THE UNIVERSITY OF ARIZONA
COLLEGE OF AGRICULTURE AND LIFE SCIENCES
COOPERATIVE EXTENSION
School of Plant Sciences

Selection Pressure, Shifting Populations, and Herbicide Resistance and Tolerance

Dr. Bill McCloskey
Extension Weed Specialist

Outline

- Selection pressure
- Shifting populations
- Tolerance vs resistance
- Understanding herbicides
- Current state of herbicide resistance
- Factors contributing to resistance
- Identifying resistance

Origin of Weeds

- Where do the opportunistic species or weedy invaders of bare ground or empty space come from?
  - They are species that have always been part of the natural environment.
  - Natural ecosystem processes have always resulted in disturbed sites or habitats.
    - retreating ice sheets following glacial ice ages
    - stream banks
    - alluvial flood plains (e.g., Mississippi River)
    - volcanic deposits (e.g., Mount St. Helens)
    - meteorite impact craters and surrounding areas
    - severe wild fires

Opportunistic Plant Characteristics

1. Germination requirements met in many environments
2. Discontinuous germination and seed longevity
3. Rapid growth through vegetative phase to flowering
4. Continuous seed production for as long as growing conditions permit
5. Very high seed output in favorable environments
6. Production of some seed in a wide range of environmental conditions; tolerance and plasticity
7. Adaptations for short-distance dispersal and long-distance dispersal
8. If perennial, vigorous vegetative reproduction or regeneration from fragments

Origin of Weeds

- When humans first began to domesticate plants, they created disturbed sites.
- As agricultural technology became more powerful
  - the scale and intensity of disturbance increased and
  - invasion by weedy plants increased.
- Natural selection resulted in weed species that evolved simultaneously with crop plants as humans domesticated plants.
- Weed populations change in response to the weed control practices used in agro-ecosystems and natural ecosystems.

Weedy Population Shifts

- High genetic diversity in weed populations
- Weed populations in a field usually consist of a mixture of species
  - Relative proportion of individual species is dynamic and can vary over time in response to management practices
  - Repeated use of a single control tactic can lead to weed populations dominated by species not controlled by that practice

Weed Shifts

- Earliest changes in weed populations were shifts in weed species composition (i.e., weed shifts) caused by changes in agricultural practices
- In Denmark in the 60 years after 1911, there was an increase in abundance of annual weed species and concomitant decrease in herbaceous perennial weeds.

Adoption of tractors and greater soil disturbance resulting from tractor drawn tillage implements compared to horse drawn tillage implements.

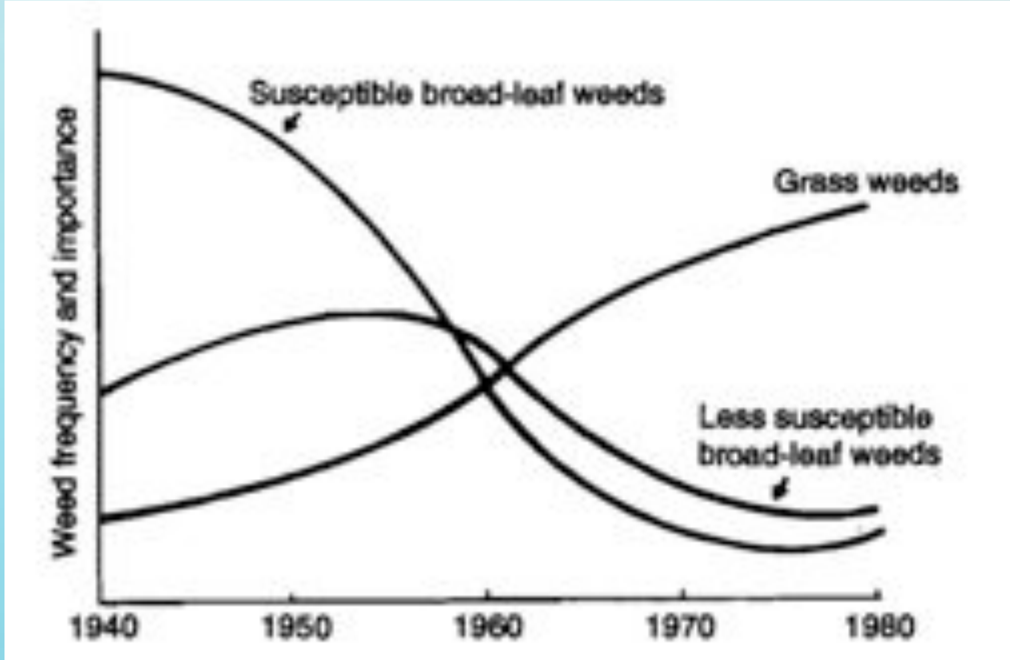
Weed Shifts - Changes in cultural practices change weed composition.

- Example: changing from disking to mowing resident weeds:
  - Favors the growth of grasses and prostrate broadleaf weeds such as puncturevine.
  - Decreases population of upright growing broadleaves such as pigweeds.

Weed Shifts - After herbicides were introduced in the 1950's

- The use of 2,4-D in cereal grain crops caused a shift in weed species:
  - Grass weeds tolerant to 2,4-D increased, and
  - Broadleaf weeds susceptible to 2,4-D decreased in abundance.

- 2,4-D is an example of the use of a ***selective*** herbicide.
  - Shift to tolerant or resistant species



Conjectured changes in the British arable weed flora over four decades. (From Fryer and Chancello
sion of the British Crop Protection Council.)

Western Arizona Alfalfa – Repeated use of trifluralin, suppression of summer annual grasses and increase in purple nutsedge (8-4-2008)

Western Arizona Alfalfa – Repeated use of trifluralin, suppression of summer annual grasses and increase in purple nutsedge (9-5-2008)

Western Arizona Alfalfa – Repeated use of trifluralin, suppression of summer annual grasses and increase in purple nutsedge (2-19-2009)

Weed Shifts

With the repeated use of a herbicide, certain weed species may become dominant due to selection for those that are tolerant.

These populations are not herbicide-resistant.

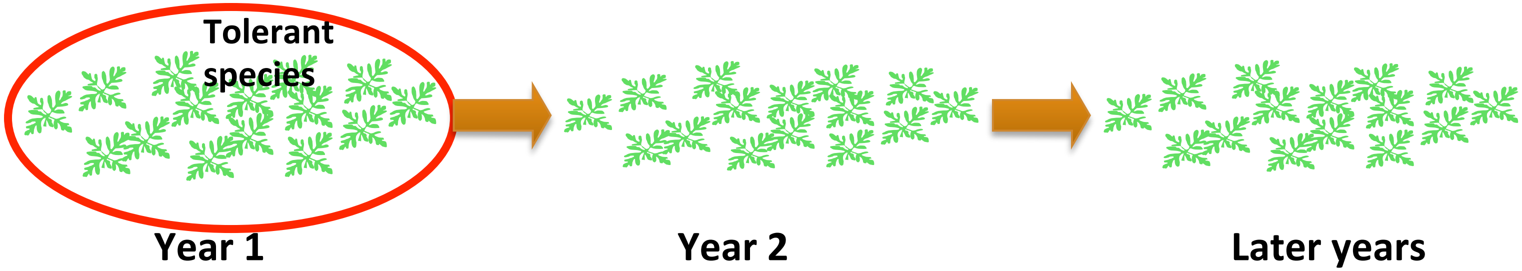
Weed shifts due to herbicide use can be caused by:

- Using a herbicide to which the species is tolerant
- Using rates that are lower than recommended
- Using postemergence herbicides when weeds are too large

Herbicide Resistance WSSA Definitions

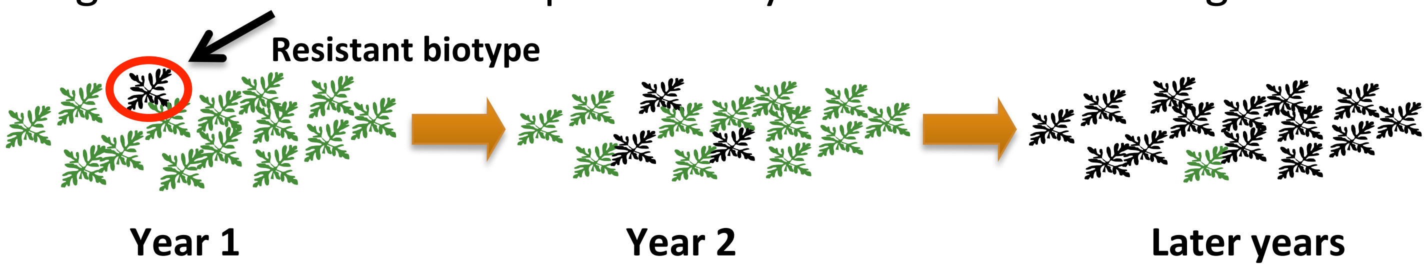
“We’ve never gotten dependable control of this weed with this herbicide…”

"**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."



