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Minnesota Crop Production Retailers Association Trade Show

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Herbicide Resistant Weeds
A Global Perspective

Crop Pest Management Short Course

Minneapolis, December 9th, 2015

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Herbicide-Resistant Weeds
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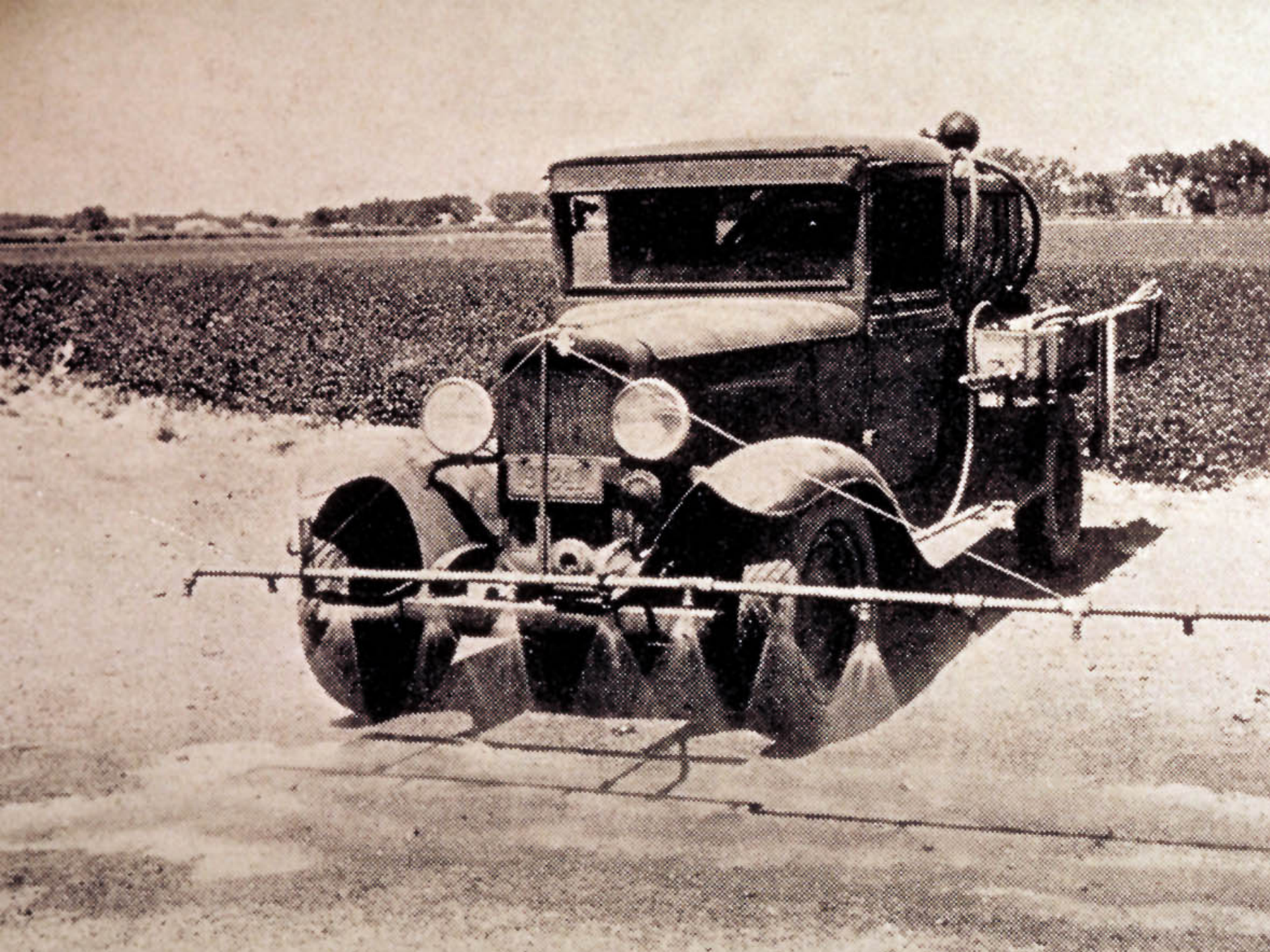
COOPAZINE
SHEEP WORM DRENCH
COOPER'S
COOPAZINE
SHEEP WORM DRENCH



Group C1 - Triazine Resistant Common Groundsel – 1970.

Herbicide Resistance – Simple Definition

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

Genetic diversity – rare resistant mutation

+

Selection – the repeated use of the same herbicide, or herbicides with the same site of action

=

RESISTANCE

Prerequisites for Resistance Evolution

- Individuals with genes conferring resistance within the population
- Selection pressure on individuals possessing those genes

Resistance is Evolution at Work

Resistance is a naturally occurring evolutionary response to selection pressure by a mortality agent (i.e., a herbicide)

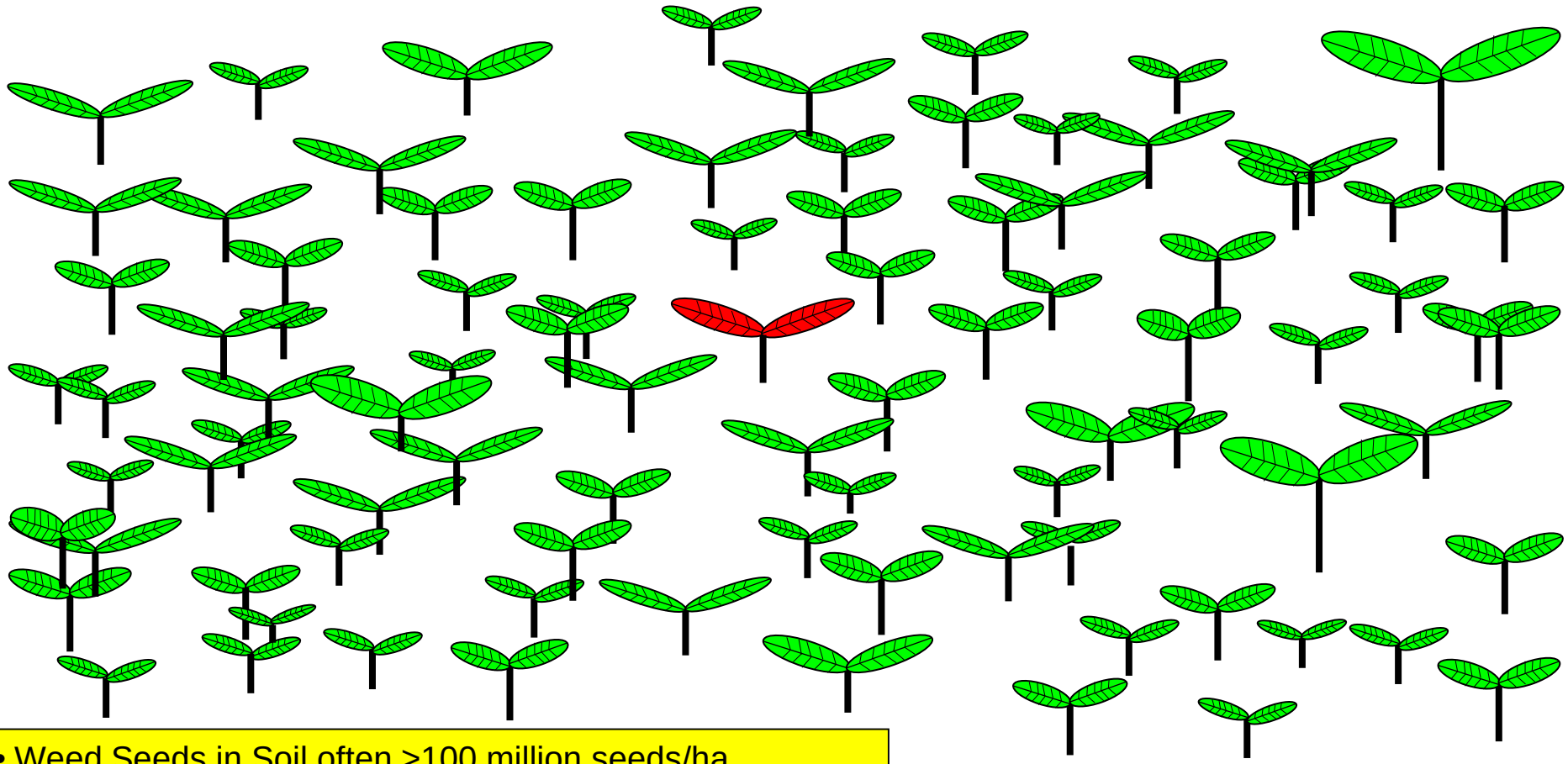
How Does Herbicide Resistance Develop?

- Herbicides do not “create” resistance
- Individual plants naturally resistant are present in very low numbers
- Herbicides select for those resistant individuals

Weed Resistance

Scientific Guesstimates:
- ALS inhibitors - 1 in 100,000?
- ACCase inhibitors - 1 in 1,000,000?
- Many herbicides - 1 in 10,000,000?
- Auxins & Glyphosarte - 1 in 100,000,000?

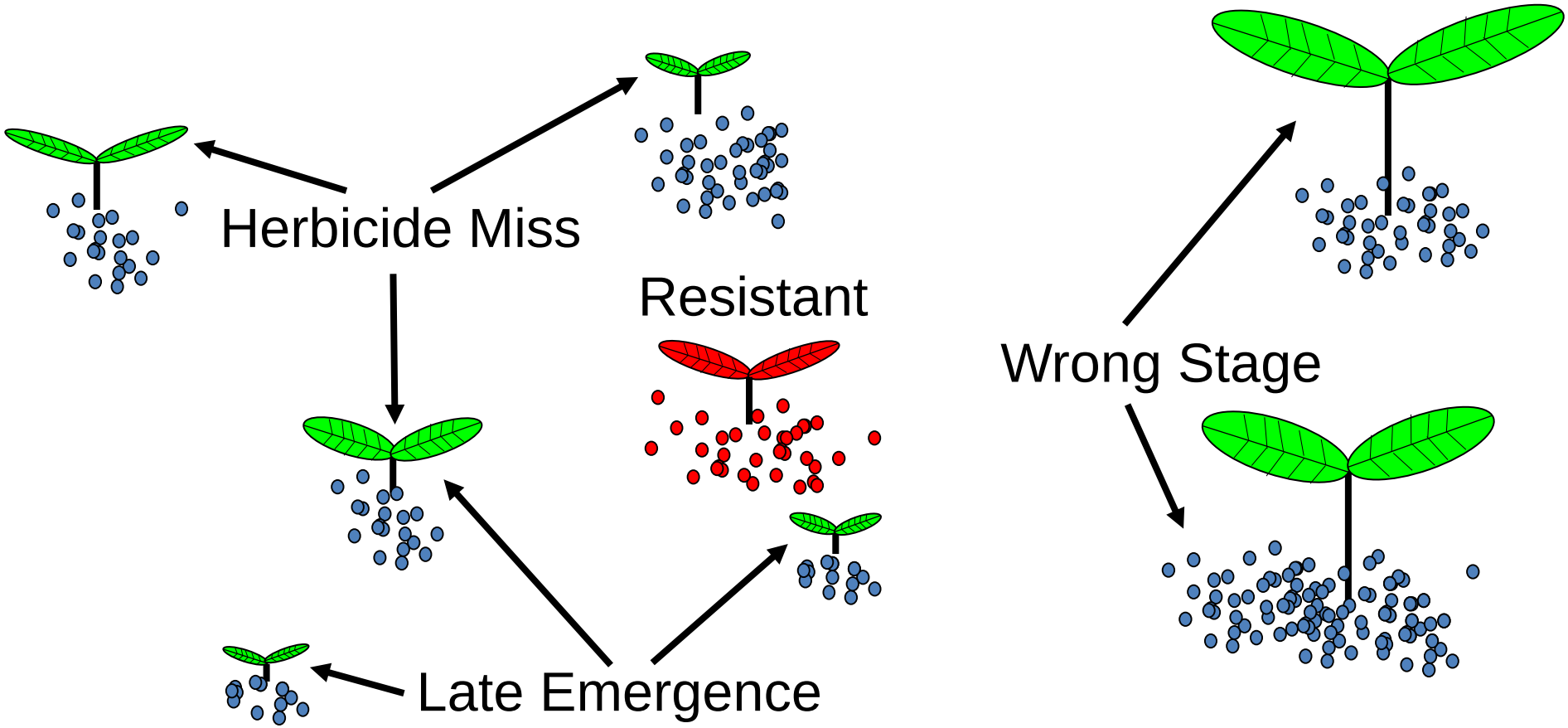
SELECTION PRESSURE



- Weed Seeds in Soil often >100 million seeds/ha
- Weed Seedling Populations often >1 million seedlings/ha

