholine at the post-synaptic nicotinic ACh receptor (nAChR). This leads to neuronal overstimulation and hyperactivity.
Group 5 Acetylcholine receptor modulators
Spinosyns act at the nAChR, interfering with normal functioning.
Group 3 Sodium channel modulators
Sodium channels are involved in the propagation of action potentials along nerves. Pyrethroids rapidly interfere with their action, causing hyperactivity and nerve block.
Group 22 Voltage dependent sodium channel blocker
Indoxacarb blocks sodium channels leading to neural dysfunction.
Use Mode of action wisely for good IRM!
Cuticle Synthesis
Groups 15, 16 and 17 Inhibitors of chitin biosynthesis
New cuticle is synthesised during the moult cycle. The Benzoylureas in Group 15 are broadly active and inhibit a key part of this process, leading to insect death. Similar Inhibitors of Homopteran and Dipteran chitin biosynthesis are in Groups 16 (Buprofezin) and 17 (Cyromazine).
Moulting & Metamorphosis
Controlled by two hormones, juvenile hormone (JH) and ecdysone.
Group 18 Ecdysone agonist / disruptor
Tebufenozide acts as an ecdysone agonist
Group 7 Juvenile hormone mimics
Applied in the pre-metamorphic instar, disrupt and prevent metamorphosis
Metabolic Processes
Acting on a wide range of metabolic processes:
Group 12 Inhibitors of oxidative phosphorylation, disruptors of ATP - Diafenthiuron & Organotin miticides
Group 12 Uncoupler of oxidative phosphorylation via disruption of H proton gradient – Chlorfenapyr
Group 20 Site I electron transport inhibitors – Hydramethylon and Dicofol
Group 21 Site II electron transport inhibitors – Rotenone, METI acaricides
Inhibitory Nervous System
In the insect nervous system system GABA is an inhibitory neurotransmitter. The GABA receptor is a target for a number of insecticide groups.
Group 2 GABA-gated chloride channel antagonists
The Cyclodienes and Fiproles bind to the GABA receptor complex and inhibit the action of GABA causing neuronal hyperactivity.
Group 6 Chloride channel activators
Avermectin, Emamectin Benzoate and Milbemycin. The mectins bind to the GABA receptor complex, mimicking GABA and causing paralysis.


GROUP 1B INSECTICIDE
LORSBAN 75WG
Insecticide
For control of listed insects infesting certain field, fruit, nut, and vegetable crops.
ACTIVE INGREDIENT
Chlorpyrifos: O,O-diethyl O-(3,5,6-trichloro-2 pyridinyl) phosphorothioate 75.0%
OTHER INGREDIENTS 25.0%
TOTAL 100.0%
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Moulting &

Fungicides - FRAC codes

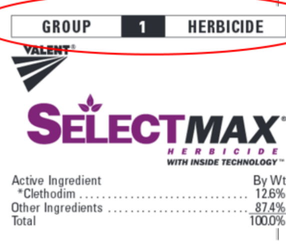
MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
A: nucleic acids synthesis	**A1:** RNA polymerase I	**PA** – fungicides (Phenyl**A**mides)	acylalanines	benalaxyl benalaxyl-M (=kiralaxyl) furalaxyl metalaxyl metalaxyl-M (=mefenoxam)	Resistance and cross resistance well known in various Oomycetes but mechanism unknown. **High risk. See FRAC Phenylamide Guidelines for resistance management**	**4**
			oxazolidinones	oxadixyl		
			butyrolactones	ofurace		
	A2: adenosin-deaminase	hydroxy-(2-amino-) pyrimidines	hydroxy-(2-amino-) pyrimidines	bupirimate dimethirimol ethirimol	Medium risk Resistance and cross resistance known in powdery mildews. Resistance management required.	**8**
	A3: DNA/RNA synthesis (proposed)	heteroaromatics	isoxazoles	hymexazole	Resistance not known.	**32**
			isothiazolones	octhilinone		
	A4: DNA topoisomerase	carboxylic acids	carboxylic a		Bactericide. Resistance known	