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."



"We used to be able to control this weed with this treatment but it doesn't work as well anymore…"

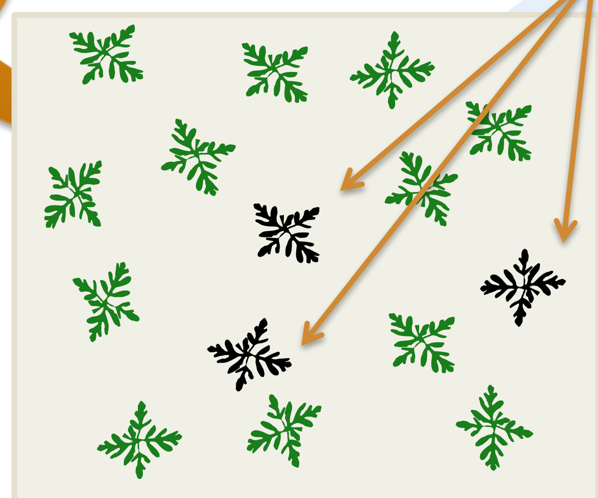
Selection by Herbicides Changes the Population Over Time

Example

Year 1

1 in a million resistant to a herbicide

Year 2 begins with more resistant weeds

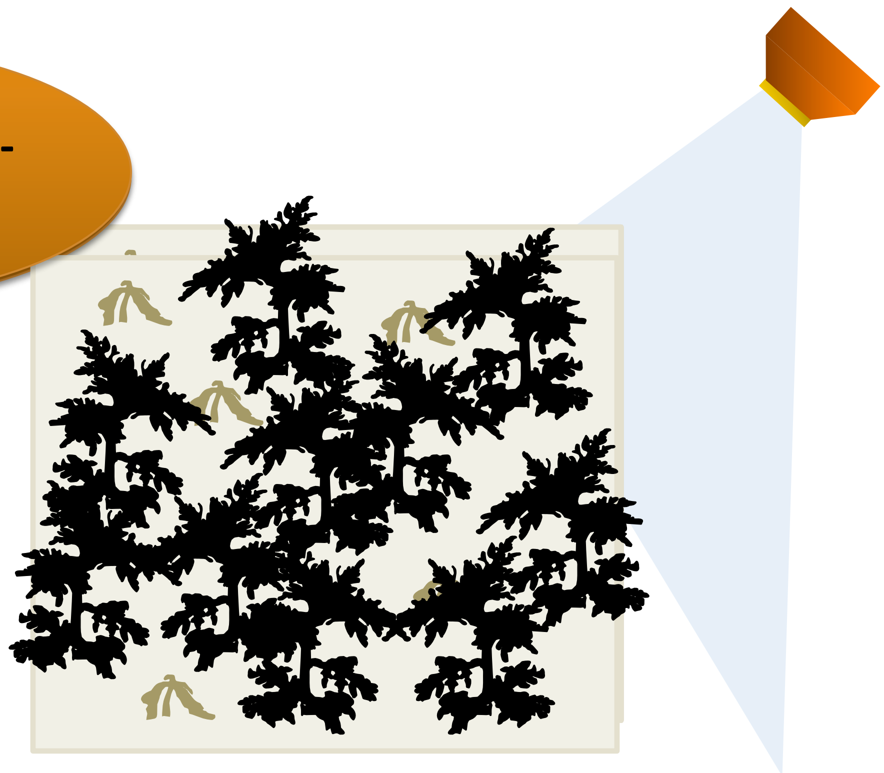


Selection by Herbicides Changes the Population Over Time

Example

Year 3

And in later years even more herbicide-resistant weeds are present



Herbicide Resistance Defined

Herbicide resistance can be defined as the acquired ability of a weed population to survive a herbicide application that previously was known to con … on.

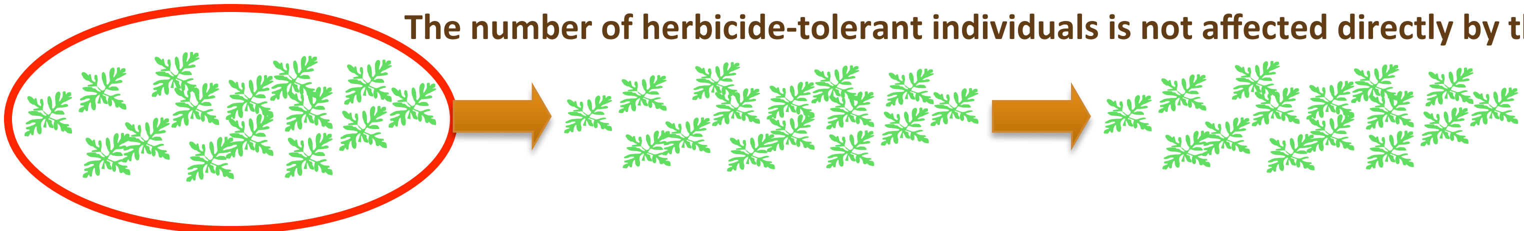
The number of herbicid…
tim…

Later years

In herbicide resistance there is a change in the response of the weed population over time; it is no longer controlled by the herbicide.
In herbicide tolerance, there is no change over time, the population has always been tolerant to the herbicide.

H… is the inherent ability of a species to survive and reproduce after herbicide treatment. There has been no selection acting on the tolerant weed species, and there has been no change in the weed species lack of response to the herbicide over time.

The number of herbicide-tolerant individuals is not affected directly by the herbicide.



Year 1 | Year 2 | Later years

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.

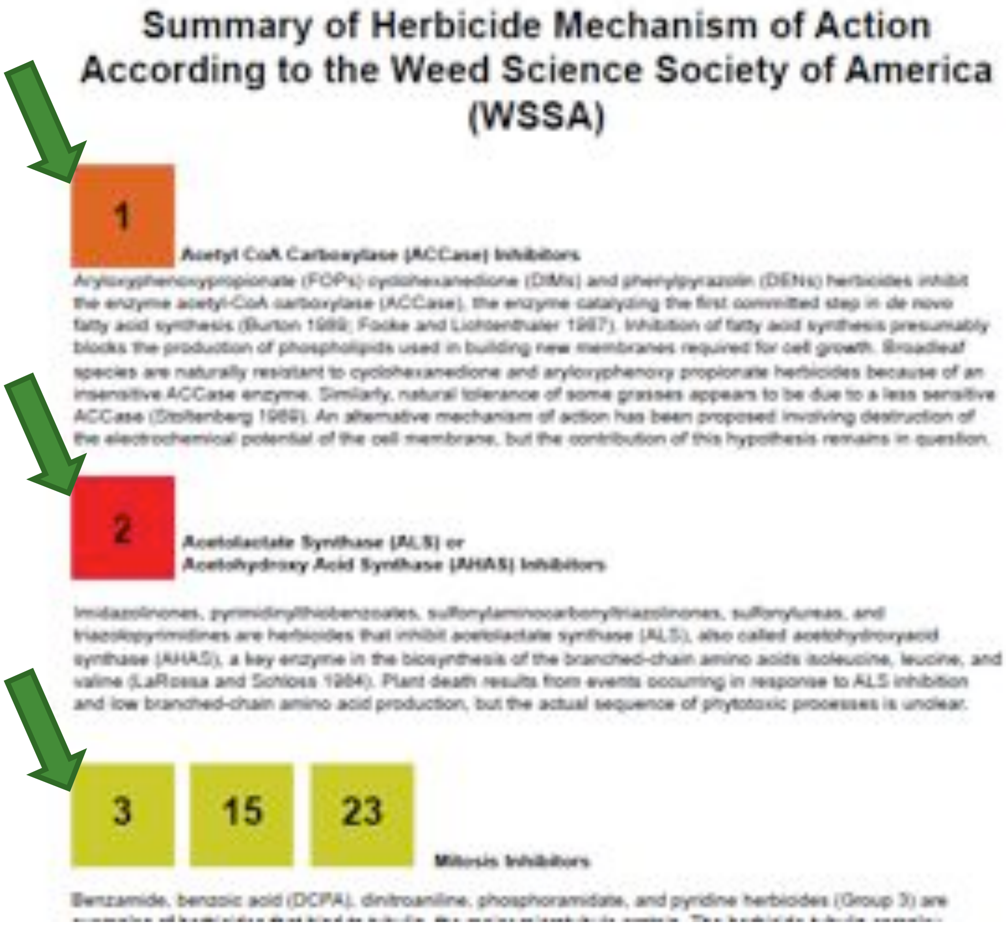
- Includes absorption, translocation, metabolism & interaction at the mechanism of action

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.