Weed Resistance

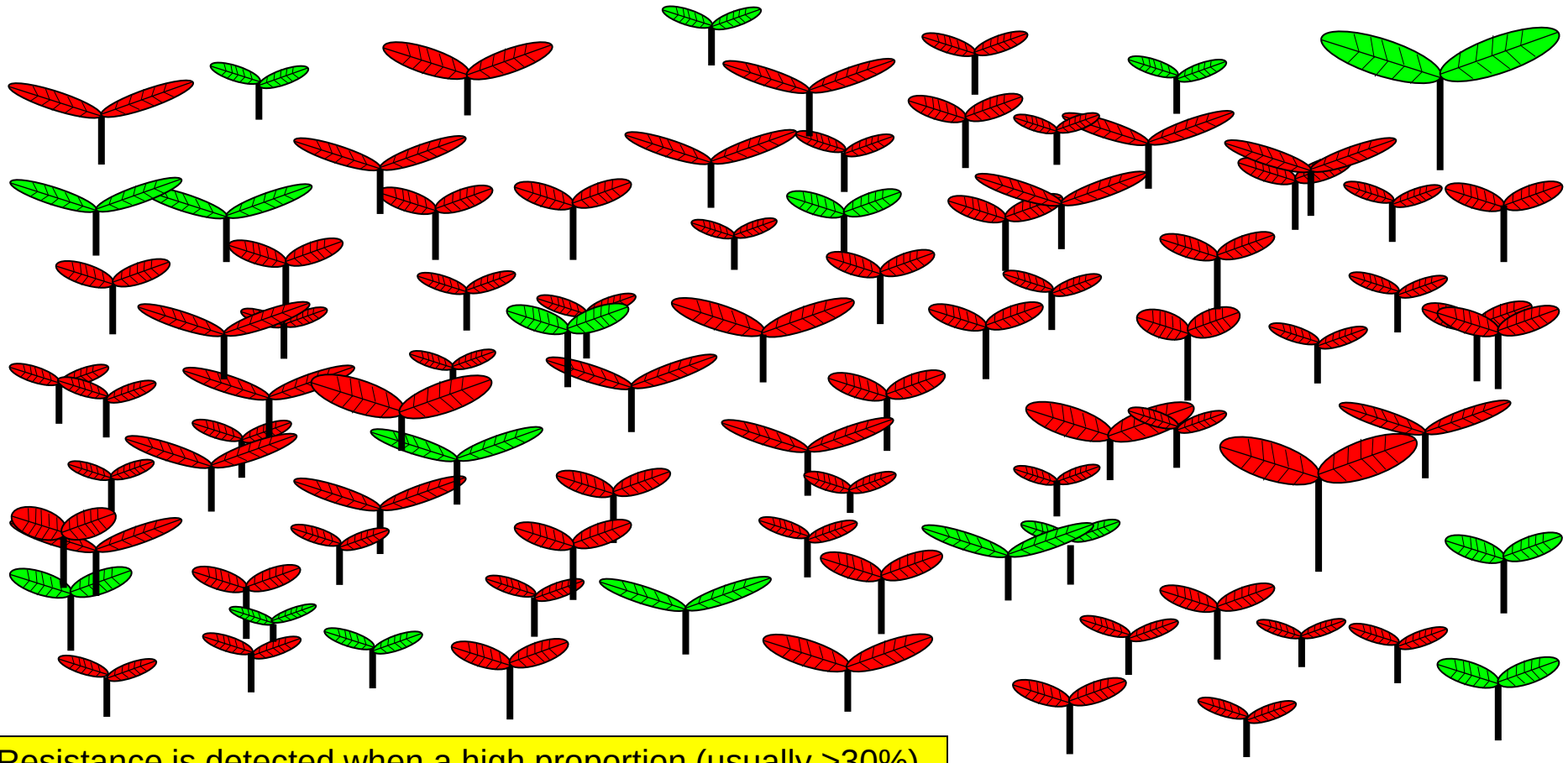
SURVIVORS SET SEED



Also Seed Bank

Weed Resistance

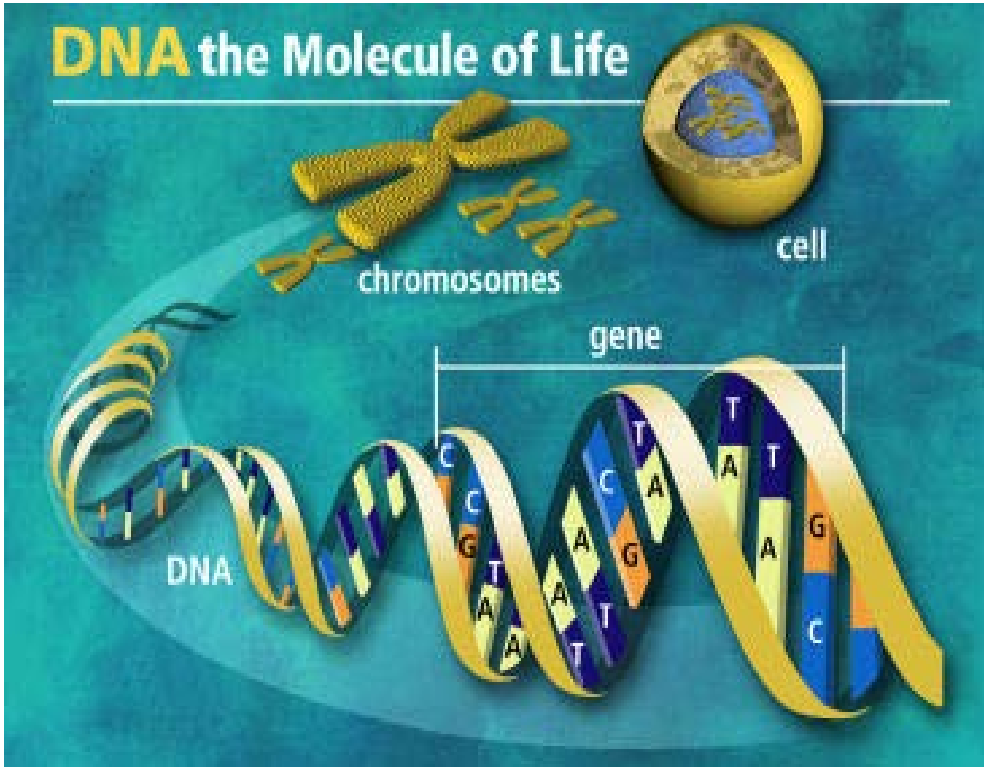
HERBICIDE FAILURE DUE TO RESISTANCE

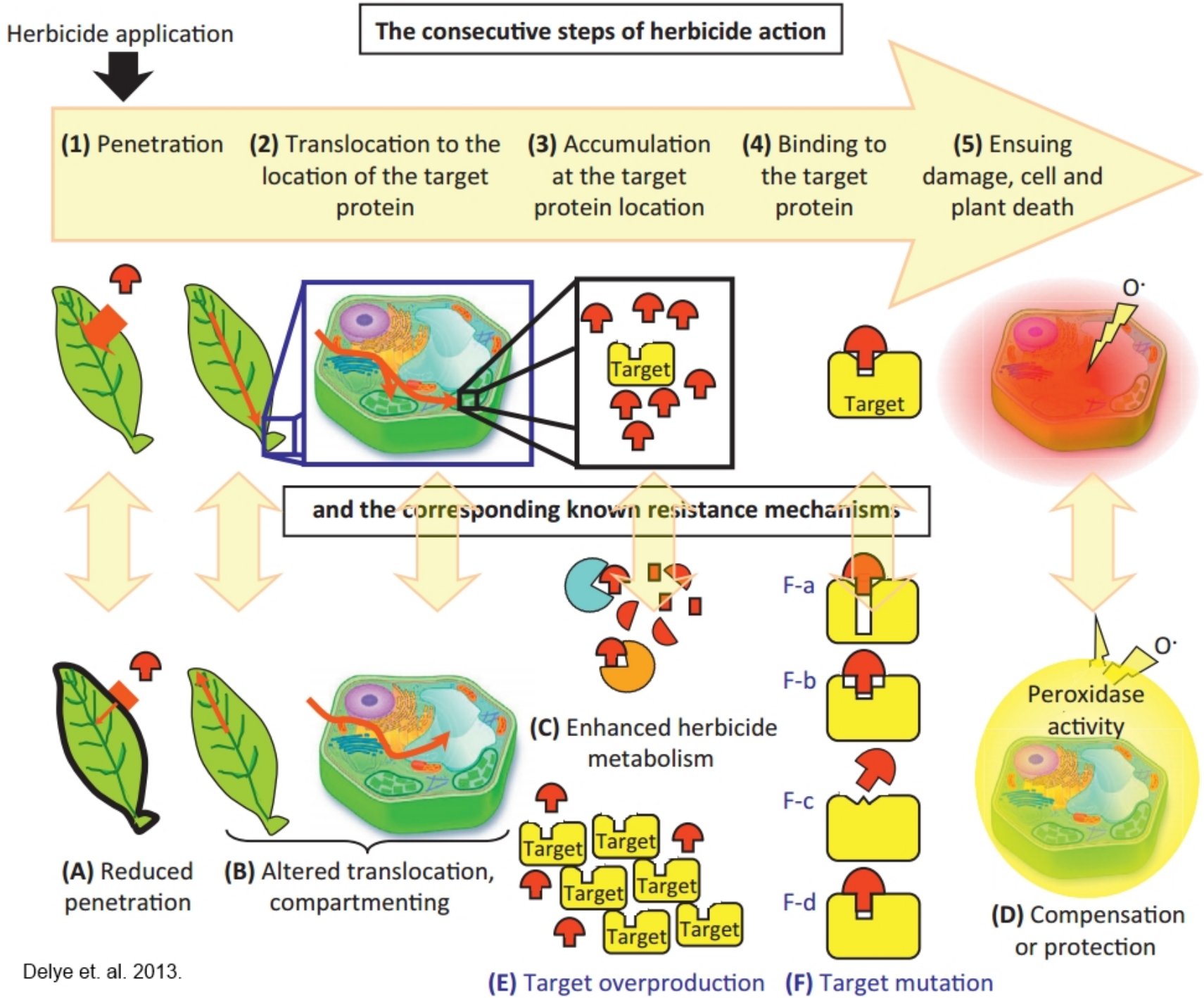


Resistance is detected when a high proportion (usually >30%) of the population are resistant to the herbicide.

