

Pesticide Resistance Prevention

**Cassie Bouska, Paul
Jepson**

Oregon State University

I P P C

integrated plant protection center



OSU
Oregon State
UNIVERSITY

Defining resistance

‘A heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species’

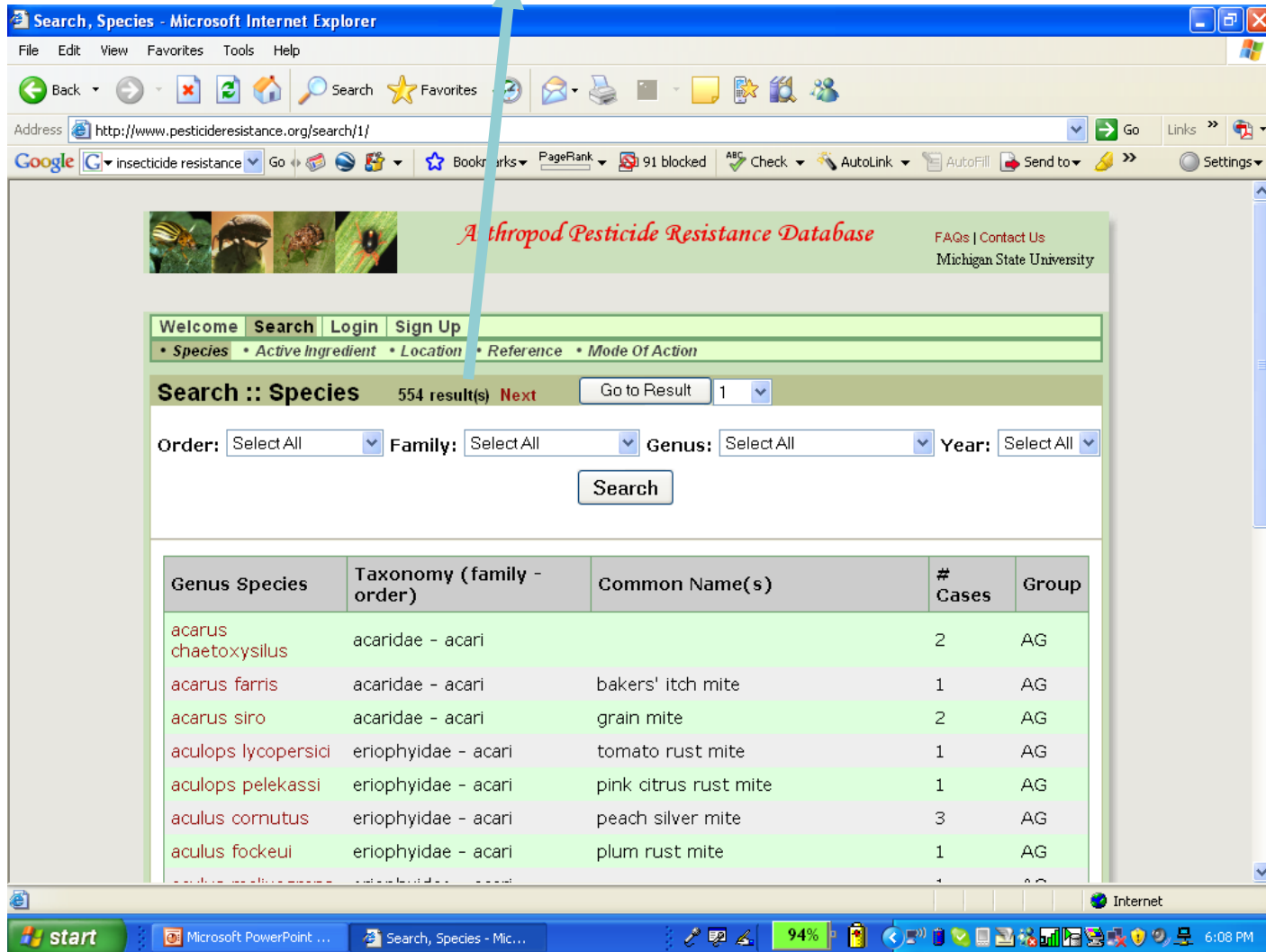
IRAC, 2007

BUT, resistance often begins a long time before ‘field resistance’ is detected

First detected

- **Insecticides: 1940' s**
 - Use pattern
 - Insect distribution
- **Herbicides: 1950' s**
 - Use pattern
- **Fungicides: 1970' s**
 - Appearance of systemic fungicides
 - Use pattern

Arthropod pesticide resistance database includes >500 species



Search, Species - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Forward Stop Home Search Favorites

Address <http://www.pesticideresistance.org/search/1/> Go Links

Google insecticide resistance Go PageRank 91 blocked ABC Check AutoLink AutoFill Send to Settings

Arthropod Pesticide Resistance Database FAQs | Contact Us Michigan State University

Welcome Search Login Sign Up

Species Active Ingredient Location Reference Mode Of Action

Search :: Species 554 result(s) Next Go to Result 1

Order: Select All Family: Select All Genus: Select All Year: Select All

Search

Genus Species	Taxonomy (family - order)	Common Name(s)	# Cases	Group
acar	acaridae - acari		2	AG
chaetoxysilus	acaridae - acari		1	AG
acar farris	acaridae - acari	bakers' itch mite	2	AG
acar siro	acaridae - acari	grain mite	1	AG
aculops lycopersici	eriphyidae - acari	tomato rust mite	1	AG
aculops pelekassi	eriphyidae - acari	pink citrus rust mite	3	AG
aculus cornutus	eriphyidae - acari	peach silver mite	1	AG
aculus fockeui	eriphyidae - acari	plum rust mite		AG

start Microsoft PowerPoint ... Search, Species - Mic... 94% Internet 6:08 PM

<http://www.pesticideresistance.org/>

Weed resistance database includes >250 species

International Survey of Herbicide Resistant Weeds - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address <http://www.weedscience.org/in.asp>

Home Resistant Weeds Researchers Herbicides Add Case Weed Photos Contact

WeedScience.com

International Survey of Herbicide Resistant Weeds

Funded and Supported by the
Herbicide Resistance Action Committee (HRAC), the
North American Herbicide Resistance Action Committee (NAHRAC),
and the Weed Science Society of America (WSSA).

The purpose of this survey is to monitor the evolution of herbicide-resistant weeds and assess their impact throughout the world. Global collaboration between weed scientists make the survey and this web site possible.