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

FOR MORE INFORMATION

Categorization by Mechanism of Action



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

1

Acetyl CoA Carboxylase (ACCase) Inhibitors

Aryloxyphenoxypropionate (FOPs) cyclohexanedione (DIMs) and phenylpyrazolin (DENs) herbicides inhibit the enzyme acetyl-CoA carboxylase (ACCase), the enzyme catalyzing the first committed step in *de novo* fatty acid synthesis (Burton 1989; Focke and Lichtenthaler 1987). Inhibition of fatty acid synthesis presumably 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 ACCase enzyme. Similarly, natural tolerance of some grasses appears to be due to a less sensitive ACCase (Stoltenberg 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 Acetohydroxy Acid Synthase (AHAS) Inhibitors

Imidazolinones, pyrimidinylthiobenzoates, sulfonylaminocarbonyltriazolinones, sulfonylureas, and triazolopyrimidines are herbicides that inhibit acetolactate synthase (ALS), also called acetohydroxyacid synthase (AHAS), a key enzyme in the biosynthesis of the branched-chain amino acids isoleucine, leucine, and valine (LaRossa and Schloss 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 15 23

Mitosis Inhibitors

Benzamide, benzoic acid (DCPA), dinitroaniline, phosphoramidate, and pyridine herbicides (Group 3) are

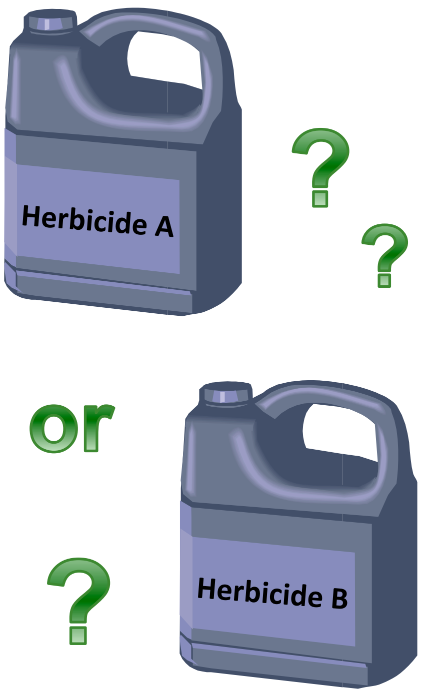
The numbering system assigns each herbicide to a mechanism of action group.
[Link to herbicide mechanism of action classification]

The EPA recommends that labels display the group number that identifies the mechanism of action for the active ingredient(s) in a formulated product.

Goal of the Mechanism of Action Numbering System

The goal of herbicide group number classification system is to provide a tool that aids in herbicide selection.

Herbicide labels also include herbicide resistance management guidelines to direct growers and dealers to local extension experts for assistance with weed management decisions.



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_8-binding niche on the D1 protein of the photosystem II complex in the chloroplast thylakoid membranes resulting in inhibition of photosynthesis.

GROUP	15 9 27	HERBICIDE

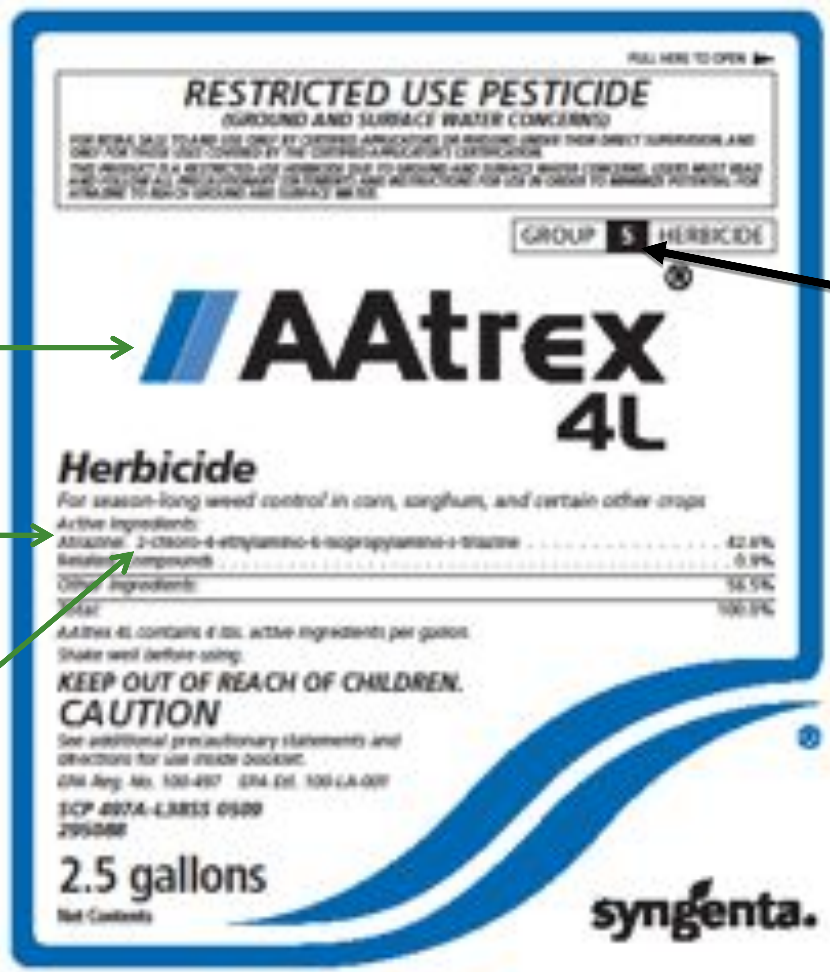
The product with this symbol contains s-metolachlor, glyphosate, and mesotrione, active ingredients with three different mechanisms of action, designated by Group 15 - inhibition of very long chain fatty acids resulting in inhibition of cell division; Group 9 - binding to the EPSP synthase enzyme and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

Example of a Group Number on a Label

Trade name

Common name

Chemical name



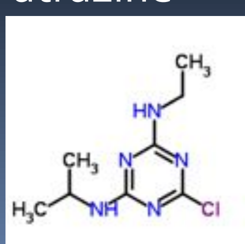
Mechanism of Action Group Number

Herbicide Chemistry (Family)

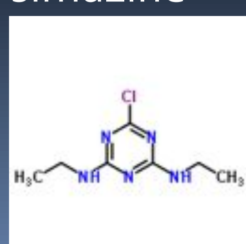
- Herbicides are grouped into families or classes according to chemical structures
  - Herbicides in the same family usually have a base molecule with different side chains or groups
    - Different functional groups can dramatically change herbicidal activity, selectivity, and persistence

Example: various triazine herbicides

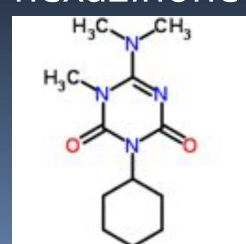
atrazine



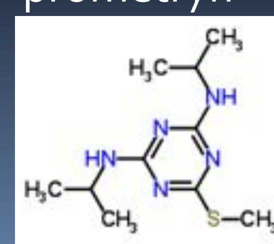
simazine



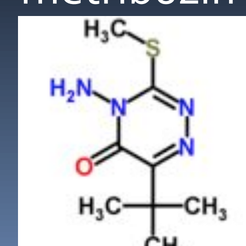
hexazinone



prometryn



metribuzin



Structures from www.chemspider.com

MOA vs. herbicide family vs. active ingredient

MOA

ALS Inhibitor

ALS is an enzyme involved in branched chain AA synthesis

Family

sulfonylurea

imidazolinone

SU and IMI both inhibit ALS, but at different sites

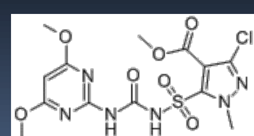
Active ingred.