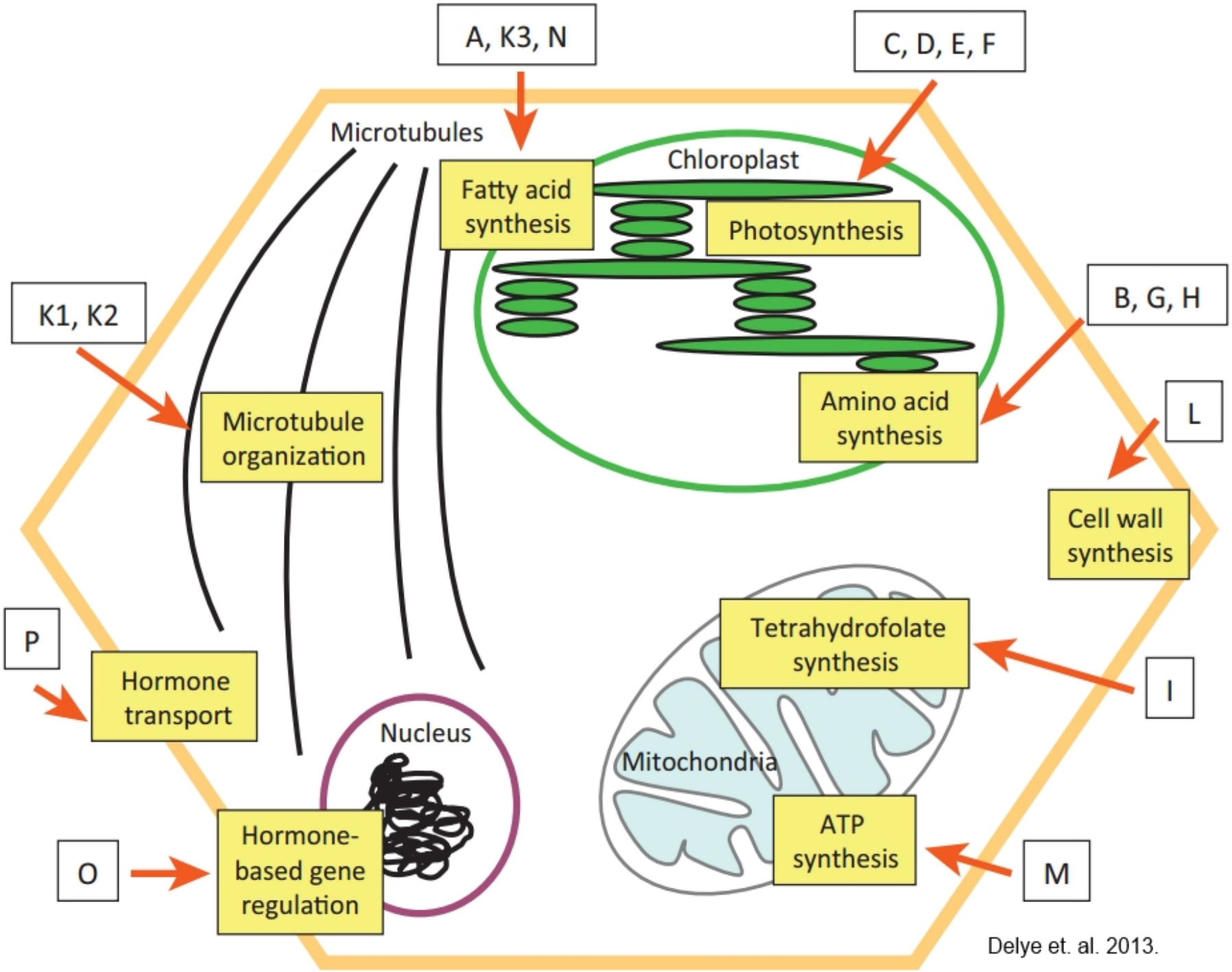
Resistance Caused by
Genetic Mutations that Convey

- Altered site of action
  - change in target enzyme
- Gene Overexpression
  - More enzyme produced endowing resistance
- Enhanced metabolism
  - ability to degrade herbicide
- Decreased translocation
  - Herbicide does not get to its site of action
- Sequestration
  - Herbicide not available to the plant – tied up.





Delye et. al. 2013.



Delye et. al. 2013.

WHY WORRY ABOUT HERBICIDE-RESISTANT WEEDS?

- ECONOMICS!

  If you do not plan to manage herbicide resistance, then you are likely to loose the utility of effective, inexpensive herbicides.

- ECONOMICS!

  If you are not aware of herbicide resistance, then you may waste your money on re-treatment of resistant weeds.

- ECONOMICS!

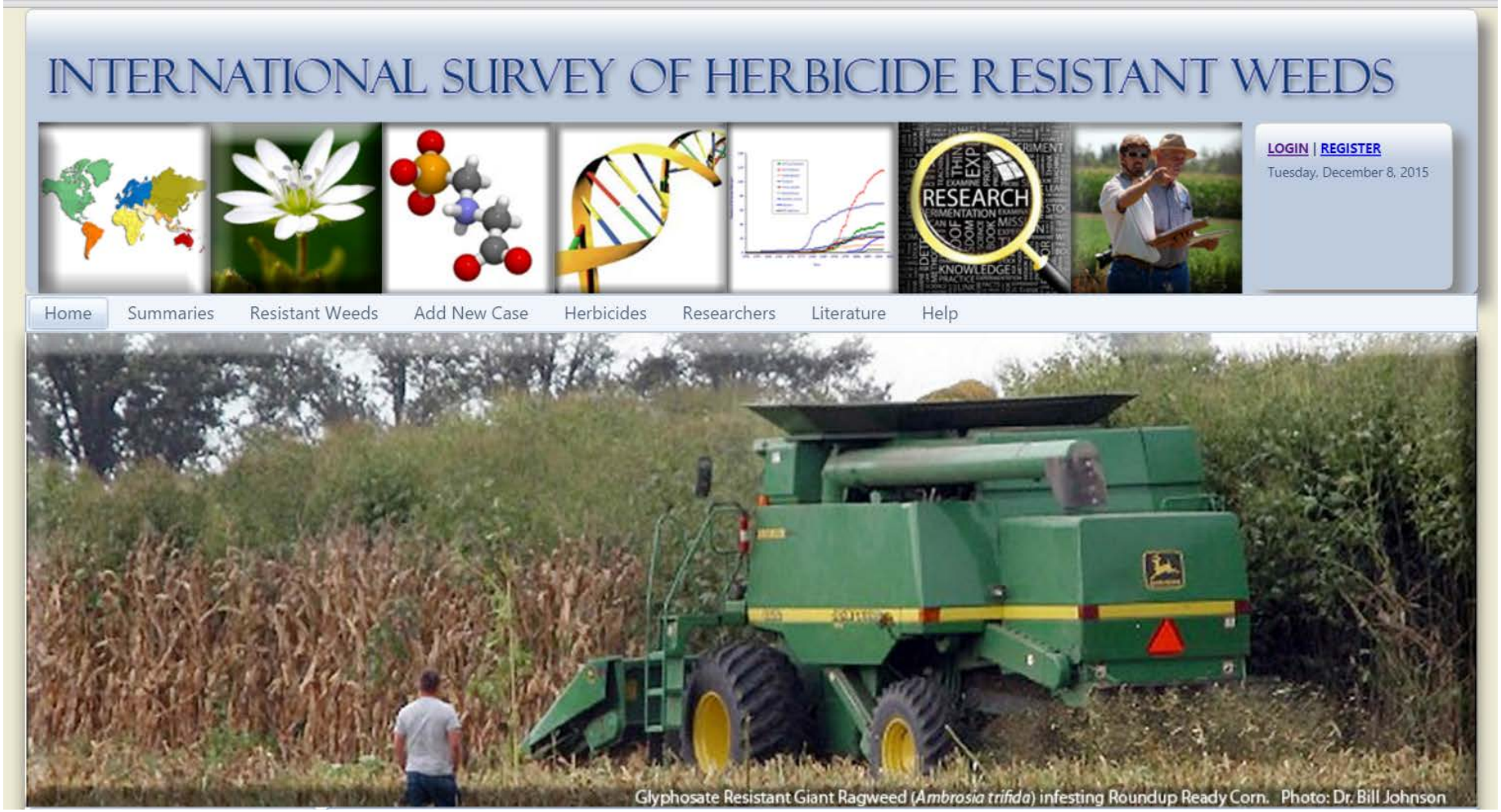
  Gr that fail to take the threat of herbicide-resistant weeds seriously may well be left with no herbicide options and skyrocketing weed control costs.

Current Status of Herbicide Resistant Weeds Globally

WEEDSCIENCE.ORG

International Survey of Herbicide-Resistant Weeds

21 Years Online



International Survey of Herbicide-Resistant Weeds

Current Status of Survey – December 2015

- 461 Unique Resistant Biotypes (Species x SOA)
- 247 Species
- 144 Dicots and 103 Grass Weeds
- over 1,200,000 fields/sites
- Approximately 11 new biotypes discovered per year
- WWW.WEEDSCIENCE.ORG

What is Classified as a Unique Case?

- A Unique Species X Site of Action (group or class of herbicide)
- Wild Oat (1, 2, 3, 8, 25)*
  - = 5 Unique cases
- Whilst multiple resistance is recorded separately, they don't necessarily contribute to unique cases
- Otherwise every combination would contribute to a unique case, and wild oat would potentially account for nearly a hundred combinations

* Letters represent different herbicide sites of action - WSSA Classification of herbicides, this classification system can be found at http://www.weedscience.org.

WSSA number classification system originally developed by Ian Heap in 1990 at University of Manitoba

Table 3: Herbicide groups based on their mechanism of action

1990

Group 1 Excel, Fusilade, Fusilade II, Hoe-Grass 284, Hoe-Grass II*, Poast, Laser*, Triumph Plus*, Achieve**, Select**, Assure**, Puma **	**Group 2** Ally, Glean, Muster, Refine, Triumph Plus*
Group 3 Edge, Rival, Treflan, Trifluorex, Fortress*	**Group 4** 2,4-D, MCPA, Banvel, Blagal*, Buctril M*, Diphenoprop 660*, Estaprop*, Dyvel*, Kil-Mor*, Lontrel, Target*, Tordon 202C*, Tropotox Plus*, Triumph Plus*
Group 5 Bladex L, Blagal*, Lexone, Sencor	**Group 6** Buctril M*, Hoe-Grass II*, Pardner, Laser*
Group 7 Lorox, Afolan	**Other Herbicides** The herbicides Avadex BW, Assert, Avenge 280C, Carbyne, Eptam Mataven, Stampede, TCA and Basagran are in groups of their own.

* Products contain more than one active ingredient and therefore may appear in more than one group.

** Products not registered of January 1991.

New herbicides do not necessarily have a unique mechanism of action and may fall within the groups listed above.

Note: Herbicides that have the same mechanism of action do NOT necessarily control the same weed spectrum or have the same crop safety. For example, Assert and Ally have the same mechanism of action, however, Assert controls wilds oats; Ally does not. Remember to always read and follow label instructions.

Prepared by: Dr. Ian Heap and Dr. Ian Morrison
Department of Plant Sciences
University of Manitoba

How to Delay or Avoid the Development of Resistance

Follow the guidelines below to delay the appearance of resistance.

- **Rotate herbicides**

  Using the same herbicide year after year may cause resistance to develop. **To avoid resistance herbicides must be rotated. It is important not only to use a different herbicide but to use one in a different herbicide group with a different mechanism of action.** If rotation is not practised, resistant plants escape control and continue to add to the problem. Table 3 lists herbicides in groups with the same mechanism of action. Successive use of products in the same group is not a true herbicide rotation. In planning a herbicide rotation farmers should reserve the use of a group of herbicides for crops where there are few or no alternative classes that could be used.

- **Use herbicides only when needed**

  Herbicides should be used as part of an integrated control program and not as the sole method of weed control. Cultural control practices that favour strong crop competition and timely cultivation can be used effectively to reduce weed populations. Attempting to eradicate a particular weed in a field over 8-10 years with a program using the same herbicide can result in the development of resistance. Weeds should be tolerated in a crop if they are below economic damage levels. Refer to Weed Facts — Knowing When it Pays to Spray Wild Oats — Agdex No. 641, March 1988.

- **Keep records of herbicide applications**

  Records are necessary to make sensible decisions on herbicide rotation and to evaluate the probability of resistance developing. Records should consist of the field location/name, year, crop, herbicides and rates applied, weed infestations present at spraying and the control provided by the herbicide(s). The more detailed the records (e.g. environmental conditions at time of spraying, date and time of spraying, spray volume/acre) the better the chance of accurately interpreting the probable cause of weed control failures.

- **Use of tank mixes**

  In a few special cases, use of a tank mix may delay the appearance of resistance. Use of a tank mix for this purpose is only worthwhile in combatting resistance if the components of the tank mix kill the same weed by different mechanisms.