By Weed Scientists For Weed Scientists

314 Resistant Biotypes, 183 Species (110 dicots and 73 monocots) and over 280,000 fields

[Click Here for a Summary of Resistant Weeds by Mode of Action](#)

Criteria for Confirmation of Herbicide-Resistant Weeds

November 05, 2007 Researchers USA Survey Herbicides Weed Photos Contacts

[FAQ](#)
[Register](#)
[About Us](#)
[Cite this site](#)
[Upload Data](#)
[How do I add data or edit a case of resistance?](#)
[AutoEmail me my Password](#)

Select Lists of Herbicide Resistant Weeds by one of the below.

—Select by Common Name— Go [Global Summary USA State Map](#)

—Select by Scientific Name— Go —By Country— Go

—By Herbicide Mode of Action— Go —By USA State— Go

start Microsoft Power... Herbicide Resist... International Sur... 89% 6:17 PM

<http://www.weedscience.org/>

Why is resistance difficult to detect?

- Resistant pests are mixed with susceptible pests while resistance is building up
- Resistant pests can spread from heavily sprayed regions or even close neighbors
- Market shifts, price, availability of pesticides may suddenly alter selection pressure for resistance
- % control is rarely measured or even noticed, and gradual decreases in efficiency may go unseen
- Not all pesticides give ‘miraculous’ control, and we do not have high expectations for them!

Other reasons why efficiency may be poor

- **Regional**

- Unusually serious pest outbreak
- Favorable weather for the pest
- Unfavorable weather for the pesticide

- **Local**

- Poor targeting of the spray
- Poor calibration
- Worn or inappropriate nozzles
- Inefficient chemical AI, &/or poor storage conditions
- Fewer natural enemies

INSECTICIDES AND MITICIDES

The screenshot shows the IRAC (Insecticide Resistance Action Committee) website as it appeared in the early 2000s, viewed through Microsoft Internet Explorer. The browser's title bar reads "IRAC: Insecticide Resistance Management: Crop Protection, Biotechnolog - Microsoft Internet Explorer". The address bar shows the URL "http://www.irac-online.org/". The website's header features the IRAC logo, which includes a stylized insect, and the text "Insecticide Resistance Action Committee" and "Resistance Management for Sustainable Agriculture and Improved Public Health". Below the header is a navigation bar with links to "Country Groups", "Overview", "Core Activities", "eTools", "Membership", and "Downloads". A search bar is located on the left side of the page. The main content area is divided into several sections: "Latest News Items" featuring three news items with icons and brief descriptions, "eTools" describing the development of a suite of tools for communication and education, and "MoA Resources" providing a full listing of Mode of Action documents. The bottom of the browser window shows the Windows taskbar with the Start button, several open applications (Microsoft PowerPoint, IRAC: Insecticide Res...), and the system clock showing 7:11 PM.

IRAC: Insecticide Resistance Management: Crop Protection, Biotechnolog - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Forward Stop Home Search Favorites Reload Print Mail New Window

Address http://www.irac-online.org/ Go Links

Google insecticide resistance Go Bookmarks PageRank 91 blocked ABC Check AutoLink AutoFill Send to Settings

IRAC

Insecticide Resistance Action Committee
Resistance Management for Sustainable Agriculture and Improved Public Health

username password Go

Country Groups

Overview Core Activities eTools Membership Downloads

Search: [input] Search

Site Map
Get Support

Quicklinks:

- >> Introduction to IRAC
- >> Committee Structure
- >> Links to Further Information
- >> Next Exec. Concall - Call Details
- >> Next Concall - Participants

Next Event:

- >> Basle, Nov 28, 2007
IRAC Public Health Team

Latest News Items

- IRAC Promotes IRM at NPMA & BCPC**
IRAC poster displays at the National Pest Management Association (NPMA) PestWorld Trade Show in Florida and the British Crop Protection Council Exhibition in Glasgow were well recieved by all visitors to the booths. At the NPMA the focus was IRM and Public Health with a general overview of IRAC activities at the BCPC
- Nufarm & Chemtura Join IRAC Executive**
Following an initiative to increase membership, Nufarm and Chemtura have become full members of the IRAC Executive Committee and IRAC International. This brings the number of IRAC member companies contributing to IRM at a global level to eleven
- New IRAC SE Asia Group**
The IRAC SE Asia group has been formed to tackle increasing resistance problems in the region. They held their first face-to-face meeting in September and appointed their elected officers. One of the first challenges facing the group will be resistance in the brown plant hopper

eTools

IRAC are in the process of developing a suite of eTools to help in the communication and education of good IRM practices. Available so far is eConnection, the quarterly IRAC Newsletter and eClassification which provides quick

MoA Resources

A full listing of all the Mode of Action documents can be found via the link at the bottom of the panel.

Done Internet

start Microsoft PowerPoint ... IRAC: Insecticide Res... 100% 7:11 PM

<http://www.irac-online.org/>

INSECTICIDE RISK FACTORS

- **High pest reproduction (multiplication)**
- **Large number of generations a year**
- **High genetic variability**
- **Isolation, enclosure**
- **Low immigration by susceptible pests**
- **High proportion of population exposed**
- **Frequent applications**

**THE THREE INGREDIENTS FOR EVOLUTION, CAPACITY FOR INCREASE,
HERITABLE VARIATION AND SELECTION PRESSURE**

RESISTANCE MANAGEMENT

- **Minimize selection for resistance by one ‘type’ of insecticide**
 - **Sequences or rotation of ‘Mode of Action’ (MoA) groups**
 - **Apply each MoA group during one stage of crop growth or pest development**
 - **Avoid treating successive generations of pests with same MoA group**
- **Avoid spraying where possible; use IPM**
- **Predators and parasites do not select for resistance: they represent a non-specific MoA group**



**Natural
enemies are
exposed to
pesticides, as
well as pests,
but they
rarely become
resistant**

WHY?



MAXIMIZE BIOLOGICAL PEST SUPPRESSION

To conserve pesticides!



**Every 1% increase in pest resistance increases
the job that natural enemies have to do**

How many insecticide mode of action classes are there?

8, 18, 28, 48?



Insecticide Mode of Action Classification:

A key to effective insecticide resistance management



Insecticide Resistance Action Committee

IRAC website: www.irac-online.org

Introduction

IRAC promotes the use of a Mode of Action (MoA) classification of insecticides as the basis for effective and sustainable insecticide resistance management (IRM). Insecticides are allocated to specific groups based on their target site. Reviewed and re-issued periodically, the IRAC MoA classification list provides farmers, growers, advisors, extension staff, consultants and crop protection professionals with a guide to the selection of insecticides or acaricides in IRM programs. Effective IRM of this type preserves the utility and diversity of available insecticides and acaricides. A selection of MoA groups is shown below.

