Herbicide Resistance Summit II

September 10, 2014





Welcome to the 2nd National Herbicide Summit

- As you enter the room, please power up your voting device by pressing the power button on the bottom right of the keypad.
- To vote, you will simply press the number that corresponds with the answer option you wish to select.
- When asked to select more than one answer option, you will press SEND after each entry.

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Question

Now that the NFL is playing on Sundays, Mondays, and Thursdays, I believe we should have:

1. More football
2. Less football
3. What's football?

Please Identify Yourself

(Enter all that apply – Press SEND after each)

1. Grower
2. Academia
3. Agricultural Chemical Industry
4. Government
5. Landowner
6. Agricultural Input Supply Network
7. Public Interest Group
8. Press
9. Professional Society
10. Agricultural Equipment Industry
11. Consultant
12. Lending Institution
13. Commodity Organization
14. Educator

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Herbicide Resistance Summit II

David R. Shaw
Mississippi State University

September 10, 2014





Insanity….

Doing the same thing over and over again and expecting a different result.

Albert Einstein

Herbicide Resistance Evolution

- A biology problem…
- A technology problem…
- A HUMAN BEHAVIORAL problem…

What Have We Been Doing?

- Two Glyphosate Stewardship Forums
- National Academy study
- 1st Herbicide Resistance Summit
- WSSA, other symposia
- Planning workshop
- ….

What Have We Said?

- APHIS-sponsored herbicide resistance papers on state of knowledge, best management practices, and recommendations
- Training modules
- Papers, websites, flyers, workshops, field days….

What Has Happened?

- Thousands of downloads of training modules
- Pesticide applicator certification and certified crop advisor CEUs
- Stewardship requirements on new Enlist Duo label
- MOA labeling on herbicides
- Increased use of soil-applied herbicides

Herbicide Resistance – Best Management Practices

- Understand the biology of the weeds present.
- Use a diversified approach toward weed management focused on preventing weed seed production and reducing the number of weed seed in the soil seedbank.
- Plant into weed-free fields and then keep fields as weed free as possible.

Herbicide Resistance – Best Management Practices

- Plant weed-free crop seed.
- Scout fields routinely.
- Use multiple herbicide mechanisms of action (MOAs) that are effective against the most troublesome weeds or those most prone to herbicide resistance.

Herbicide Resistance – Best Management Practices

- Emphasize cultural practices that suppress weeds by using crop competitiveness.
- Use mechanical and biological management practices where appropriate.
- Prevent field-to-field and within-field movement of weed seed or vegetative propagules.

Herbicide Resistance – Best Management Practices

- Manage weed seed at harvest and after harvest to prevent a buildup of the weed seedbank.

- Prevent an influx of weeds into the field by managing field borders.

WSSA Position Paper Recommendations

- Reduce the weed seedbank through diversified programs that minimize weed seed production.
- Implement an herbicide MOA labeling system for all herbicide products, and conduct an awareness campaign.
- Communicate that discovery of new, effective herbicide MOAs is rare and that the existing herbicide resource is exhaustible.

WSSA Position Paper Recommendations

- Demonstrate the benefits and costs of proactive, diversified weed-management systems for the mitigation of HR weeds.

- Foster the development of incentives by government agencies and industry that conserve critical herbicide MOAs as a means to encourage adoption of best practices.

WSSA Position Paper Recommendations

- Promote the application of full-labeled rates at the appropriate weed and crop growth stage. When tank mixtures are employed to control the range of weeds present in a field, each product should be used at the specified label rate appropriate for the weeds present.