  For instance, either Refine or MCPA will kill lamb's-quarters — each using a different method of killing the plant. Using the tank mix of Refine and MCPA, rather than using one product or the other on its own, means less chance of lamb's-quarters developing herbicide resistance.

  Tank mixing does not delay resistance if the products used in the mix each control different weeds.

How to Tell if You Have Resistance

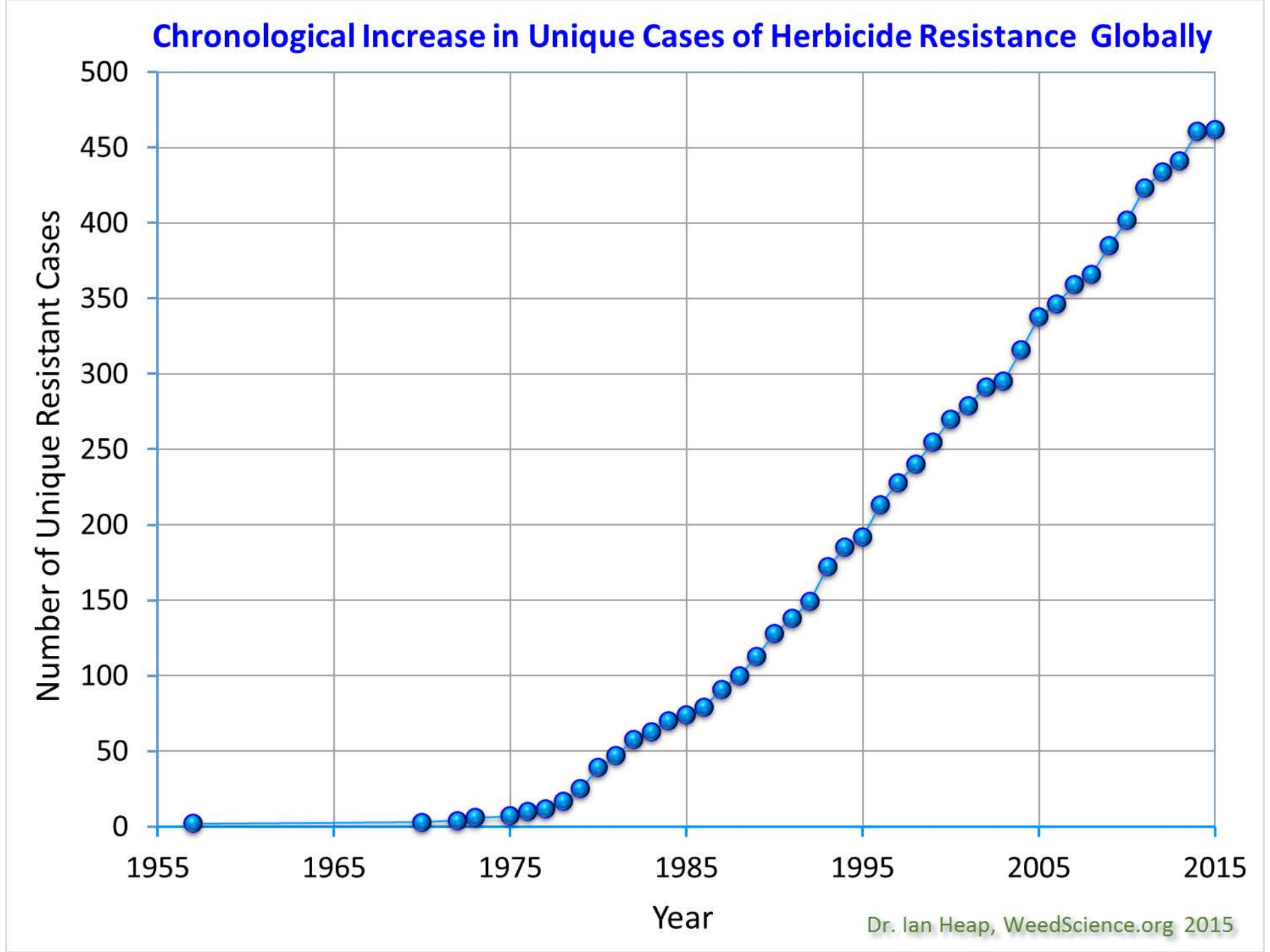
To date, few instances of poor control by herbicides are due to weed resistance. However, this does not mean the possibility should be ignored. Suspicious situations should be checked out as soon as a problem appears. Before assuming herbicide resistance, rule out all other factors that might have affected herbicide performance including misapplication, spray misses, unfavourable weather conditions, improper leaf staging and weed flushes after application. Having ruled out the above possibilities look for the following:

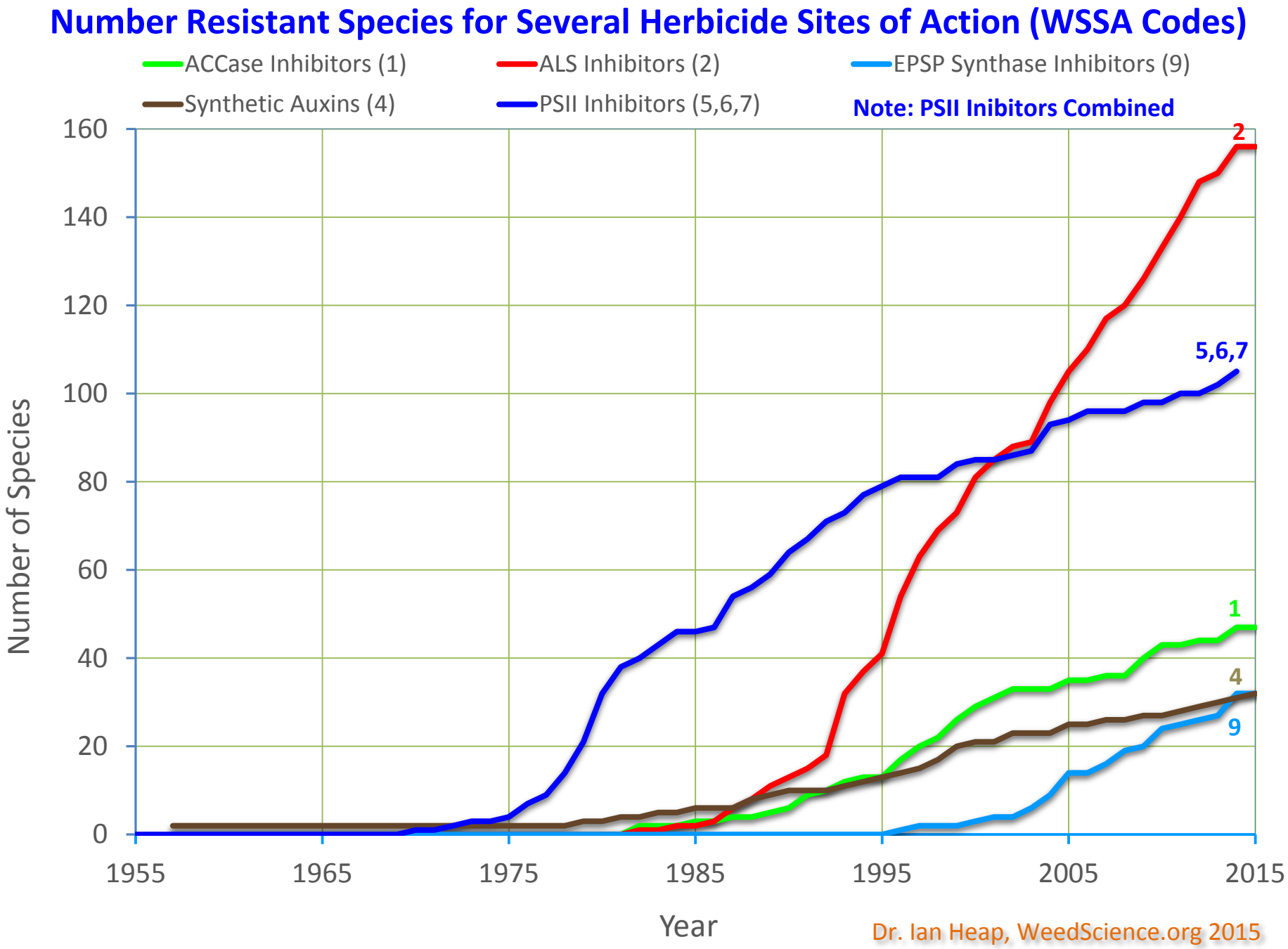
- Other weeds listed on the product label are controlled satisfactorily,
- Herbicide failure is patchy and there is no reasonable explanation,

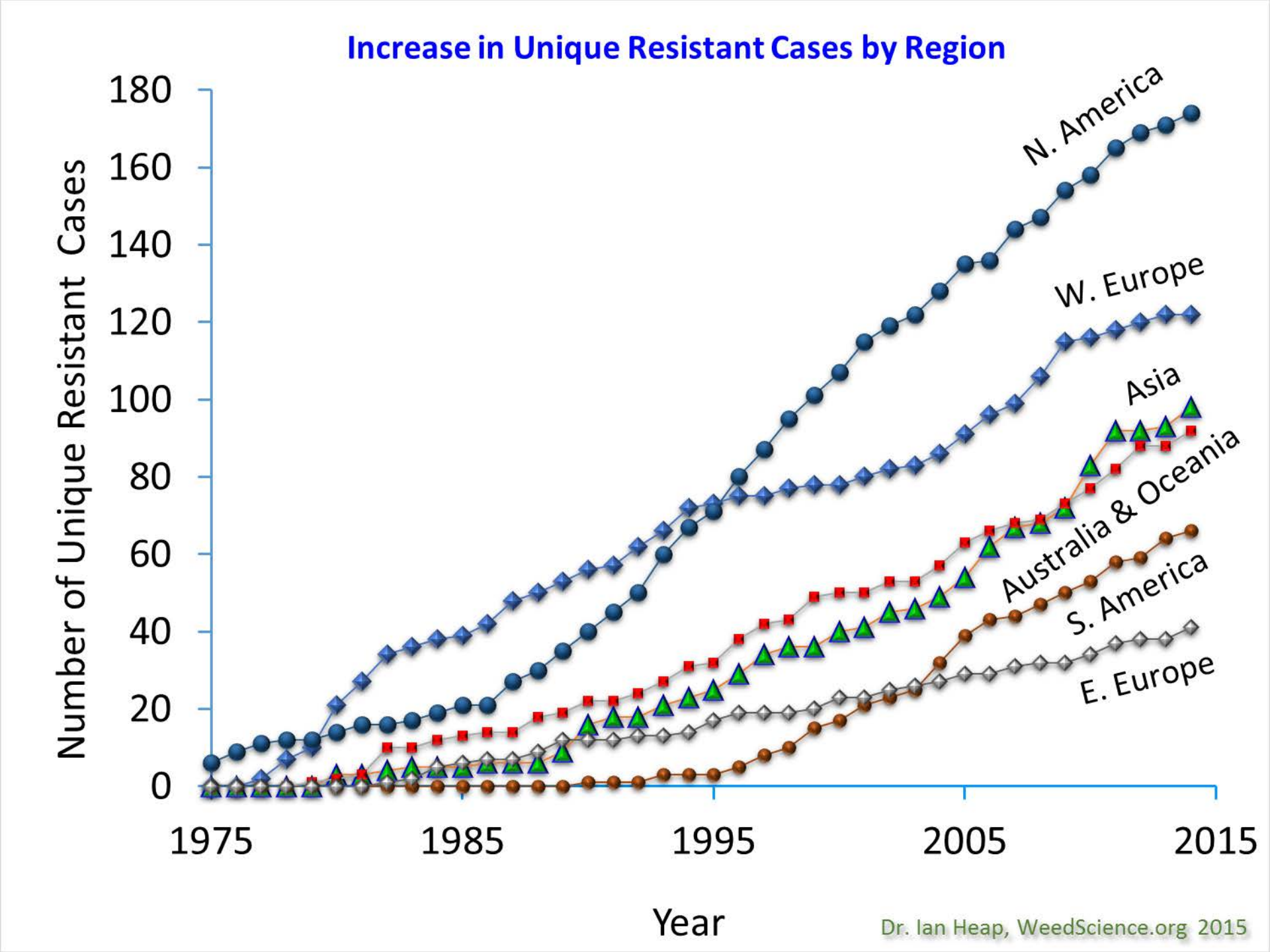
Table 2

In Reality Almost Every Population is a Unique Case

- Each different mutation is a unique case
- Metabolic resistance – levels vary from population to population – each is a unique case
- Gene over expression – number of copies varies from population to population, even differing between individuals – each is a unique case
- Populations can be a mixture of mechanisms, each is a unique case……..etc.