Use Mode of Action wisely for good IRM!



Effective IRM strategies: Alternations or sequences of MoA

All effective insecticide (and acaricide) resistance management (IRM) strategies seek to minimise the selection for resistance from any one type of insecticide or acaricide. In practice, alternations, sequences or rotations of compounds from different MoA groups provide sustainable and effective IRM. This ensures that selection from compounds in the same MoA group is minimised. Applications are often arranged into MoA spray windows or blocks that are defined by the stage of crop development and the biology of the pest(s) of concern. Local expert advice should always be followed with regard to spray windows and timings. Several sprays of a compound may be possible within each spray window but it is generally essential to ensure that successive generations of the pest are not treated with compounds from the same MoA group. Metabolic resistance mechanisms may give cross-resistance between MoA groups, and where this is known to occur, the above advice must be modified accordingly.

Moulting & Metamorphosis

Group 18 Ecdysone agonist / disruptor
Diacylhydrazines (e.g. Tebufenozide)
Group 7 Juvenile hormone mimics
JH analogues, Fenoxycarb, Pyriproxyfen, etc

Midgut

Group 11 Microbial disruptors of insect midgut membranes
Toxins produced by the bacterium *Bacillus thuringiensis* (Bt): Bt sprays and Cry proteins expressed in transgenic Bt crop varieties (specific cross-resistance sub-groups)

Nervous System

Groups 1A & B Acetylcholinesterase (AChE) inhibitors
Carbamates and Organophosphates
Group 2 GABA-gated chloride channel antagonists
Cyclodienes OCs and Phenylpyrazoles (Fiproles)
Group 3 Sodium channel modulators
DDT, pyrethroids, pyrethrins
Group 4A Acetylcholine receptor (nAChR) agonists
Neonicotinoids
Group 5 nAChR agonists (Allosteric) [not group 4A]
Spinosyns
Group 6 Chloride channel activators
Avermectins, Milbemycins
Group 22 Voltage dependent sodium channel blocker
Indoxacarb

Non-specific MoA

Group 9 Compounds of non-specific mode of action (selective feeding blockers)
Pymetrozine, Flonicamid, etc.

Cuticle Synthesis

Groups 15 and 16 Inhibitors of chitin biosynthesis
Benzoylureas (Lepidoptera and others), Buprofezin (Homoptera)

Metabolic Processes

Many groups acting on a wide range of metabolic processes including:
Group 12 Inhibitors of oxidative phosphorylation, disruptors of ATP
Diflufenhiuron & Organotin miticides
Group 12 Uncouplers of oxidative phosphorylation via disruption of H proton gradient - Chlorfenvapry

Non-specific MoA

Group 10 Compounds of non-specific mode of action (mite growth inhibitors)
Clofentezine, Hexythiazox, Etoxazole

Metabolic processes

Group 20 Mitochondrial complex III electron transport inhibitors
Acequinocyl, Flucyprym, etc
Group 21 Mitochondrial complex I electron transport inhibitors
Rotenone, METI acaricides
Group 23 Inhibitors of lipid synthesis
Tetronic acid derivatives

INSECTICIDE CLASSIFICATION

28 Mode of Action classes, plus 'unknowns'

**Class 1: Acetylcholine esterase inhibitors, 1A carbamates;
1B OP's**

**Class 3: Sodium channel modulators, including
pyrethroids**

**Class 4: Nicotinic Acetylcholine receptor agonists, 4A
neonicotinoids**

**For apples and cherries: Kaiser et al,
EM 8951 2008 OSU Extension**

<http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20525/em8951.pdf?sequence=1>

FUNGICIDES



<http://www.frac.info/frac/index.htm>

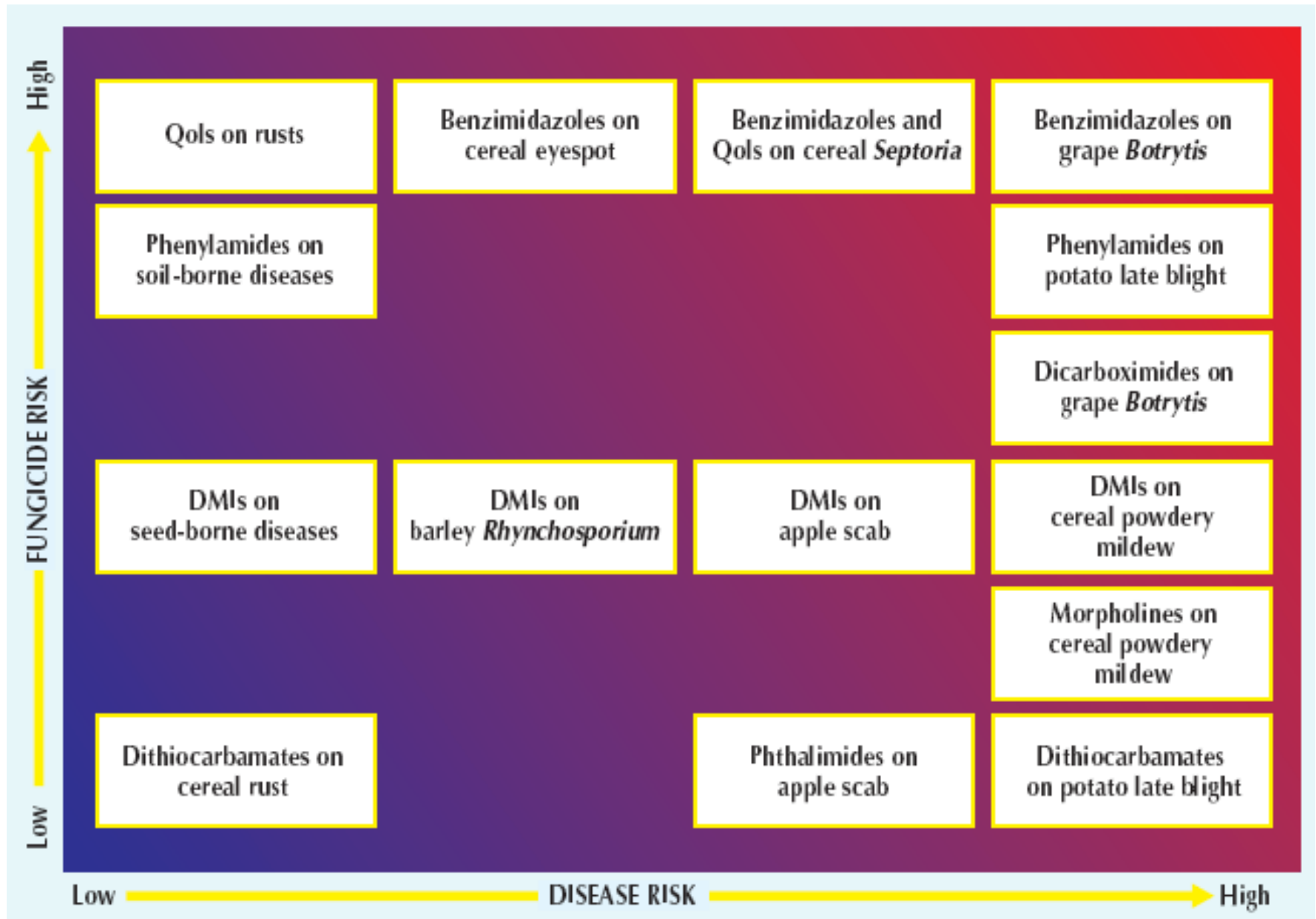
The time from marketing to onset of resistance is getting much shorter