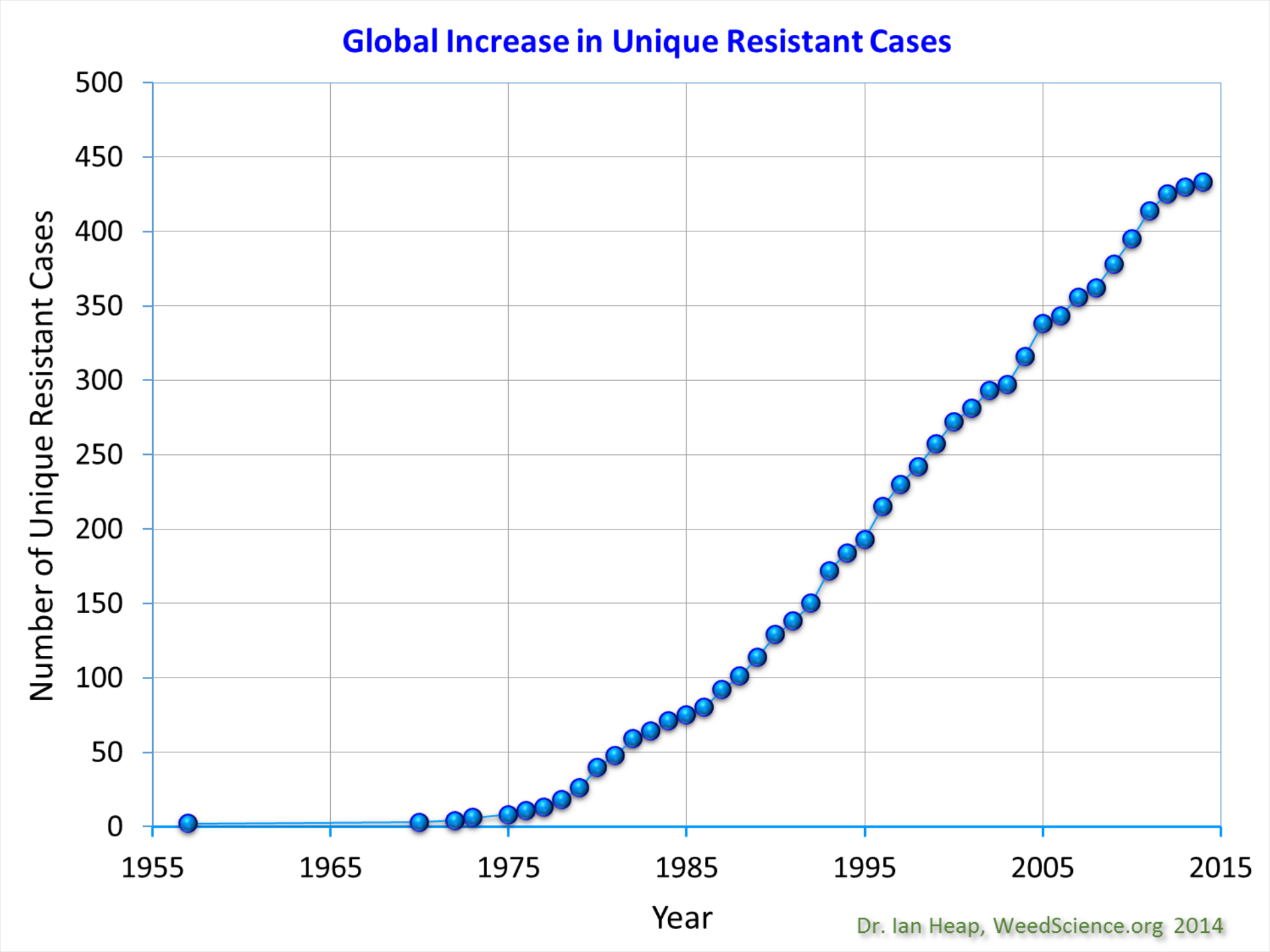
- Identify and promote individual BMPs that fit specific farming segments with the greatest potential impact.