Chronological Increase in Unique Cases of Herbicide Resistance Globally
Number 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 2015


Number 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 Inibitors Combined
Number of Species
Year
0
20
40
60
80
100
120
140
160
1955
1965
1975
1985
1995
2005
2015
2
5,6,7
1
4
9
Dr. Ian Heap, WeedScience.org 2015


Increase in Unique Resistant Cases by Region
Number of Unique Resistant Cases
180
160
140
120
100
80
60
40
20
0
1975
1985
1995
2005
2015
Year
N. America
W. Europe
Asia
Australia & Oceania
S. America
E. Europe
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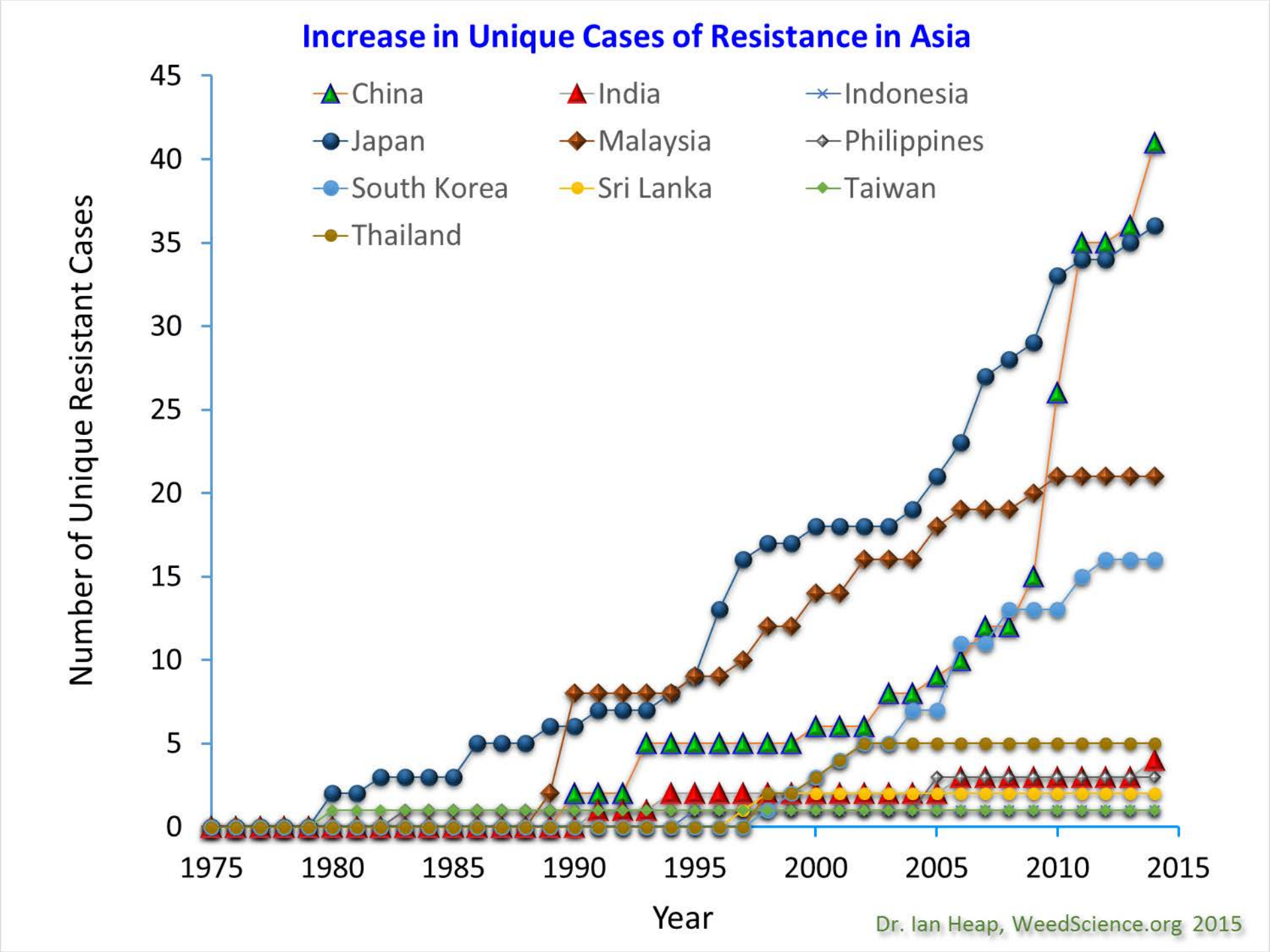
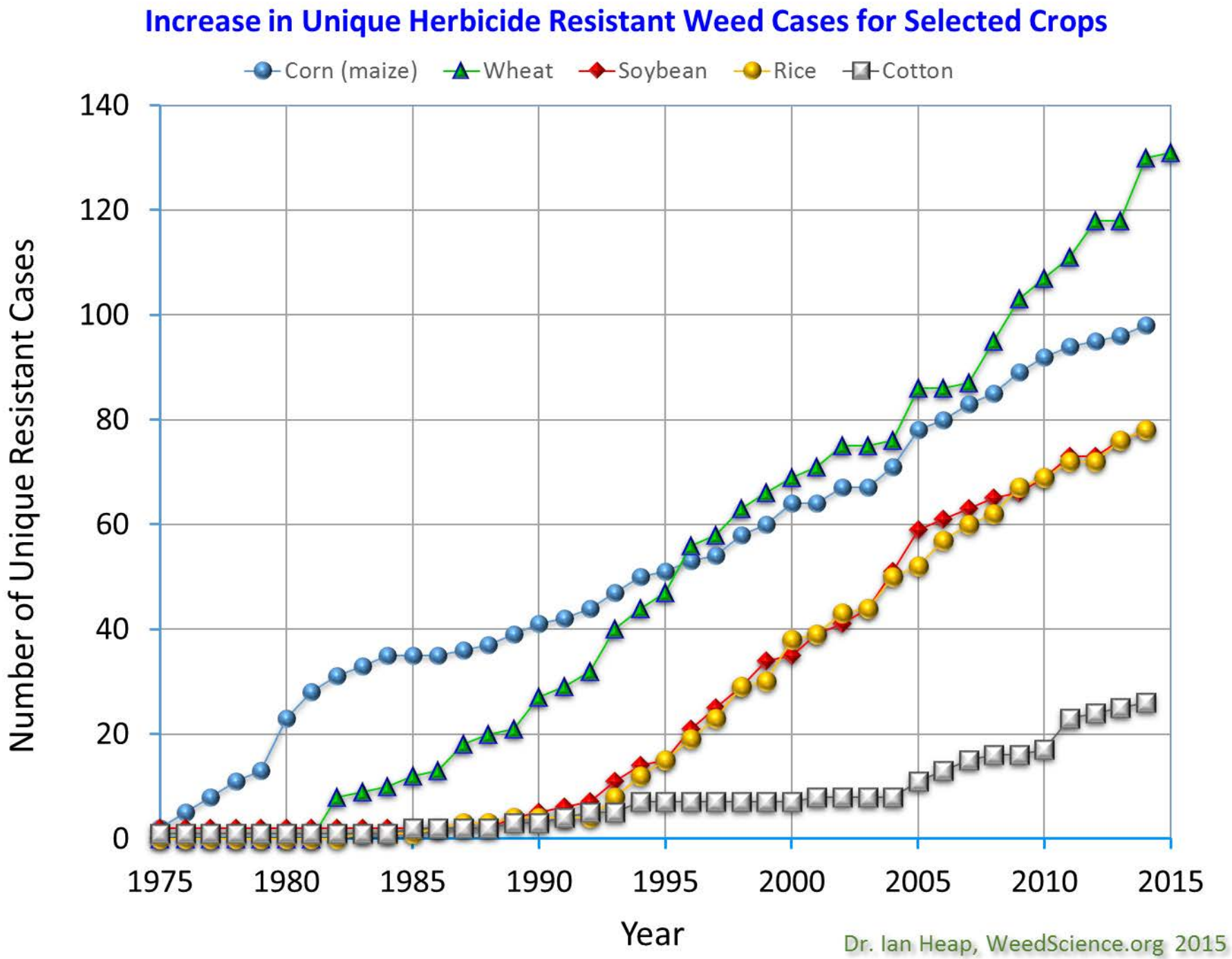

Increase in Unique Cases of Resistance in Asia
China
India
Indonesia
Japan
Malaysia
Philippines
South Korea
Sri Lanka
Taiwan
Thailand
Number of Unique Resistant Cases
0
5
10
15
20
25
30
35
40
45
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
Dr. Ian Heap, WeedScience.org 2015


Increase in Unique Herbicide Resistant Weed Cases for Selected Crops
Corn (maize)
Wheat
Soybean
Rice
Cotton
Number 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 2015

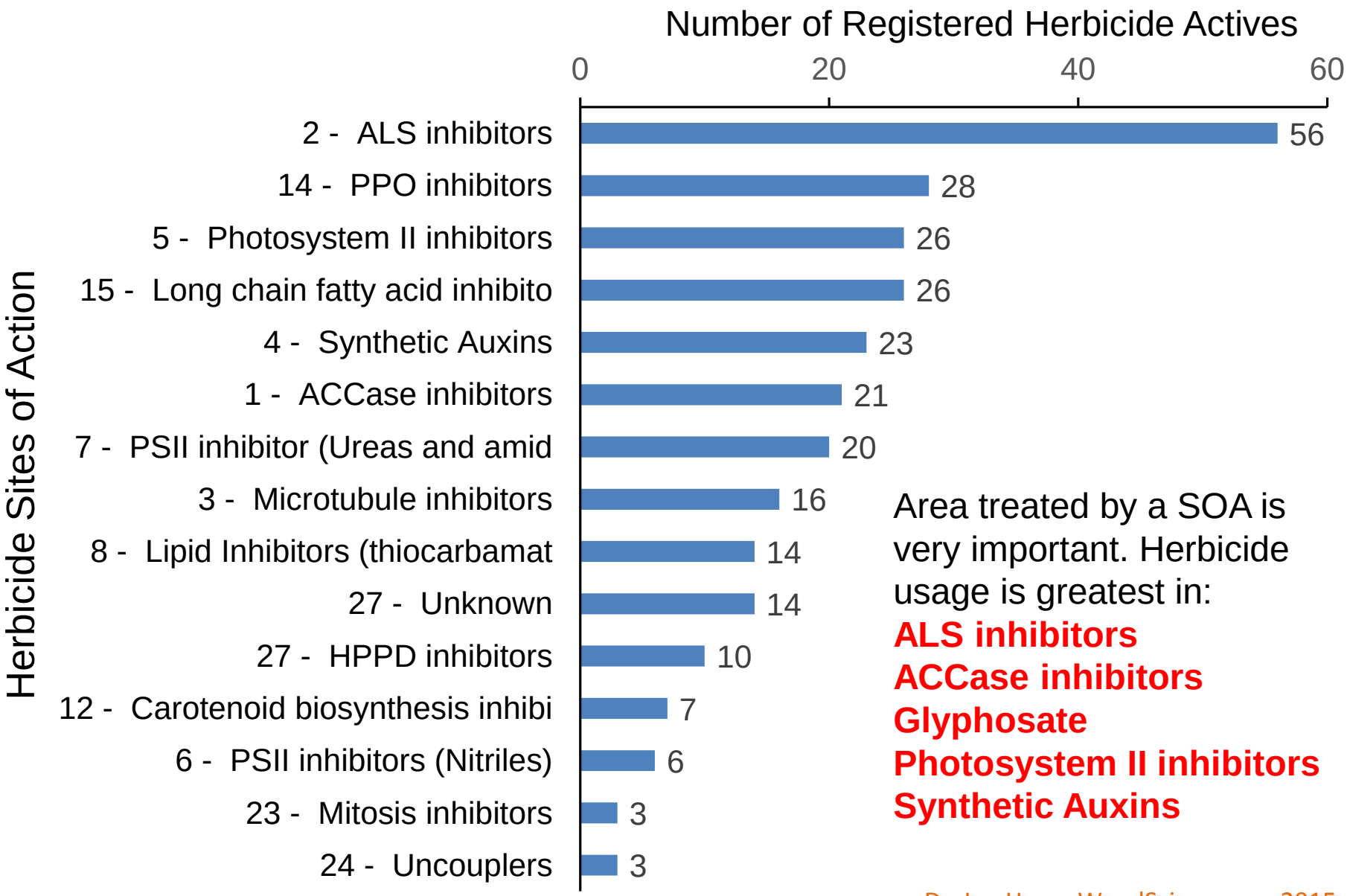
Factors Influencing the Evolution of Resistance