Organomercurials, 40 years; Triphenyltin, 13 years; Carboxanilides, 15 years

VS

Quinone outside Inhibitors (e.g. Strobilurins), 2 years; Melanine biosynthesis inhibitors, 2 years

FUNGICIDE RISK FACTORS



FUNGICIDE RESISTANCE MANAGEMENT

- **Avoid excessive use**
- **Rotate/alternate MoA classes**
- **Use specialized mixtures or label instructions about resistance management strategies for different MoA groups**
- **Recommended dose rate**
- **Use thresholds, and IPM approaches**

**How many fungicide mode of
action classes are there?**

12, 22, 32, 42?

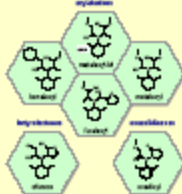
Mode of Action of Fungicides

FRAC classification on mode of action 2007 (www.frac.info)

A: Nucleic Acid Synthesis

A1: DNA synthesis
→ DNA polymerase I
1: 10 fungicides (Glyoxalimides)

A2: purine metabolism
→ adenine-deaminase
1: 1 fungicide (2-thiouracil) pyrimidines



A3: DNA / RNA synthesis (prop.)
2: 2 fungicides

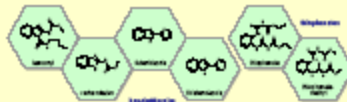


A4: DNA supercoiling
→ DNA topoisomerase type II (gyrase)
1: 1 fungicide (2-thiouracil)



B: Mitosis and Cell Division

B1: → α -tubulin assembly in mitosis
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



B2: → α -tubulin assembly in mitosis
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



B3: → α -tubulin assembly in mitosis
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



B4: cell division (prop.)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



B5: delocalization of spectrin-like proteins
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



C: Respiration

C1: inhibition of complex I
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



C2: inhibition of complex II
→ succinate dehydrogenase
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)

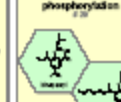


C: Respiration

C3: inhibition of complex II
→ cytochrome b_L (cytochrome b_L at Q_o site)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



C4: uncoupling of oxidative phosphorylation
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



C5: inhibitors of oxidative phosphorylation, ATP synthase
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)

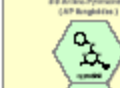


C6: ATP production (prop.)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



D: Amino Acid and Protein Synthesis

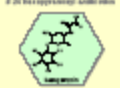
D1: methionine biosynthesis (opt gene) (prop.)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



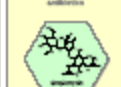
D2: protein synthesis
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



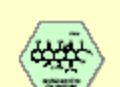
D3: protein synthesis
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



D4: protein synthesis
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)

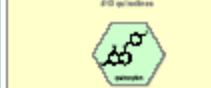


D5: protein synthesis
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



E: Signal Transduction

E1: G-proteins in early cell signaling (prop.)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)

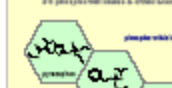


E2: G-proteins in early cell signaling (prop.)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



F: Lipid and Membrane Synthesis, Cell Wall Deposition

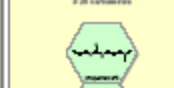
F1: phospholipid biosynthesis
→ methyltransferase
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



F2: lipid peroxidation (prop.)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



F3: cell membrane permeability, fatty acids (prop.)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



F4: phospholipid biosynthesis and cell wall deposition (prop.)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)

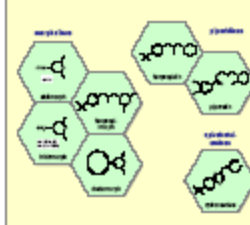


G: Sterol Biosynthesis Inhibitors (SBI fungicides)

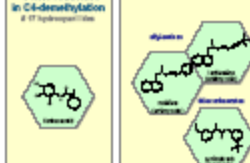
G1: SBI class I: DMF fungicides
→ C-14 demethylase (erg11) (erg11)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



G2: SBI class II: Azoles
→ Δ^14 -reductase (erg11) and Δ^14 - Δ^2 -epoxidase (erg11)
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)

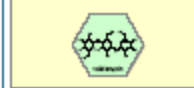


G3: SBI class III: hydroxamate
→ 3-oxo reductase in C-14 demethylation
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)

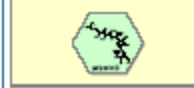


H: Glucan Synthesis

H1: inhibition and blocked biosynthesis
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



H2: chitin synthesis
→ chitin synthase
1: 10 fungicides (Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls, Biphenyls)



FUNGICIDE CLASSIFICATION

42 Mode of Action classes, plus unknowns

HIGH RISK EXAMPLES

**1, Beta-tubuline assembly in mitosis. ‘MBC fungicides’,
incl. benzimidazoles (benomyl)**

**2, MAP/Histidine-Kinase in osmotic signal transduction.
‘Dicarboximides’, incl. vinclozin**

**11, Complex III: cytochrome bc1 at Qo site. ‘Qol
fungicides’, incl. methoxy acrylates (azoxystrobin)**

HERBICIDES


Herbicide Resistance Action Committee - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Forward Stop Reload Home Search Favorites RSS Print Mail Wordpad Notepad Explorer

Address <http://www.plantprotection.org/HRAC/> Go Links

Google herbicide resistance a Go 91 blocked Check Show Book Info AutoFill Send to Settings



Herbicide Resistance Action Committee

The Herbicide Resistance Action Committee (HRAC) is an international body founded by the agrochemical industry as part of the GCPF organization.