Based on cross resistance behavior

Herbicides - HRAC and WSSA groups

HRAC and WSSA (Weed Science Society of America) codes, differ slightly but very similar

Systems based on site of action



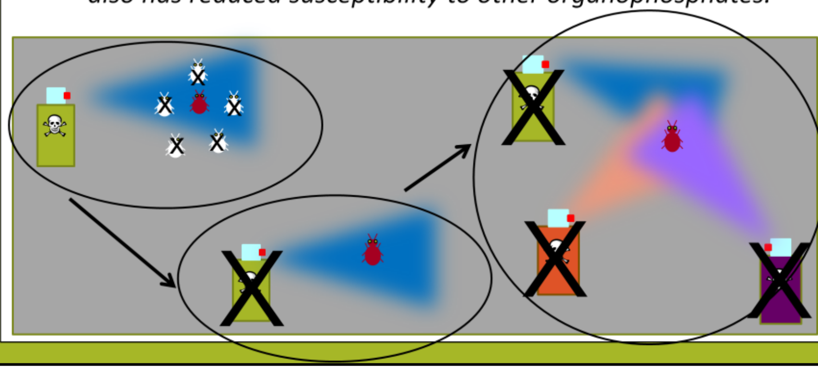
HRAC Group	Site of Action	Chemical Family	Active Ingredient	WSSA Group
A	Inhibition of acetyl CoA carboxylase (ACCase)	Aryloxyphenoxy-propionate 'FOPs'	clodinafop-propargyl cyhalofop-butyl diclofop-methyl fenoxaprop-P-ethyl fluazifop-P-butyl haloxyfop-R-methyl propaquizafop quizalofop-P-ethyl	1
		Cyclohexanedione 'DIMs'	alloxydim butroxydim clethodim cycloxydim *profoxydim* sethoxydim *tepraloxydim* tralkoxydim	
		Phenylpyrazoline 'DEN'	pinoxaden	
B	Inhibition of acetolactate synthase ALS (acetohydroxyacid synthase AHAS)	Sulfonylurea	amidosulfuron azimsulfuron bensulfuron-methyl chlorimuron-ethyl chlorsulfuron cinosulfuron cyclosulfamuron ethametsulfuron-methyl ethoxysulfuron	2

Just as a note to educators: WSSA is currently in discussion with EPA to see if these 2 systems can be unified somehow.

Other terminology

Cross-resistance - resistance to two or more pesticides resulting from a single resistance mechanism. Can occur even where the pest has not been exposed to all products it is resistant to.

e.g. An insect resistant to parathion (an organophosphate) also has reduced susceptibility to other organophosphates.



Other terminology

<u>Multiple resistance</u> - resistance to several pesticides from two or more distinct resistance mechanisms in the same organism.

e.g. Palmer amaranth is resistant to atrazine (a triazine herbicide), and also mesotrione (an HPPD inhibitor herbicide).

Other terminology

Quantitative Resistance

- Either the pesticide works…. or it does not.
- Complete loss of control.

Qualitative Resistance

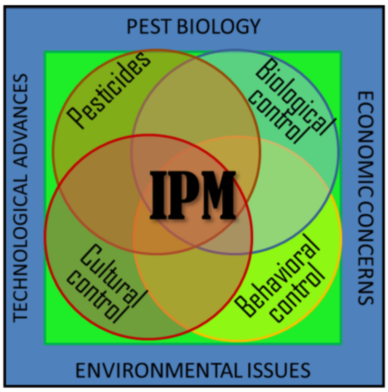
- Pest exhibits range in sensitivity.
- Gradual loss of control.
- Can be regained with higher rate or more active pesticide.

Key Points About Managing Resistance

- Goal is **delaying** development of resistance, <u>**not**</u> managing resistant pest biotypes once detected
- Use Integrated Pest Management (IPM) program
- Minimize use of at-risk products

✓ Do not rely on pesticides alone

Integrate different controls!



- synthetic pesticides
- biological pesticides
- beneficial insects (predators/parasites)
- cultural practices
- transgenic plants (where allowed)
- crop rotation
- pest-resistant crop varieties
- chemical attractants or deterrents

Alternate, rotate, or sequence different pesticide MoA classes

Use FRAC, IRAC, and HRAC when choosing chemicals!