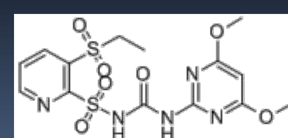
halosulfuron

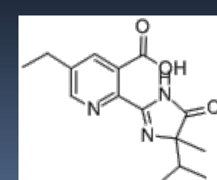
rimsulfuron

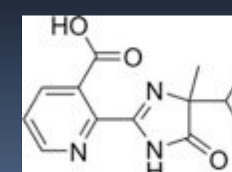
imazethapyr

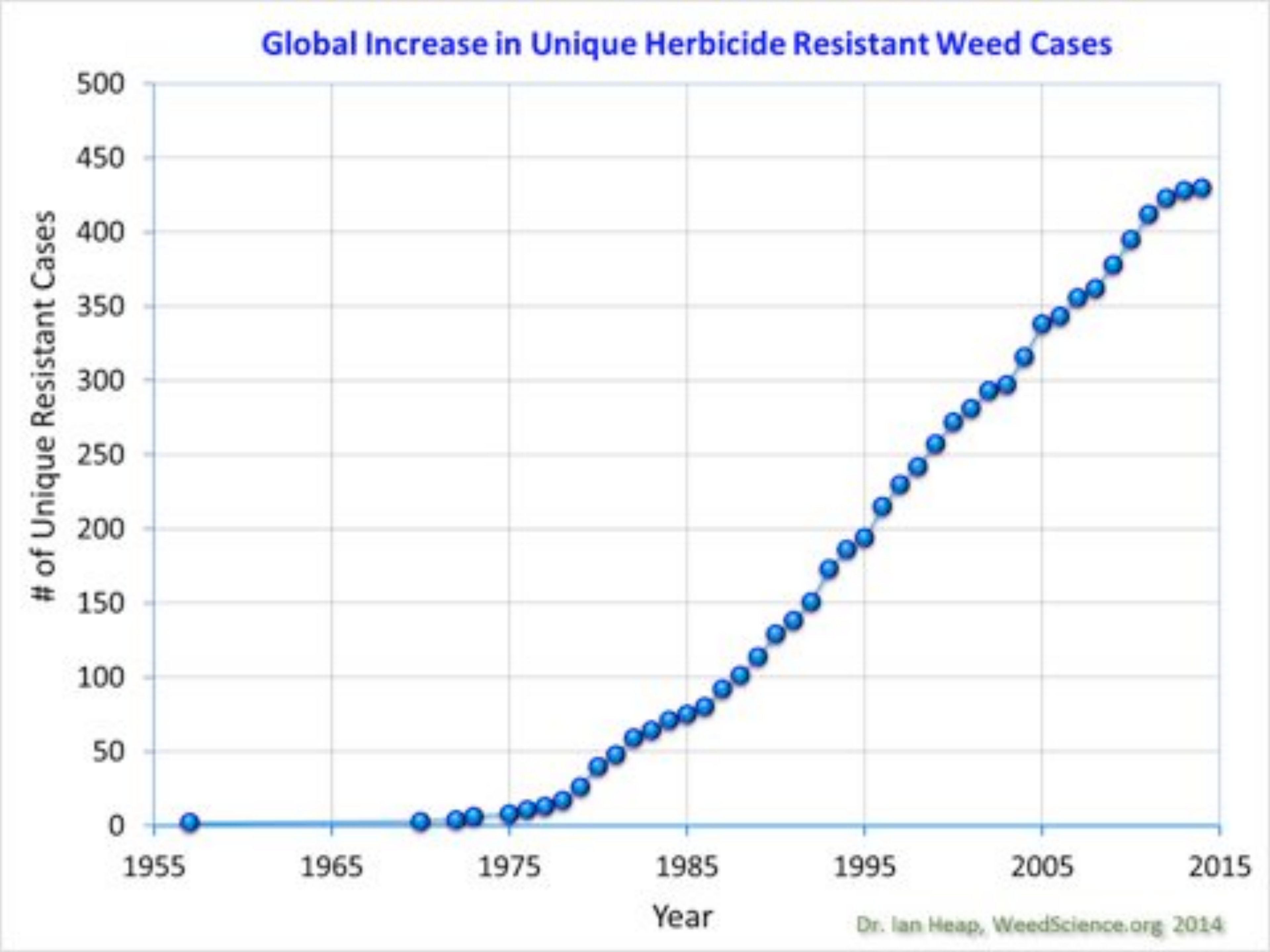
imazapyr

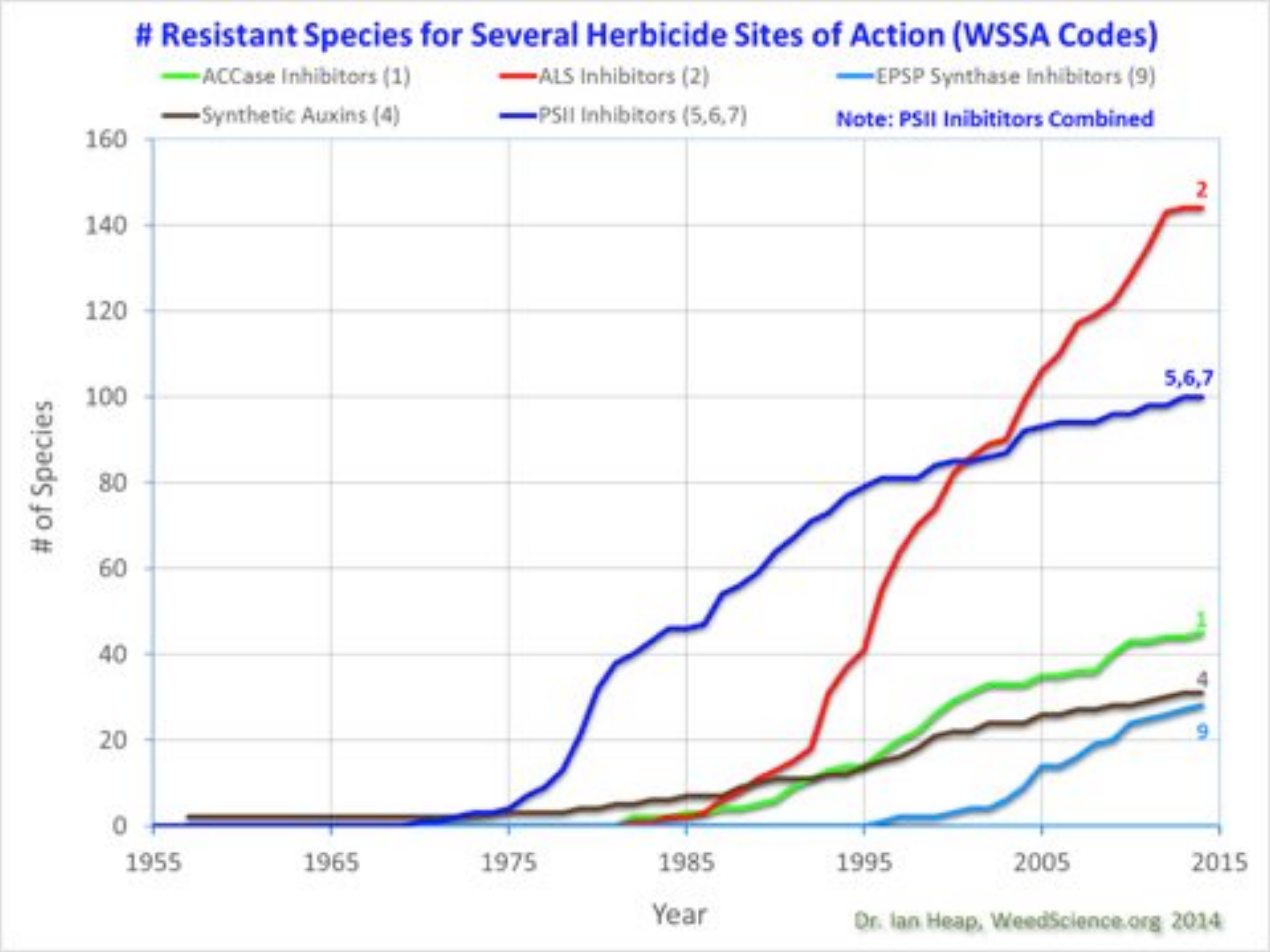


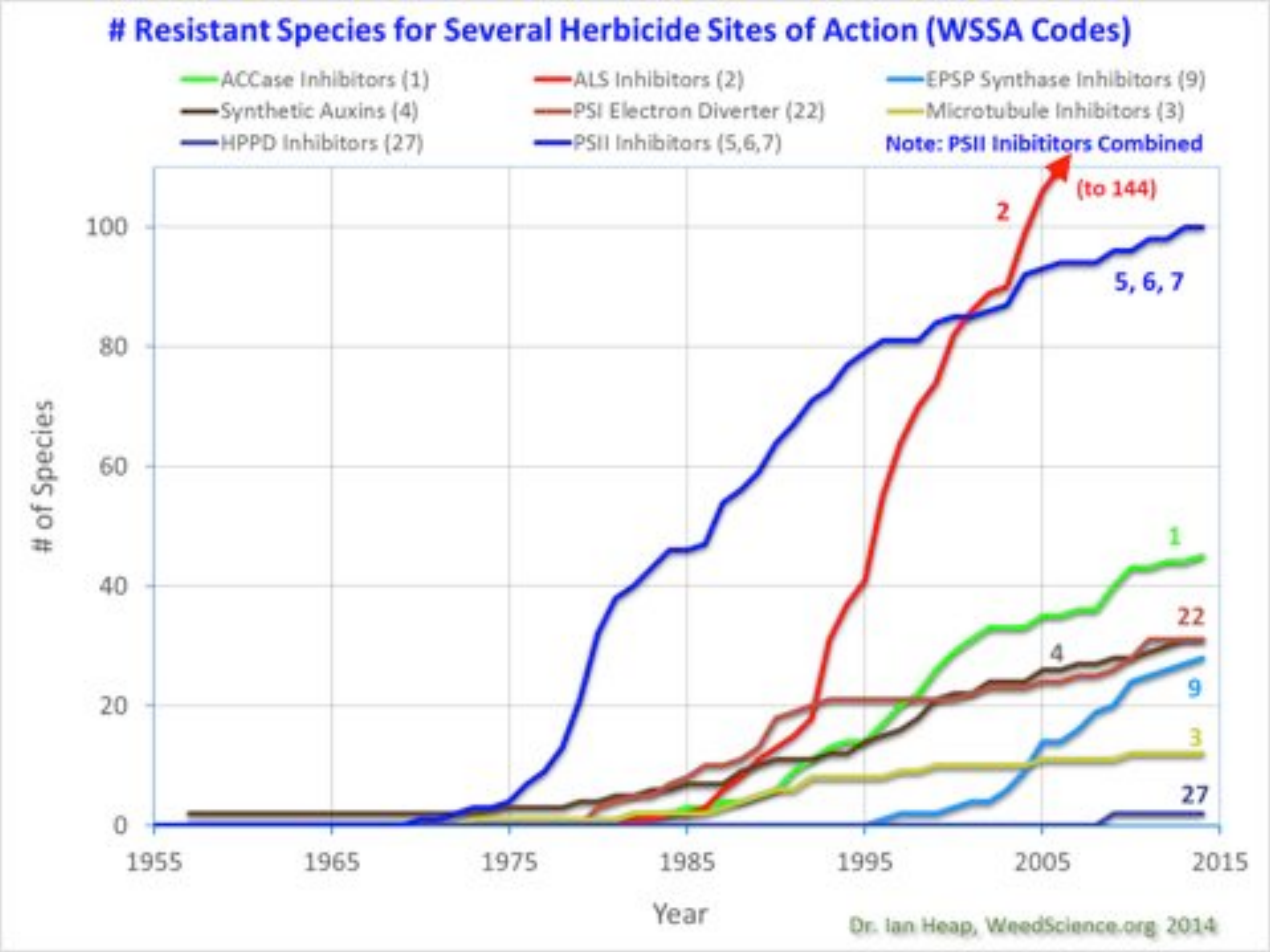







Global Increase in Unique Herbicide Resistant Weed Cases
# of Unique Resistant Cases
500
450
400
350
300
250
200
150
100
50
0
1955
1965
1975
1985
1995
2005
2015
Year
Dr. Ian Heap, WeedScience.org 2014

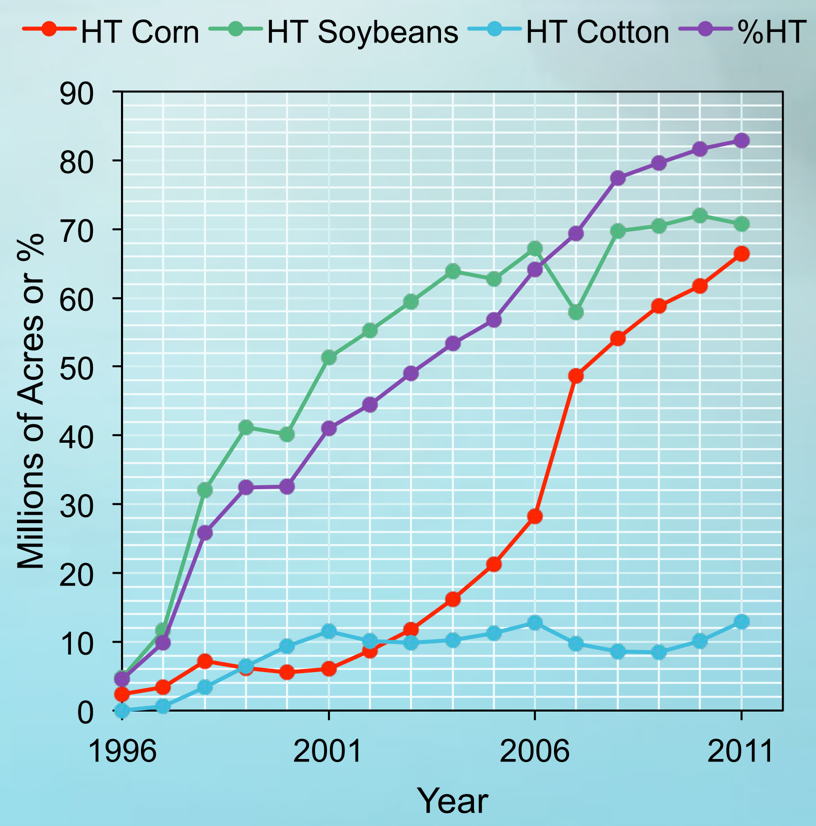

Resistant Species for Several Herbicide Sites of Action (WSSA Codes)
ACCase Inhibitors (1)
ALS Inhibitors (2)
EPSP Synthase Inhibitors (9)