The aims of HRAC have the general purpose of supporting a cooperative approach to the management of herbicide resistance.

HRAC is keen to support the establishment of a worldwide herbicide resistance database. With this aim in mind, HRAC is supporting the worldwide survey of resistant weeds initiated by the Weed Science Society of America. The International Survey of Herbicide-Resistant Weeds is being conducted by Ian Heap and is located at <http://www.weedscience.com/>

For a free copy of publications please contact **Dr. David Vitolo**

Syngenta Crop Protection 2109
9th Avenue Sacramento, CA 95818

HRAC Overview

[HRAC Address Book: Feb 2005](#)
[Partnership in the Management of Resistance](#)
[Asociación para la prevención y el control de las resistencias](#)

Publications

[English](#) ----- [En Español](#)

Available for free

HRAC Mode of Action - [the World of Herbicides](#)
[Classification of Herbicides According to Mode of Action \(2005\)](#)
[Detecting Herbicide Resistance](#)
[The Cost of Herbicide Resistance](#)
[Guidelines to the Management of Herbicide Resistance](#)

Books

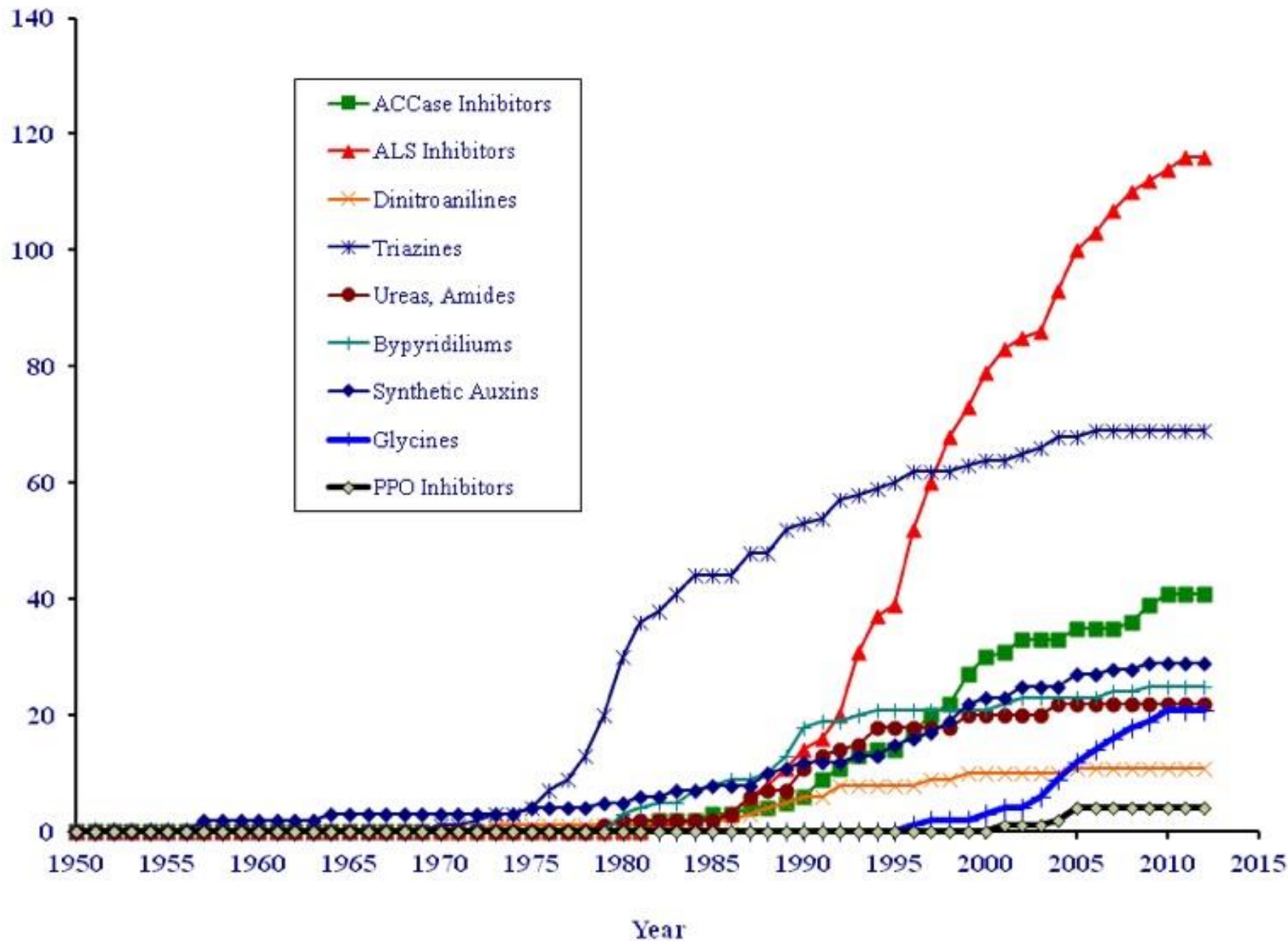
Herbicide Resistance and World Grains, 2001
(Powles SB & Shaner DL) ISBN/ISSN: 0849322197
-- see [CRC Press](#)

Weed Management Handbook - [\(click for info\)](#)
Ninth Edition, Edited by Robert E. L. Naylor
Dr. Stephen Moss is the author of the 11th chapter "Herbicide-Resistant Weeds". This chapter is a great resource for anyone interested in herbicide-