1. Initial resistance gene frequency (for the particular weed/site of action combination)
2. Selection pressure (frequency and efficacy of herbicide use).
3. Number of individuals treated over time
4. Residual activity of the herbicide
5. Genetic basis of resistance (degree of dominance of the resistance trait and the breeding system of the weed)
6. Fitness of the resistance trait
7. Weed Seed Production
8. Seed Dispersal Mechanisms
9. Seed longevity in the soil

Big Drivers of Resistance

- **Number of Individuals Treated**
  - Approximated by area treated x time
- **Species**
  - Some weeds are more prone to resistance than others – *Amaranthus, Lolium, Alopecurus, Echinochloa,* and *Conyza*
- **Herbicide Chemistry**
  - Number of ways weeds can evolve resistance
    - Resistance Gene Frequency
  - Number of species the herbicide targets
  - Area and time of use
- These factors account for >90% impact on the outcome of resistance

Number Registered Herbicides for the Major Herbicide Sites of Action (WSSA codes)



Area treated by a SOA is very important. Herbicide usage is greatest in:

ALS inhibitors
ACCase inhibitors
Glyphosate
Photosystem II inhibitors
Synthetic Auxins

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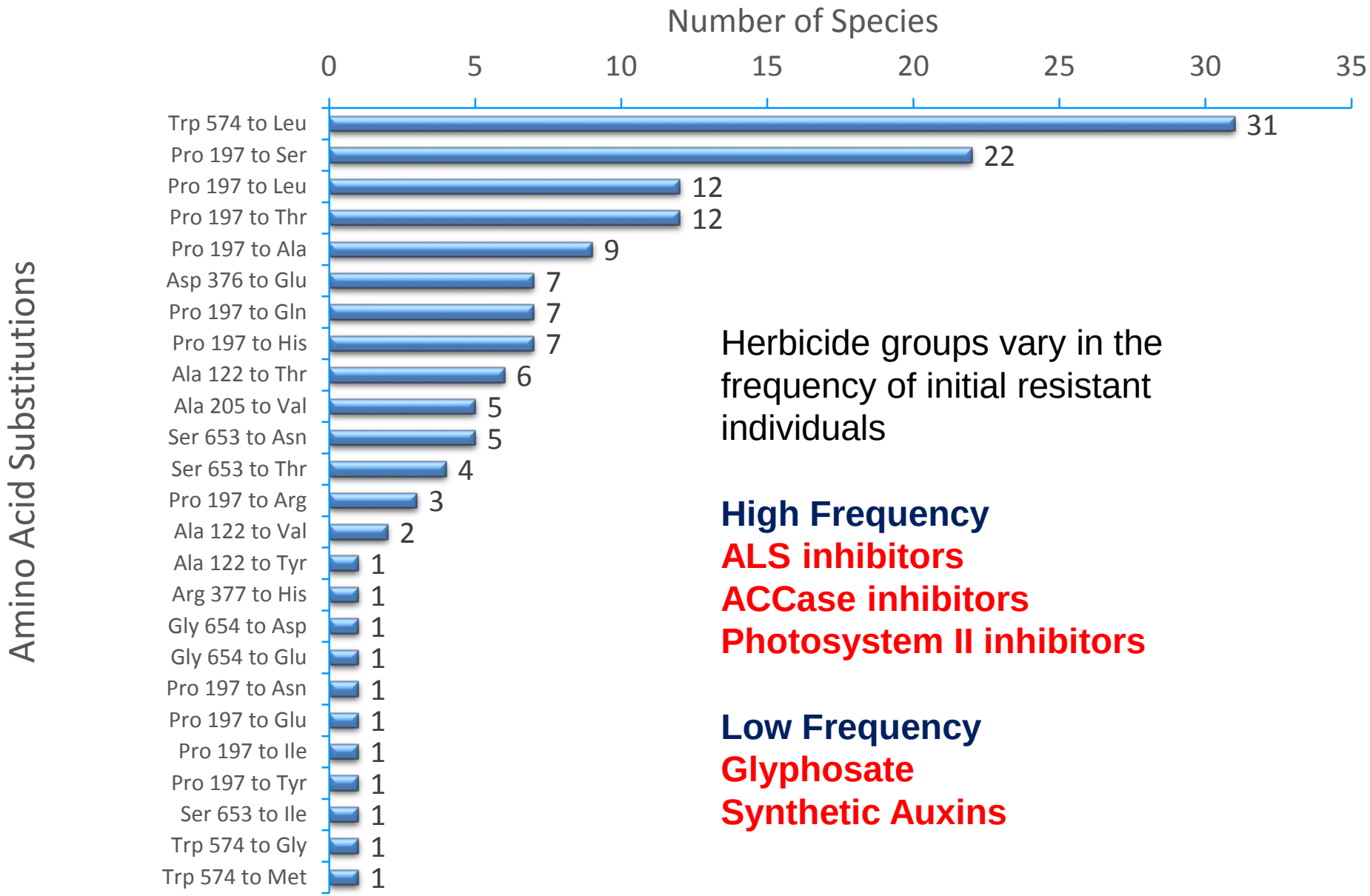
ALS inhibitor-Resistant Species by Amino Acid Substitution



Herbicide groups vary in the frequency of initial resistant individuals

High Frequency
ALS inhibitors
ACCase inhibitors
Photosystem II inhibitors

Low Frequency
Glyphosate
Synthetic Auxins

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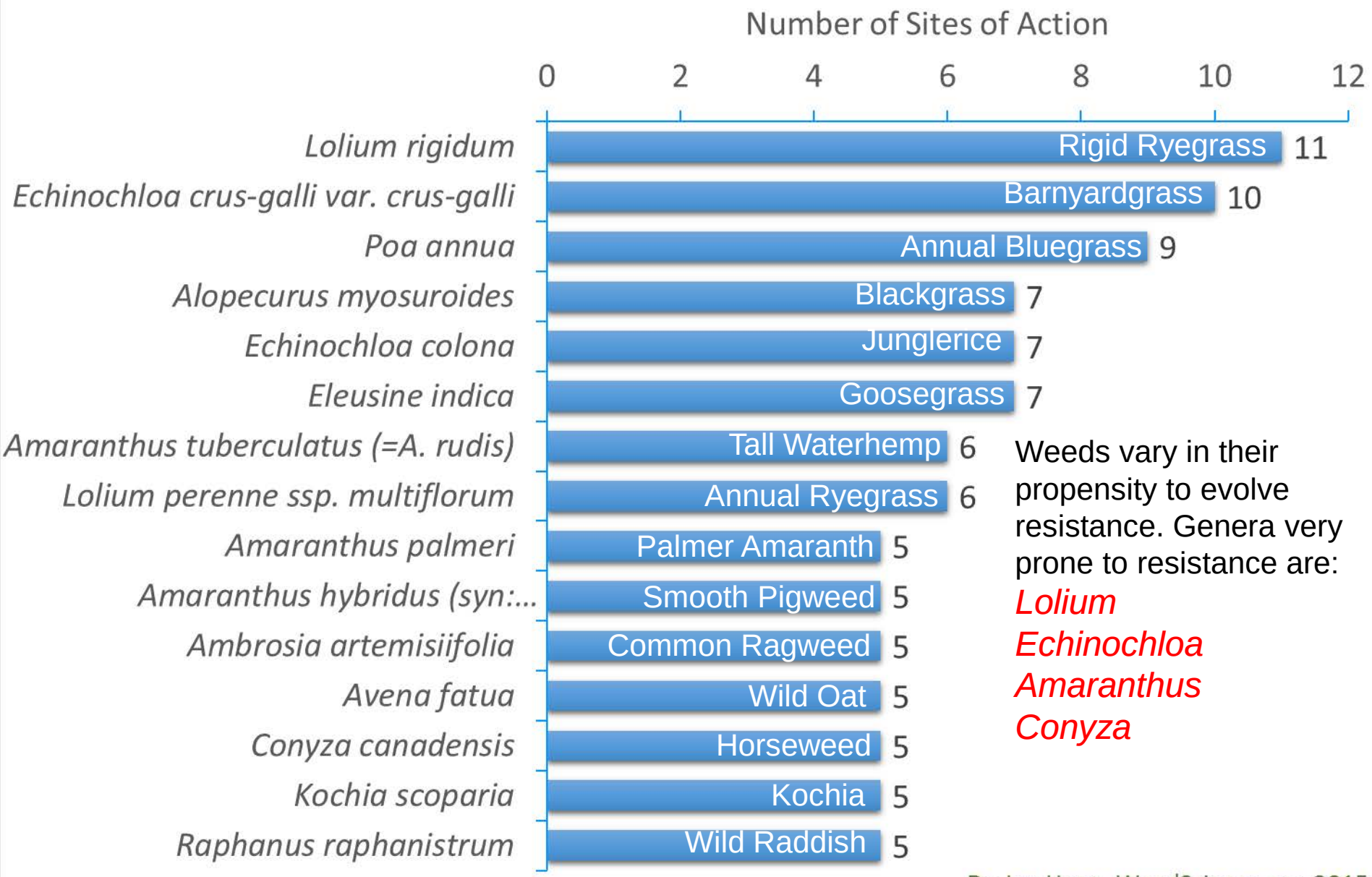
Weed Species Resistance to Multiple Herbicide Sites of Action



Weeds vary in their propensity to evolve resistance. Genera very prone to resistance are:

Lolium
Echinochloa
Amaranthus
Conyza

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Glyphosate Resistance – Researchers love it!

North American, South American, and to some extent Australian herbicide-resistance research is focusing on Glyphosate Resistance

Whilst over reliance of glyphosate in Roundup Ready crops is the main driver of glyphosate resistance it is not the only cause.