Synthetic Auxins (4)
PSII Inhibitors (5,6,7)
Note: PSII Inibititors Combined
# of Species
160
140
120
100
80
60
40
20
0
1955
1965
1975
1985
1995
2005
2015
Year
2
5,6,7
1
4
9
Dr. Ian Heap, WeedScience.org 2014



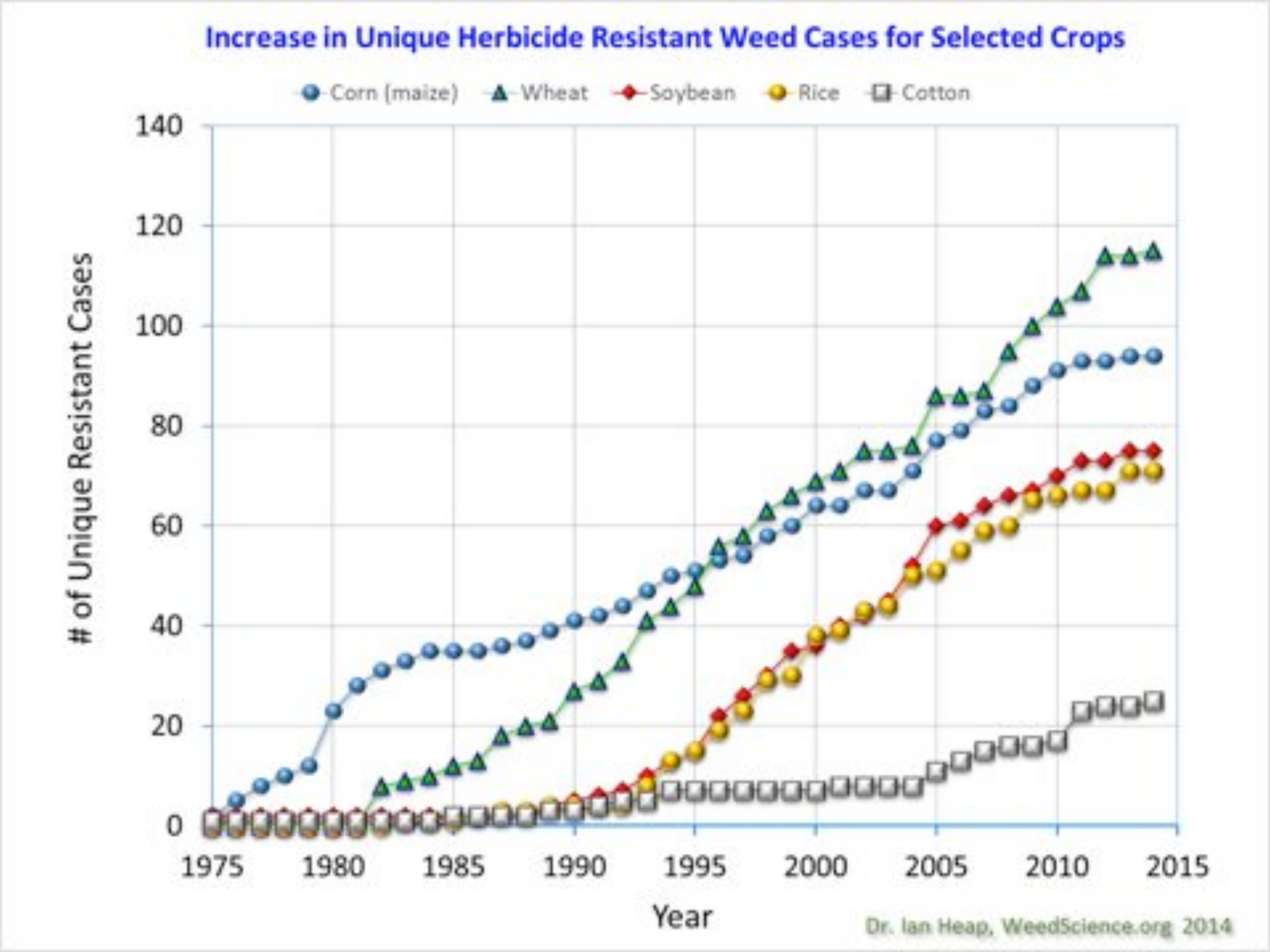
Resistant Species for Several Herbicide Sites of Action (WSSA Codes)
ACCase Inhibitors (1)
ALS Inhibitors (2)
EPSP Synthase Inhibitors (9)
Synthetic Auxins (4)
PSI Electron Diverter (22)
Microtubule Inhibitors (3)
HPPD Inhibitors (27)
PSII Inhibitors (5,6,7)
Note: PSII Inibititors Combined
(to 144)
2
5, 6, 7
1
22
4
9
3
27
# of Species
0
20
40
60
80
100
1955
1965
1975
1985
1995
2005
2015
Year
Dr. Ian Heap, WeedScience.org 2014