start Microsoft PowerPoint ... Herbicide Resistance ... 100% Internet 7:40 PM

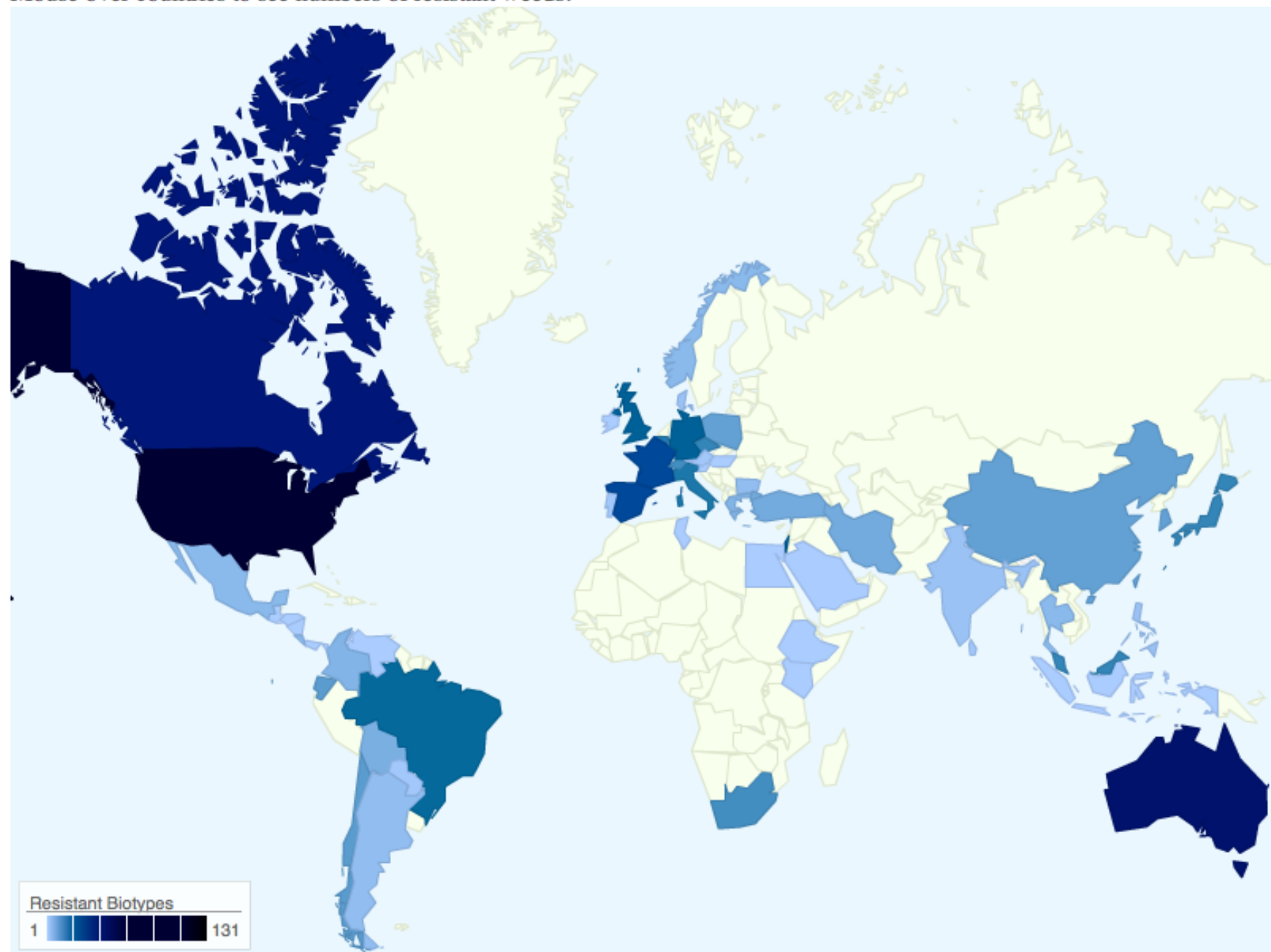
<http://www.plantprotection.org/HRAC/>

Number of Resistant Biotypes



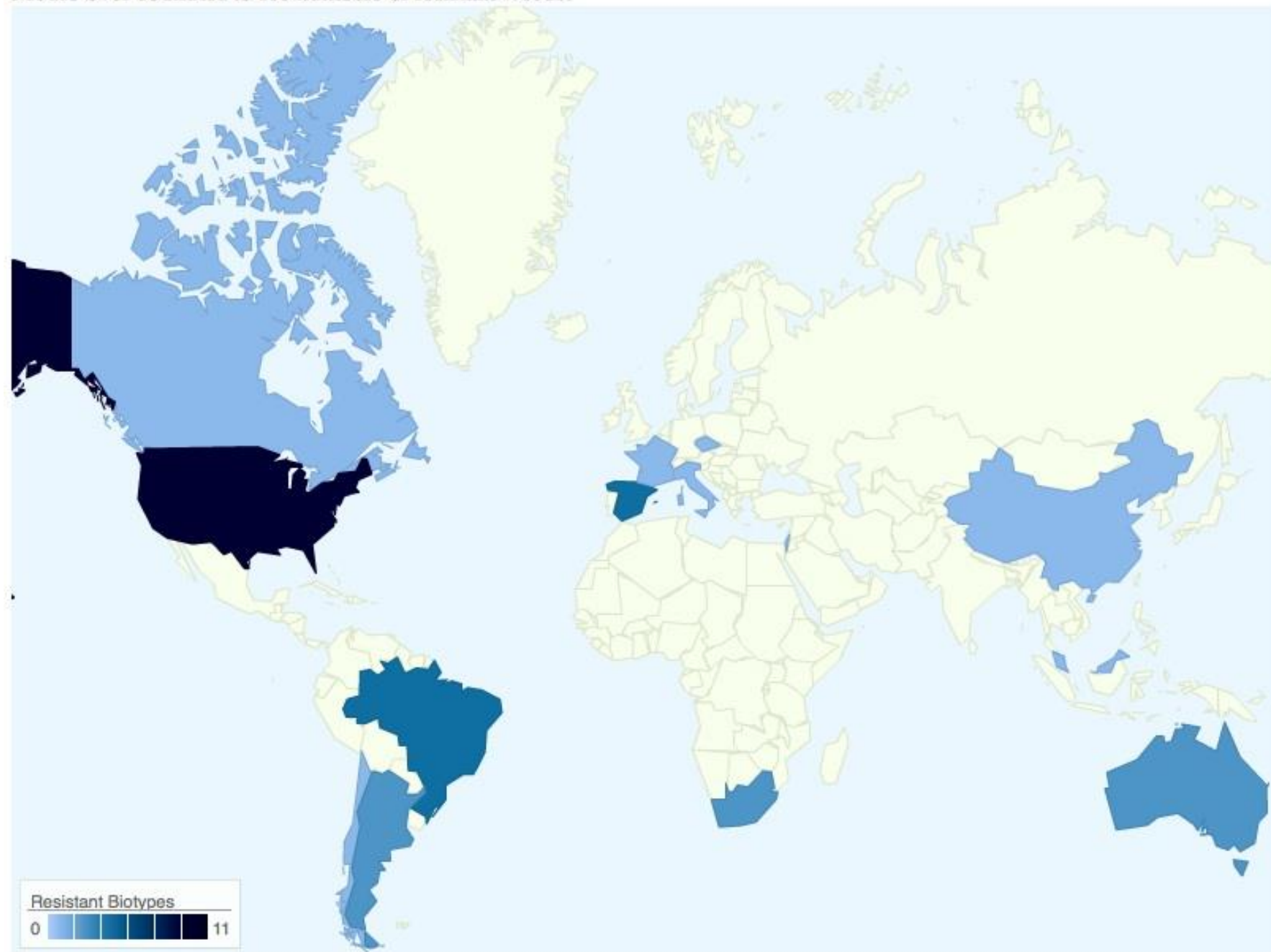
Herbicide Resistant Weeds Globally - 2010 - www.weedscience.com

Mouse over countries to see numbers of resistant weeds.