- Do not rely on product names
- Do not rely on active ingredients
    - Many different products and active ingredients can be in the same group!

Alternaria leaf spot – Cantaloupe

Fungicide	FRAC Code
Cabrio (pyraclostrobin)	11
Pristine (pyraclostrobin + boscalid)	7 + 11
Quadris (azoxystrobin)	11
Quadris Top (azoxystrobin + difenoconazol	3 + 11
Reason (fenamidone)	11

The individual educators should change slide to represent a spray program that they would routinely use for their crop. Then the educator could pick and choose the ones that they focused on during the presentation.

Crop	Target Diseases	Use Rate fl oz product/A (lb ai/A)	Remarks
Cucurbits Cantaloupe Chayote Chinese-waxgourd Cucumber Gourds Honeydew Melons *Momordica* spp. (bitter melon, balsam apple) Muskmelon Watermelon Pumpkin Squash Zucchini Including cultivars and/or hybrids of these	Alternaria blight (*Alternaria cucumerina)* Anthracnose (*Colletotrichum lagenarium)* Belly rot (*Rhizoctonia solani*) Cercospora leaf spot (*Cercospora citrulina)* Downy mildew (*Pseudoperonospora cubensis*) Gummy stem blight (*Didymella bryoniae*) Leaf spot (*Alternaria* spp., *Cercospora* spp.) Myrothecium canker (*Myrothecium roridum)* Plectosporium blight (*Plectosporium tabacinum)* Powdery mildew (*Sphaerotheca fuliginea, Erysiphe cichoracearum*) Target leaf spot (*Corynespora cassicola)* Ulocladium leaf spot	11.0-15.5 (0.18-0.25)	For both downy and powdery mildew, make preventative applications on a 5- to 7-day schedule. For belly rot control, the first application should be made at the 1-3 leaf crop stage with a second application just prior to vine tip over or 10-14 days later whichever occurs first. For all other diseases, Quadris applications should begin prior to disease development and continue throughout the season every 7-14 days following the resistance management guidelines. Applications may be made by ground, air or chemigation. An adjuvant may be added at specified rates. Do not tank mix Quadris with crop oil concentrates (COC), methylated spray oil (MSO) or silicon adjuvants. Do not tank mix Quadris with Malathion, Kelthane®, Thiodan®, Phaser®, Lannate®, Lorsban®, M-Pede® or Botran®. Do not apply more than one application of Quadris or other Group 11 fungicides before alternation with a fungicide that is not in Group 11. Do not make more than four (4) foliar applications of Quadris or other Group 11 fungicides per crop per acre per year.

Resistance management guidelines on label MUST be followed.

Applications must be timed correctly

- Target the most vulnerable life stage of the pest
- Use spray rates and application intervals recommended by the manufacturer and in compliance with local agricultural extension regulations.
  - A high rate can take out pests that might be somewhat resistant, but using too low a rate may allow them to survive

Challenges to Managing Resistance

- Do not have adequate tools
  - Not enough registered products to permit rotation
- The program may not be as effective
- The program may be more expensive
- Products with resistance risk for one pest are also used for others

Preserve susceptible genes

Preserve susceptible individuals within the target population by providing a **refuge** or haven for susceptible insects

- Unsprayed areas within treated fields
- Adjacent refuge fields

These susceptible individuals may out-compete and interbreed with resistant individuals, diluting the impact of any resistance that may have developed in the population.

Do genetically engineered crops (GMOs) contribute to resistance development?

Not directly!

Growers may manage those crops differently, encourage resistance development inadvertently

- Example: “RoundUp” ready crops, over reliance on single herbicide

Supporting funds were provided by NE-SARE Professional Development Program Grant, ENE15-140-29994

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Presentation developed by K. Ghantous, H. Sandler, and L. McDermott.

With special thanks to:

- Dr. Margaret McGrath, Cornell University
- Dr. Andrei Alyokhin, University of Maine
- Dr. Richard Bonanno, University of Massachusetts

for their expertise and contribution of materials for presentation