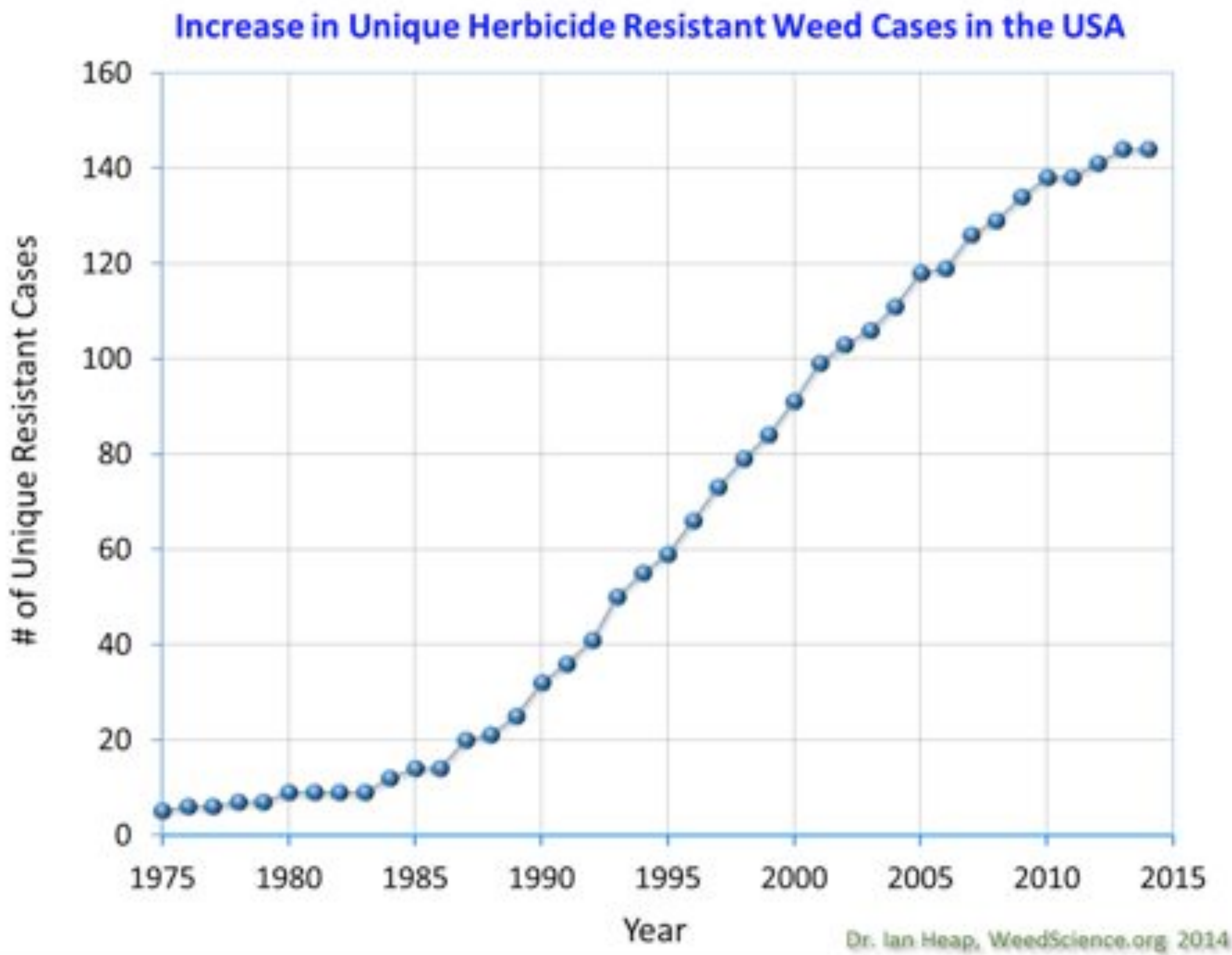
Chemicals – Impact of GMO Crops

- From 1996 through 2011 1.372 billion hectares of HT crops have been grown:
  - 406 million of HT corn
  - 829 million acres of HT soybeans
  - 135 million acres of HT cotton
- Between 1996 and 2011:
  - HR crops increased herbicide use by 527 million pounds
  - Bt crops decreased insecticide use by 123 million pounds



Benbrook CM. 2012. Impacts of genetically engineered crops on pesticide use in the U.S. – the first sixteen years. Environmental Sciences Europe 24:24. http://www.enveurope.com/content/21/1/24


Increase in Unique Herbicide Resistant Weed Cases for Selected Crops
Corn (maize)
Wheat
Soybean
Rice
Cotton
# of Unique Resistant Cases
0
20
40
60
80
100
120
140
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
Dr. Ian Heap, WeedScience.org 2014



Increase in Unique Herbicide Resistant Weed Cases in the USA
160
140
120
100
80
60
40
20
0
# of Unique Resistant Cases
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
Dr. Ian Heap, WeedScience.org 2014

Factors Affecting Speed (

The length of time for selection o

- Cultural practices
- Frequency of herbicide use
- Herbicide mechanism of action
- Biology of weed species
- Frequency of resistant biotypes amo

Another factor affecting the speed of selection is the mechanism of herbicide resistance. There are two general types of mechanisms: (1) exclusionary resistance (for example, differential uptake and translocation, compartmentalization and metabolic detoxification) and (2) target site resistance (alteration of the targeted enzyme and overproduction of a specific enzyme). Exclusionary resistance generally takes longer to evolve in the field.

[Click to close.]

? ? ?

FOR MORE INFORMATION

Year 0	Year 2	Year 4	Year 6	Year 8	Year 10	Later

Herbicide Characteristics

- Single site of action
- High efficacy
  – selection pressure
- High use rate (relative to amount needed)
- Long soil residual activity
- High frequency of use (yearly or multiple applications per year)

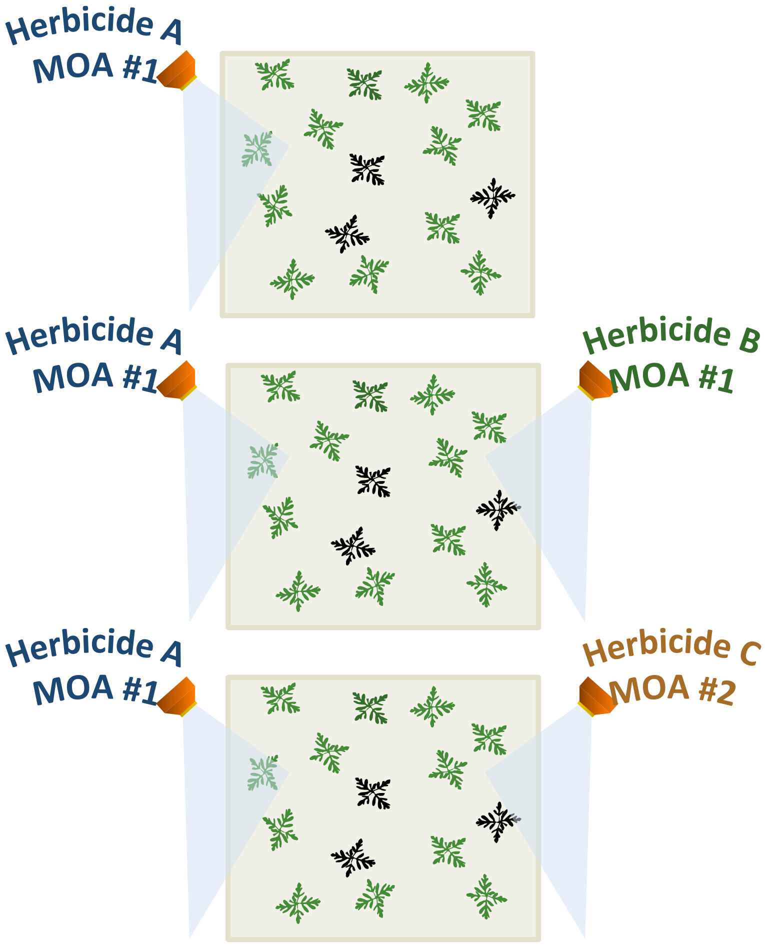
Think:
- Sulfonylurea in wheat/rice
- Triazines in field and hort crops
- ACCase inhibitors in cereals
- Paraquat and glyphosate in orchards

Weed Characteristics

- Annual growth habit
- High seed production
- Little seed dormancy
- Some seed longevity in soil
- Original frequency of R trait in population
- Multiple generations per year
- Gene flow (pollen and seed)
- Fitness of R v. S biotype
- Highly susceptible to the herbicide