Glyphosate-Resistant Weeds Globally - 2010 - www.weedscience.com

Mouse over countries to see numbers of resistant weeds.



HERBICIDE RISK FACTORS

	LOW	MODERATE	HIGH
AI mix or rotation	>2 MoA	2	1
Weed control	<i>Cultural, mechanical + chem</i>	<i>Cultural and chem</i>	<i>Chem only</i>
Use of same MoA/season	<i>Once</i>	<i>>1</i>	<i>Many</i>
Cropping system	<i>Full rotation</i>	<i>Limited</i>	<i>None</i>
Resistance to MoA	<i>Unknown</i>	<i>Limited</i>	<i>Common</i>
Weed infestation	<i>Low</i>	<i>Moderate</i>	<i>High</i>
Control last 3 years	<i>Good</i>	<i>Declining</i>	<i>Poor</i>

HERBICIDE RESISTANCE MANAGEMENT

- **Crop rotation**
 - **Enables herbicide rotation**
 - **Disrupts weed growing season**
 - **Different cultural measures**
 - **Variable competition with weeds**
- **Cultural methods**
 - **Bury non-germinated seeds**
 - **Delay planting to enable non-selective herbicide use**
 - **Weed free seed**
 - **Seed predators**
- **Herbicide rotation (NB some weeds resistant to several classes)**

E.g. Selected resistant weeds in OR

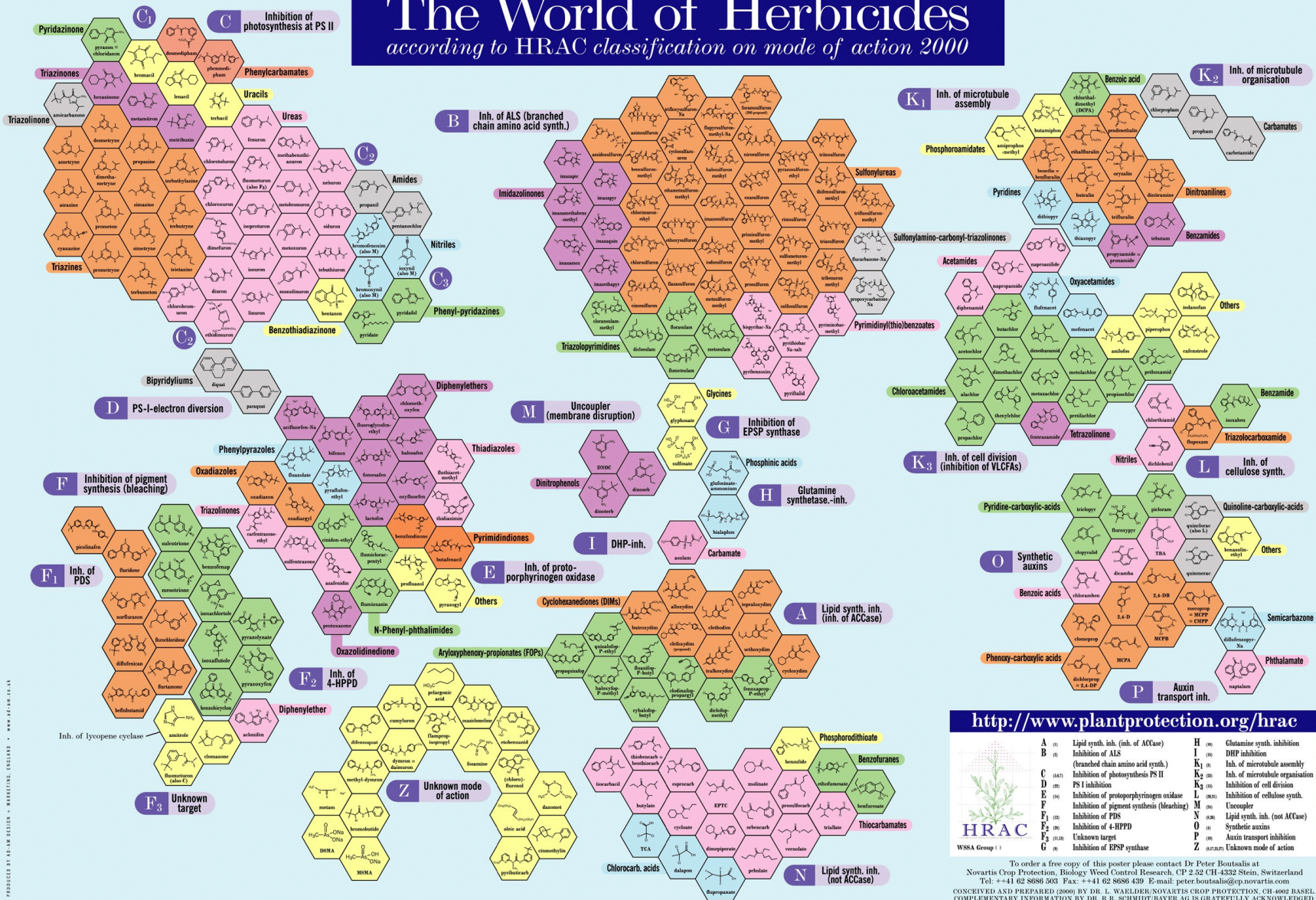
- Kochia, prickly lettuce, Russian thistle, annual bluegrass (Group 2 sulfonyleurea: e.g. Glean, Amber, Ally)
- Wild oat and Italian Ryegrass (Group 1 ACCase inhibitors: e.g. Discover; G 9)
- Powell amaranth and other pigweeds (Group 5, P. system II inhibitors: triazines: e.g. Atrazine)
- Yellow starthistle (Group 4 Synthetic auxins: e.g. Tordon)
- Wild oat (Far-Go (Group 8), Avenge (Group 26))

**How many herbicide mode of
action classes are there?**


8, 18, 28, 38?