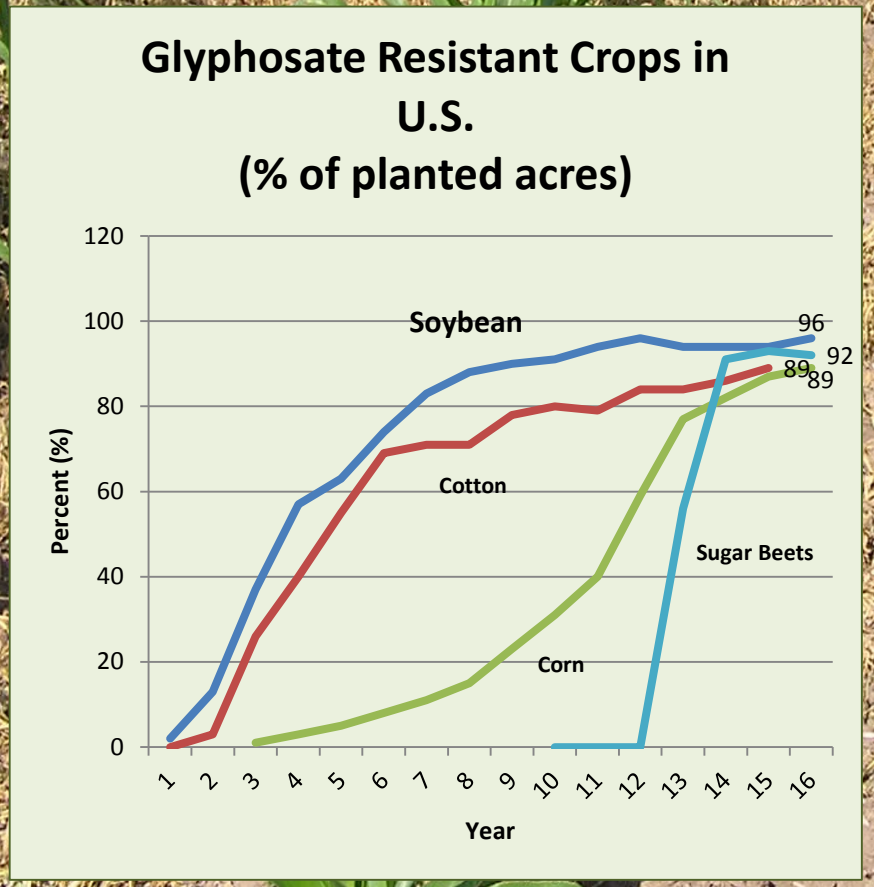
Factors Associated with Evolution of Glyphosate Resistant Weeds

- **RR Crops (glyphosate use)**
  - Glyphosate only
  - Minimum Tillage

- **Orchards / Vineyards**
  - Glyphosate only
  - Multiple (up to 6) annual app.
  - “Low rates”
  - Minimum Tillage

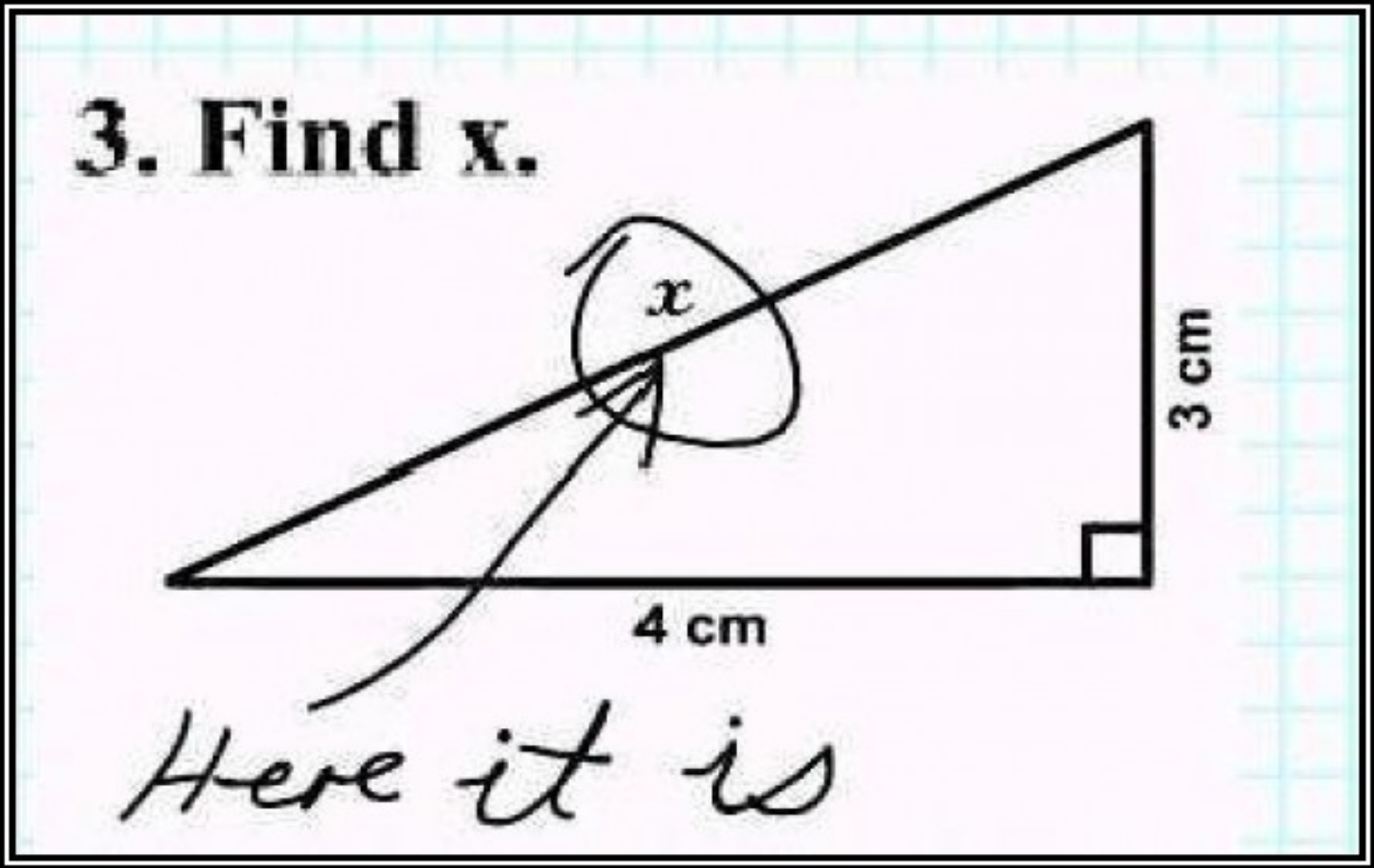
- **Fallow**
  - Glyphosate only
  - “Low rates”
  - Minimal Tillage

Glyphosate Resistant Crops Adopted Quickly in North and South America



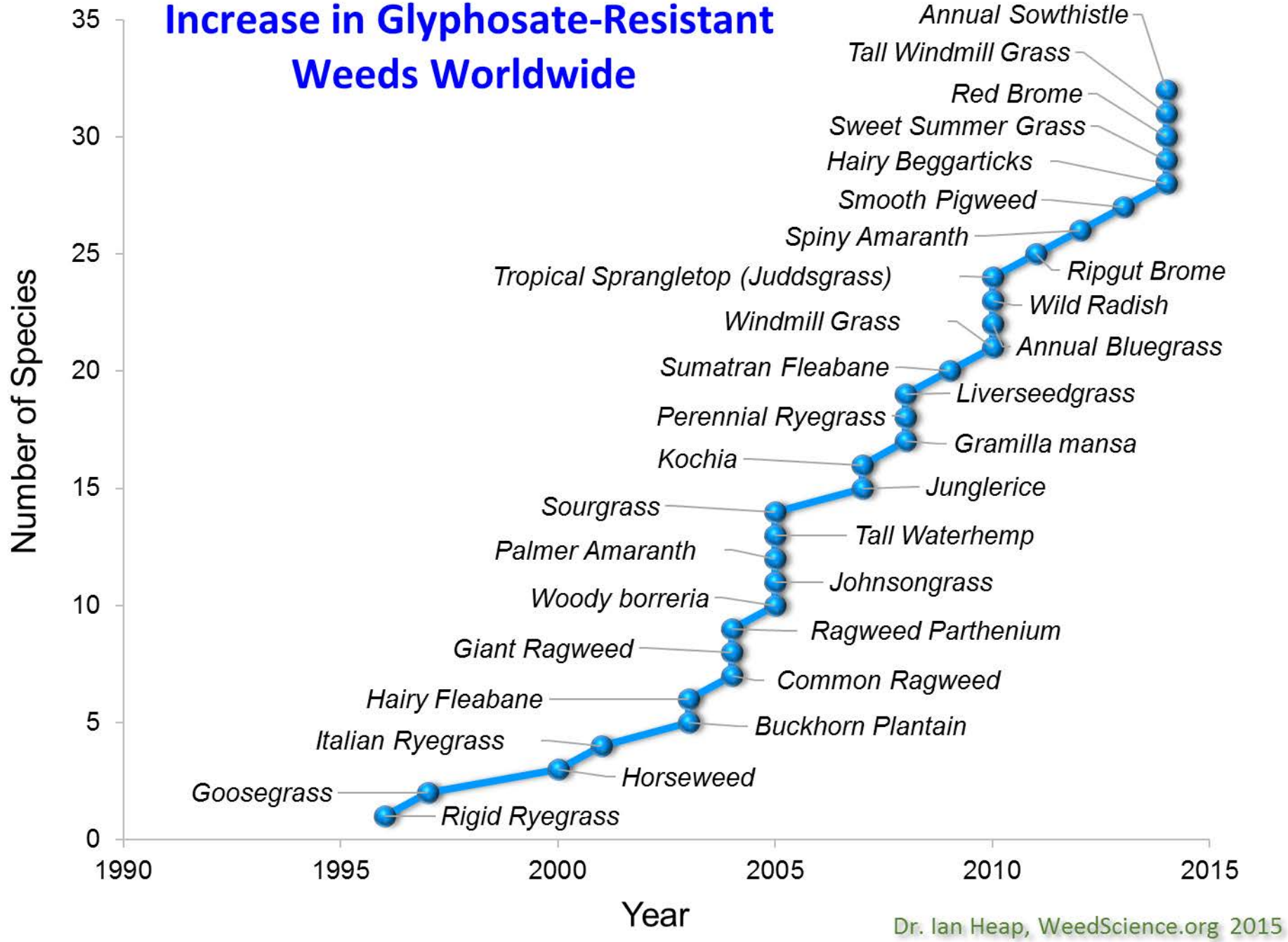
- Lower production costs
- Higher yield
- Simplicity
- Convenient
- Flexibility
- Safety (occupational, family, environmental)
- Save time
- Level of control
- Consistency
- Crop safety

Glyphosate Resistant Crops saved the corn/soybean farmers from ALS inhibitor, ACCase inhibitor, and Triazine resistant weeds.



SIMPLICITY

The simplest solutions are often the cleverest
They are also usually wrong


Increase in Glyphosate-Resistant Weeds Worldwide
Number of Species
Year
0
5
10
15
20
25
30
35
1990
1995
2000
2005
2010
2015
Annual Sowthistle
Tall Windmill Grass
Red Brome
Sweet Summer Grass
Hairy Beggarticks
Smooth Pigweed
Spiny Amaranth
Ripgut Brome
Tropical Sprangletop (Juddsgrass)
Wild Radish
Windmill Grass
Annual Bluegrass
Sumatran Fleabane
Liverseedgrass
Perennial Ryegrass
Gramilla mansa
Kochia
Junglerice
Sourgrass
Tall Waterhemp
Palmer Amaranth
Johnsongrass
Woody borreria
Ragweed Parthenium
Giant Ragweed
Common Ragweed
Hairy Fleabane
Buckhorn Plantain
Italian Ryegrass
Horseweed
Goosegrass
Rigid Ryegrass
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Seven Species account for 99% of the Reported Area Infested with Glyphosate-Resistant Weeds

Species	Acres
Horseweed	10,000,000
Palmer Amaranth	6,000,000
Sourgrass	2,000,000
Tall Waterhemp	2,000,000
Giant Ragweed	200,000
Johnsongrass	150,000
Rigid Ryegrass	100,000

Glyphosate-Resistant “Giant” Ragweed in Roundup Ready Maize
Ambrosia trifida

Palmer Amaranth (*Amaranthus palmeri*) in Cotton

Farmers now using up to 7 herbicide applications plus hand hoeing at a cost up to $360/ha