SU-resistant Russian thistle dispersal
- Stallings et al. 1995

Herbicide Resistance Types



Single Herbicide Resistance

- Resistant to only *one* herbicide

Cross Herbicide Resistance

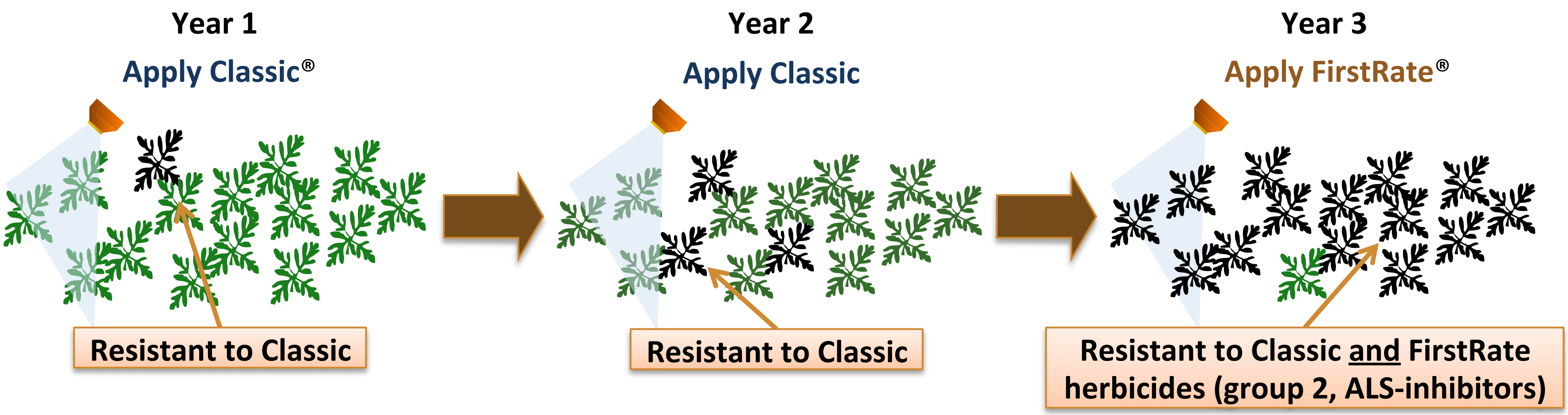
- Resistant to *two or more* herbicide families with *same mechanism of action*
- Single resistance mechanism

Multiple Herbicide Resistance

- Resistant to *two or more* herbicides with *different mechanisms of action*
- May be the result of two or more different resistance mechanisms

Herbicide Resistance Types: Cross Resistance

An example with common ragweed



Classic, a sulfonylurea, and FirstRate, a triazolopyrimidine, both belong to the ALS-inhibitors, or group 2 herbicides. Both herbicide products have the same mechanism of action.

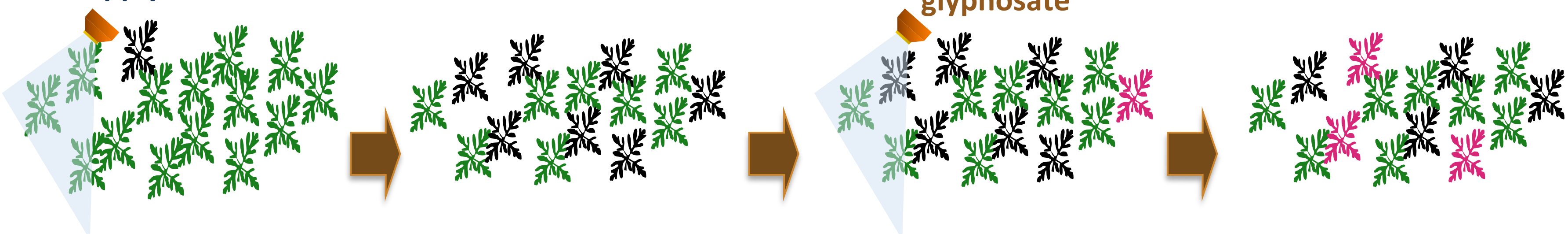
CAUTION: Weeds that are herbicide-resistant to one member of a herbicide mechanism of action group may or may not be cross-resistant to all herbicides within that group. Consult your local extension specialist for more information.

Herbicide Resistance Types: Multiple Resistance

Example

Apply atrazine

Switch to and apply glyphosate



Years 1-5 — Years 5-8 — Years 8-13 — Years 14 +

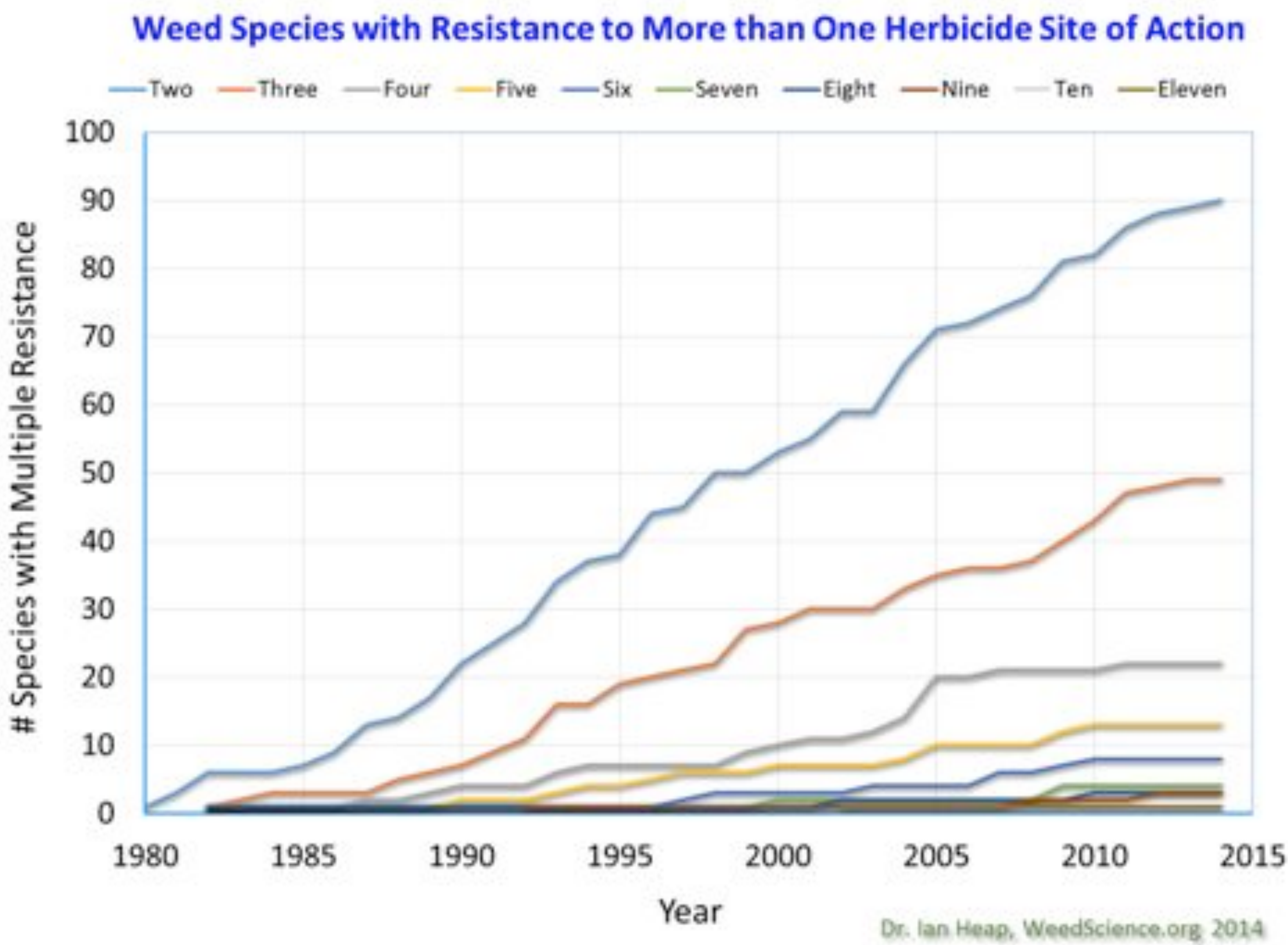
Years 1-5: Select for weeds resistant to group 5 herbicides (shown in black)