The World of Herbicides

according to HRAC classification on mode of action 2000



A ₍₁₎	Lipid synth. inh. (inh. of ACCase)	H ₍₃₀₎	Glutamine synth. inhibition
------------------	------------------------------------	-------------------	-----------------------------

	A (1)	Lipid synth. inh. (inh. of ACCase)	I (8)	Glutamine synth. inhibition
	B (1)	Inhibition of ALS (branched chain amino acid synth.)	H (8)	DHP inhibition
	C (14,7)	Inhibition of photosynthesis PS II	K₁ (2)	Inh. of microtubule assembly
	D (8)	PS I inhibition	K₂ (2)	Inh. of microtubule organisation
	E (26)	Inhibition of protoporphyrinogen oxidase	K₃ (2)	Inhibition of cell division
	F₁ (2)	Inhibition of argenit synthesis (bleaching)	L (26,2)	Inhibition of cellulose synth.
	F₂ (2)	Inhibition of PDV	M (26)	Uncoupler
	F₃ (2)	Inhibition of 4-EPD	N (1)	Lipid synth. inh. (not ACCase)
	G (18,18)	Unknown target	O (1)	Synergetic axis
	F₄ (2)	Inhibition of EPSP synthase	P (2)	Axinin transport inhibition
			Z (2)	AXININ: Unknown mode of action

To order a free copy of this poster please contact Dr Peter Boutsalis at
Novartis Crop Protection, Biology Weed Control Research, CP 2.52 CH-4332 Stenl, Switzerland
Tel: ++41 62 8686 503 Fax: ++41 62 8686 439 E-mail: peter.boutsalis@cp.novartis.com

CONCEIVED AND PREPARED (2000) BY DR. R. L. WAELEDER/NOVARTIS CROP PROTECTION, CH-4002 BASEL.
COMPLEMENTARY INFORMATION BY DR. R. SCHMIDT/BAYER AG IS GRATEFULLY ACKNOWLEDGED.

HERBICIDE CLASSIFICATION

28 MoA classes, plus unknowns

- Group 2, Inhibition of acetolacetate synthase, incl. sulfonylureas (chlorsulfuron)
- Group 5, Inhibition of photosynthesis at photosystem II, incl. triazines (atrazine)

PNW 437: Herbicide resistant weeds and their management (Hulting et al)

IF CONTROL FAILURE IS CONFIRMED WITH A HERBICIDE

- **Eradicate remaining weed population to limit build up in soil**
- **Limit field to field movement**
- **Avoid the herbicide to which resistance confirmed**
- **Consider grazing or cutting for feed (avoid spreading manure)**
- **Select field for rotation or set aside**
- **Develop a long-term plan for weed management**

CONCLUSIONS

- **Good IPM practices extend chemical life in the market**
- **Knowledge of MoA class is useful**
- **Maintain records and develop a rotation strategy**
- **Heed local advice**

IPM that limits selection pressure for resistance	Impact on resistance	Impact on efficacy	
------------------------------------------------------------------	---------------------------------	-----------------------------------	--

IPM that limits selection pressure for resistance	Impact on resistance	Impact on efficacy	
------------------------------------------------------	-------------------------	-----------------------	--

**SOURCE REDUCTION (only use pesticides when
needed)**

IPM that limits selection pressure for resistance	Impact on resistance	Impact on efficacy	
SOURCE REDUCTION			
Substitute alternatives to pesticides (biological, cultural, physical)	Eliminates risk of resistance	Can increase pest suppression by adding or substituting alternative measures	

IPM that limits selection pressure for resistance	Impact on resistance	Impact on efficacy	
SOURCE REDUCTION			
Substitute alternatives to pesticides (biological, cultural, physical)	Eliminates risk of resistance	Can increase pest suppression by adding or substituting alternative measures	
Minimize amounts applied (e.g. monitoring, thresholds)	Reduces selection pressure	Can also maximize efficacy by timing correctly	

IPM that limits selection pressure for resistance	Impact on resistance	Impact on efficacy	
SOURCE REDUCTION			
Substitute alternatives to pesticides (biological, cultural, physical)	Eliminates risk of resistance	Can increase pest suppression by adding or substituting alternative measures	
Minimize amounts applied (e.g. monitoring, thresholds)	Reduces selection pressure	Can also maximize efficacy by timing correctly	
RESITANCE RISK MITIGATION			

IPM that limits selection pressure for resistance	Impact on resistance	Impact on efficacy	
---------------------------------------------------	----------------------	--------------------	--

SOURCE REDUCTION

Substitute alternatives to pesticides (biological, cultural, physical)	Eliminates risk of resistance	Can increase pest suppression by adding or substituting alternative measures	
Minimize amounts applied (e.g. monitoring, thresholds)	Reduces selection pressure	Can also maximize efficacy by timing correctly	

RESITANCE RISK MITIGATION

If a high risk product is in use, apply an alternative, lower resistance risk pesticide	Reduces or eliminates selection pressure for existing resistance	Depends upon efficacy of alternative	
-----------------------------------------------------------------------------------------	------------------------------------------------------------------	--------------------------------------	--

IPM that limits selection pressure for resistance	Impact on resistance	Impact on efficacy	
---------------------------------------------------	----------------------	--------------------	--

SOURCE REDUCTION

Substitute alternatives to pesticides (biological, cultural, physical)	Eliminates risk of resistance	Can increase pest suppression by adding or substituting alternative measures	
Minimize amounts applied (e.g. monitoring, thresholds)	Reduces selection pressure	Can also maximize efficacy by timing correctly	

RESITANCE RISK MITIGATION

If a high risk product is in use, apply an alternative, lower resistance risk pesticide	Reduces or eliminates selection pressure for existing resistance	Depends upon efficacy of alternative	
Maximize efficacy with application management plan (apply in most favorable conditions), and good application practices	Obtains highest level of exposure to pest, disease or weed	Maximizes efficacy by increasing retention on target	

IPM that limits selection pressure for resistance	Impact on resistance	Impact on efficacy	
SOURCE REDUCTION			
Substitute alternatives to pesticides (biological, cultural, physical)	Eliminates risk of resistance	Can increase pest suppression by adding or substituting alternative measures	
Minimize amounts applied (e.g. monitoring, thresholds)	Reduces selection pressure	Can also maximize efficacy by timing correctly	
RESITANCE RISK MITIGATION			
If a high risk product is in use, apply an alternative, lower resistance risk pesticide	Reduces or eliminates selection pressure for existing resistance	Depends upon efficacy of alternative	
Maximize efficacy with application management plan (apply in most favorable conditions), and good application practices	Obtains highest level of exposure to pest, disease or weed	Maximizes efficacy by increasing retention on target	