Glyphosate 4X rate at 3 cm

Glyphosate 4X rate at 10 cm

Glyphosate 4X rate PDIR

Culpepper, UG

Glyphosate-Resistant Palmer Amaranth in Roundup Ready Cotton

Spread of glyphosate-resistant Kochia
Photo: Westra, CSU, 2011

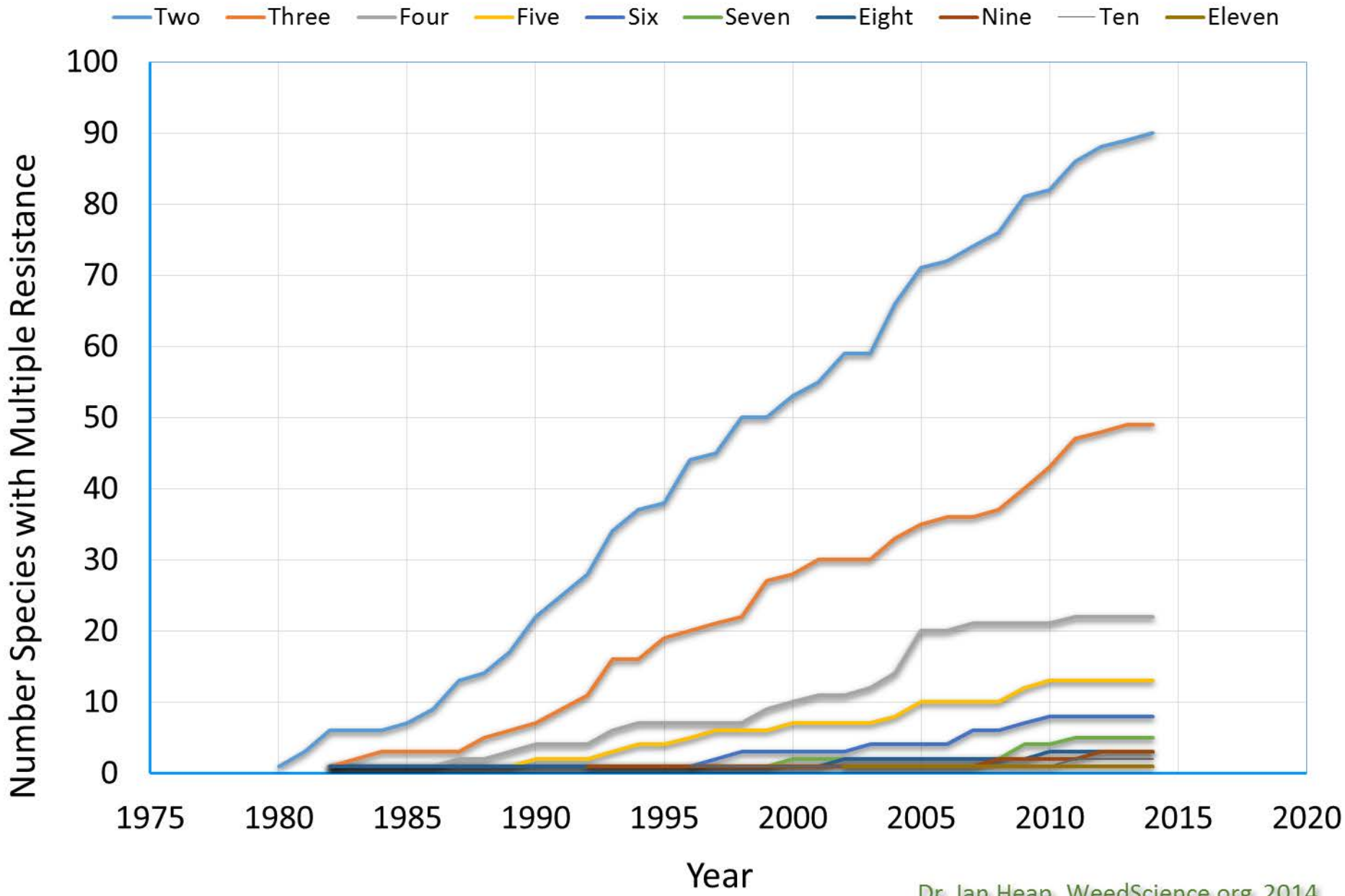
Herbicide Resistant Weeds in Minnesota

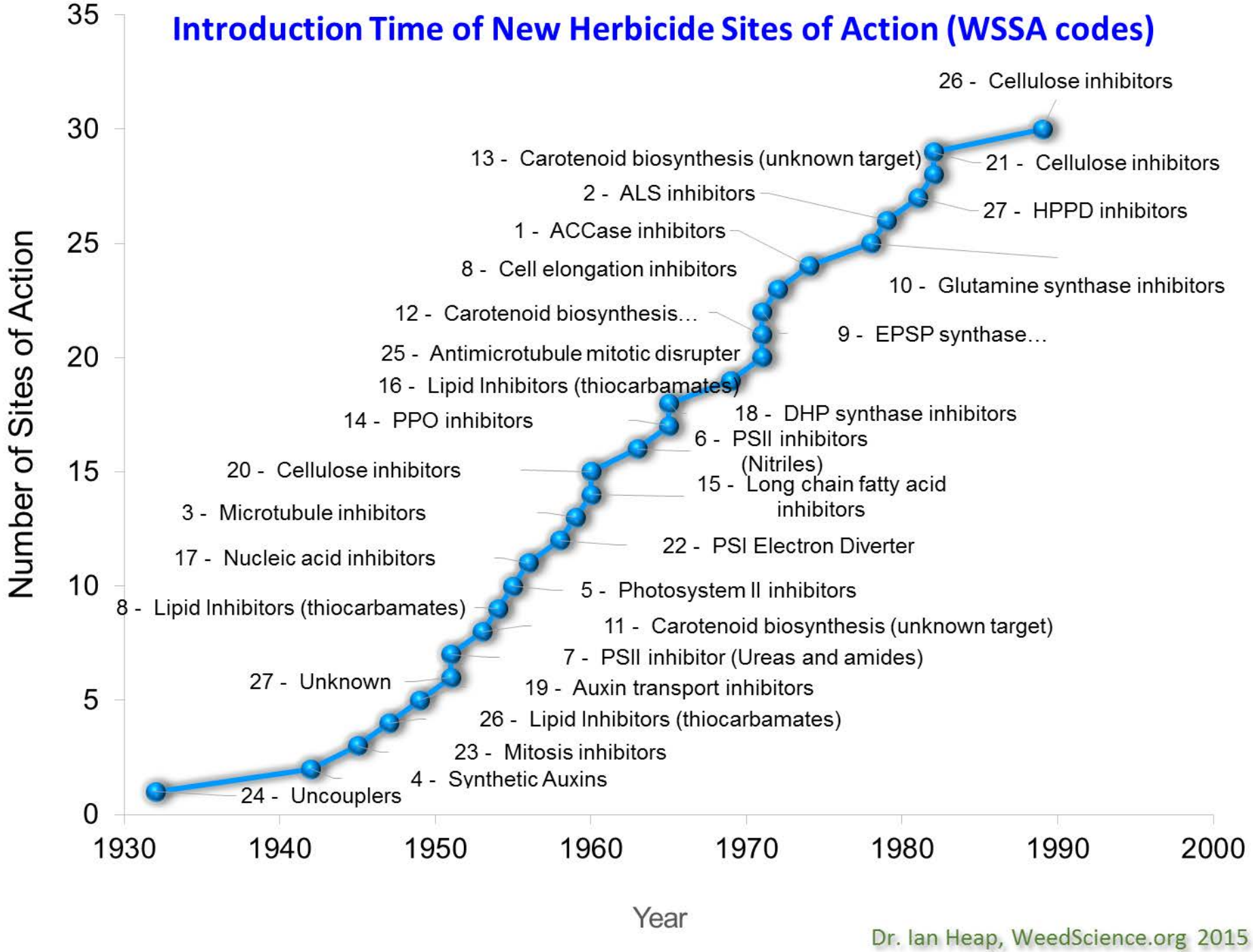
Common cocklebur	2 (ALS inhibitors)
Common Lambsquarters	5 (Photosystem II inhibitors)
Common Ragweed	2 (ALS inhibitors), 9 (EPSP synthase inhibitors)
Giant Foxtail	2 (ALS inhibitors)
Giant Green Foxtail	1 (ACCase inhibitors), 2 (ALS inhibitors)
Giant Ragweed	2 (ALS inhibitors), 9 (EPSP synthase inhibitors)
Kochia	2 (ALS inhibitors), 9?
Redroot Pigweed	5 (Photosystem II inhibitors)
Tall Waterhemp	2 (ALS inhibitors), 9 (EPSP synthase inhibitors), 14 (PPO inhibitors), 9?
Velvetleaf	5 (Photosystem II inhibitors)
Wild Oat	1 (ACCase inhibitors), 2 (ALS inhibitors)
Yellow Foxtail	2 (ALS inhibitors)

Biggest Resistance Challenges

1. Multiple Resistance
2. Non-Target Site Resistance
3. Decline in herbicide discovery
4. Over reliance on a few herbicide resistant crops
5. Farmers not adopting management strategies

Species with Resistance to More than One Site of Action




Introduction Time of New Herbicide Sites of Action (WSSA codes)
Number of Sites of Action
Year
0
5
10
15
20
25
30
35
1930
1940
1950
1960
1970
1980
1990
2000
26 - Cellulose inhibitors
13 - Carotenoid biosynthesis (unknown target)
21 - Cellulose inhibitors
2 - ALS inhibitors
27 - HPPD inhibitors
1 - ACCase inhibitors
8 - Cell elongation inhibitors
10 - Glutamine synthase inhibitors
12 - Carotenoid biosynthesis…
9 - EPSP synthase…
25 - Antimicrotubule mitotic disrupter
16 - Lipid Inhibitors (thiocarbamates)
18 - DHP synthase inhibitors
14 - PPO inhibitors
6 - PSII inhibitors (Nitriles)
20 - Cellulose inhibitors
15 - Long chain fatty acid inhibitors
3 - Microtubule inhibitors
22 - PSI Electron Diverter
17 - Nucleic acid inhibitors
5 - Photosystem II inhibitors
8 - Lipid Inhibitors (thiocarbamates)
11 - Carotenoid biosynthesis (unknown target)
7 - PSII inhibitor (Ureas and amides)
27 - Unknown
19 - Auxin transport inhibitors
26 - Lipid Inhibitors (thiocarbamates)
23 - Mitosis inhibitors
4 - Synthetic Auxins
24 - Uncouplers
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HOW DID WE (the west) GET HERE?

Up until the 1940's

- Diversified cropping systems
- Small Farms
- Livestock integrated with cropping
- Tillage
- Hand Weeding
- Significant Losses due to weed control

1940's to mid 1990's

- Modern Herbicides
- Larger Farms
- Livestock decoupled from cropping
- Reduced Tillage
- Less Diversity
- Better weed control
- Higher Yields
- Greater Profitability
- Herbicide Resistance
- Diversity in Herbicide SOA's

1990's to 2015

- Roundup Ready Crops
- Herbicide Discovery Drops
- Multiple herbicide resistance increases
- Less Tillage and Less Diversity in Weed Control
- Farmers with no clue about conventional weeds and weed control techniques
- Resistance reduces profitability

WHERE ARE WE GOING?

2015 to 2025?

- Re-education of Farmers
- Diversified cropping systems
- Herbicide Resistant Crops (multiple stacked traits)
- A Few New Herbicide Sites of Action
- Adoption of Resistance Management Strategies
- Increased Tillage
- Cover Crops
- Stale Seedbeds
- Integration of Weed Control Systems
- Zero tolerance for weed escapes

2025 into the future?

- Greater Diversity in Cropping Systems
- True Integrated Weed Management Systems
- More New Herbicide Sites of Action (China?)
- Herbicide Resistant Crops
- Cheap Robotic Weeder's?
- Genetically Engineered Biocontrols
- Blindsided by a New Weed Control Technology

How to Avoid/Delay Resistance

- Rotation of herbicide sites of action.
- **Tank mixing herbicides with different modes of action**
  Both herbicides must be active on the same target species.
- Use pre-emergence herbicides in addition to post-emergence herbicides
- Use full rates
- Use of non-herbicidal weed control where economical
- **PRACTICE INTEGRATED WEED MANAGEMENT**

Any consistent practice to control weeds year after year will result in directed evolution towards survival.

The solution is to vary weed control practices and destabilize evolution.

Integrated Weed Management