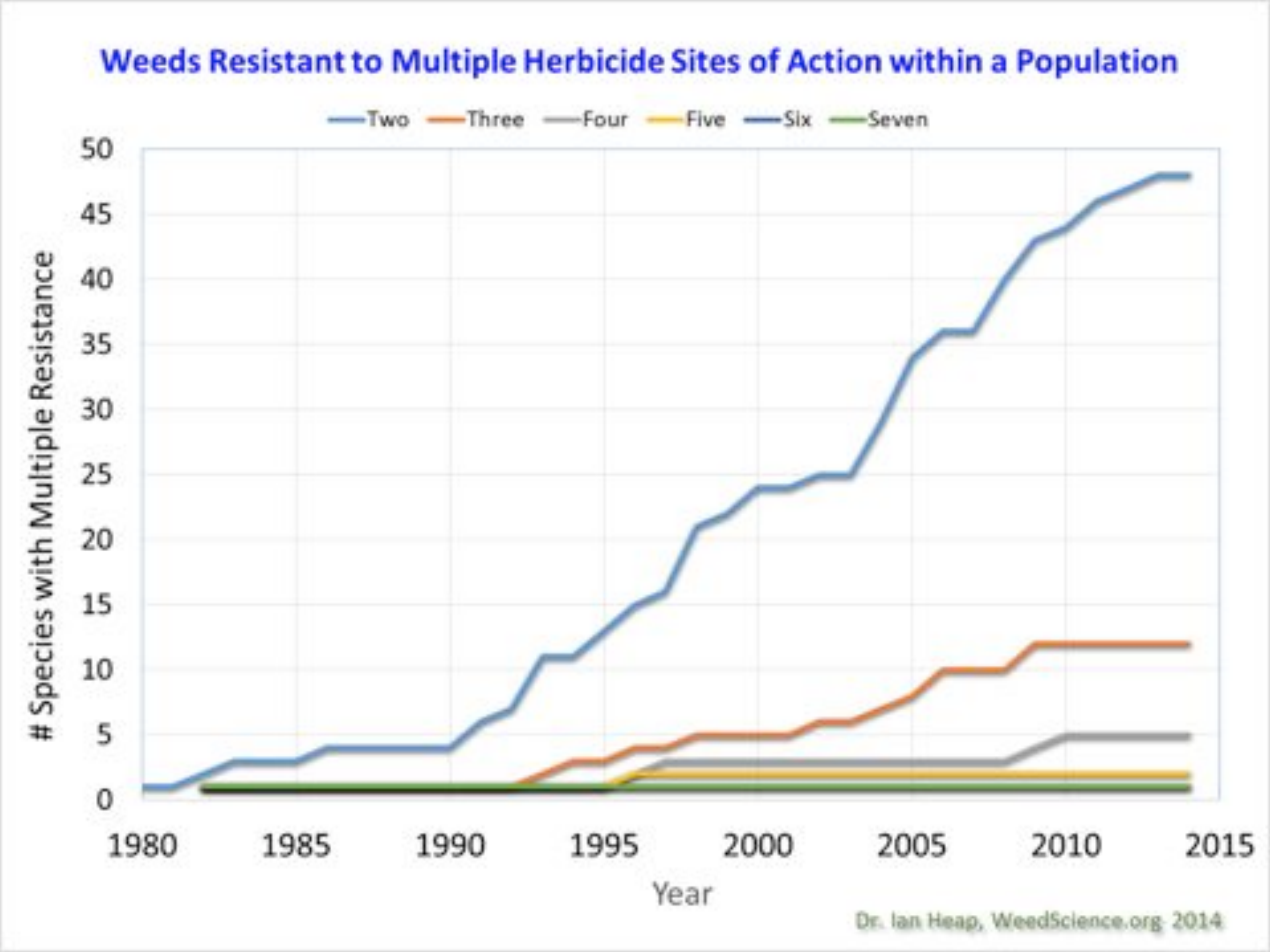
Years 5-8: The population with resistance to group 5 herbicides increases

Years 8-13: Select for weeds resistant to group 9 herbicides (shown in pink) from a population that is resistant to group 5

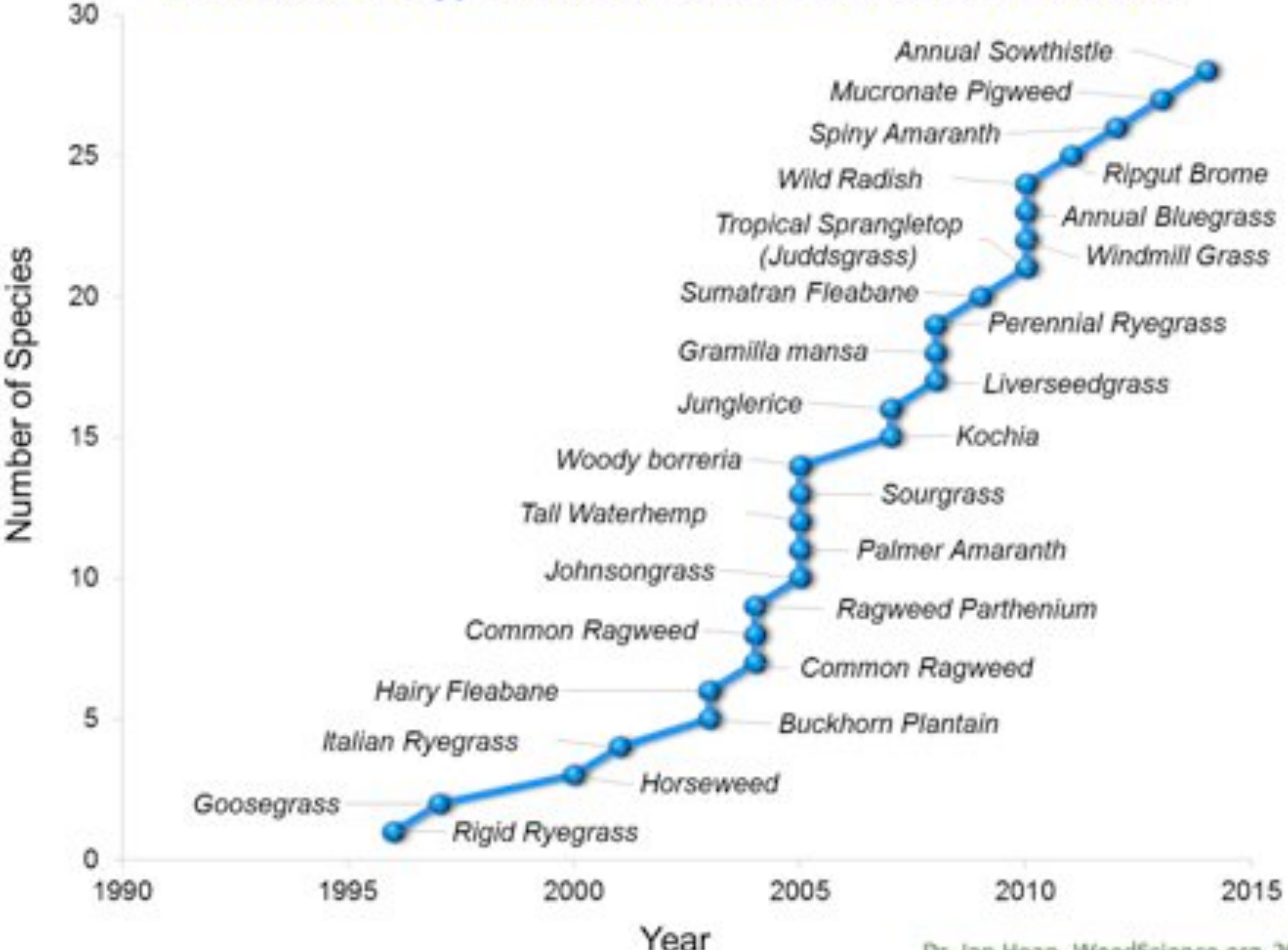
Years 14 +: The population with multiple resistance to group 5 and 9 increases

Multiple resistance can occur following repeated applications of a single herbicide and selection for herbicide-resistant biotypes followed by repeated applications of another herbicide and selection for herbicide-resistant biotypes.


Weed Species with Resistance to More than One Herbicide Site of Action
Two
Three
Four
Five
Six
Seven
Eight
Nine
Ten
Eleven
Species with Multiple Resistance
100
90
80
70
60
50
40
30
20
10
0
1980
1985
1990
1995
2000
2005
2010
2015
Year
Dr. Ian Heap, WeedScience.org 2014


Weeds Resistant to Multiple Herbicide Sites of Action within a Population
Two
Three
Four
Five
Six
Seven
50
45
40
35
30
25
20
15
10
5
0
Species with Multiple Resistance
1980
1985
1990
1995
2000
2005
2010
2015
Year
Dr. Ian Heap, WeedScience.org 2014

Increase in Glyphosate-Resistant Weeds Worldwide



Dr. Ian Heap, WeedScience.org 2014

Herbicide resistance should 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.
- One weed species that is normally controlled is NOT controlled while other weed species are controlled.
- Healthy weeds are mixed with killed weeds (same species)
- A single-species weed patch of uncontrolled plants is spreading.

Concluding Comments

- Weed Management exerts selection pressure
  - Tolerance, species shifts & resistance
- Understand and increase the diversity of herbicide modes of action
- Use other weed management tactics to reduce selection pressure