WSSA Position Paper Recommendations

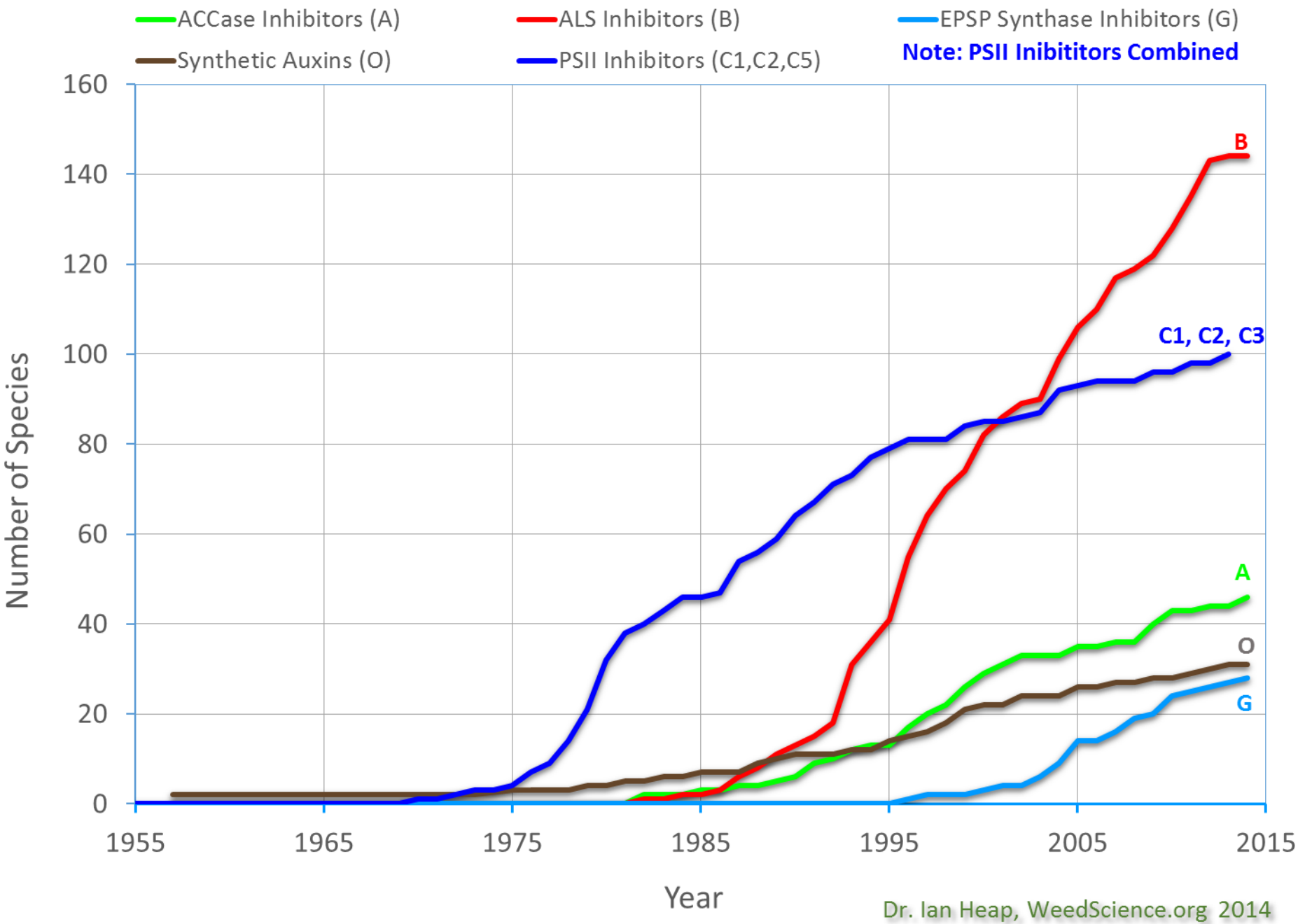
- Engage the public and private sectors in the promotion of BMPs, including those concerning appropriate herbicide use.

- Direct federal, state, and industry funding to research addressing the substantial knowledge gaps in BMPs for herbicide resistance and to support cooperative extension services as vital agents in education for resistance management.

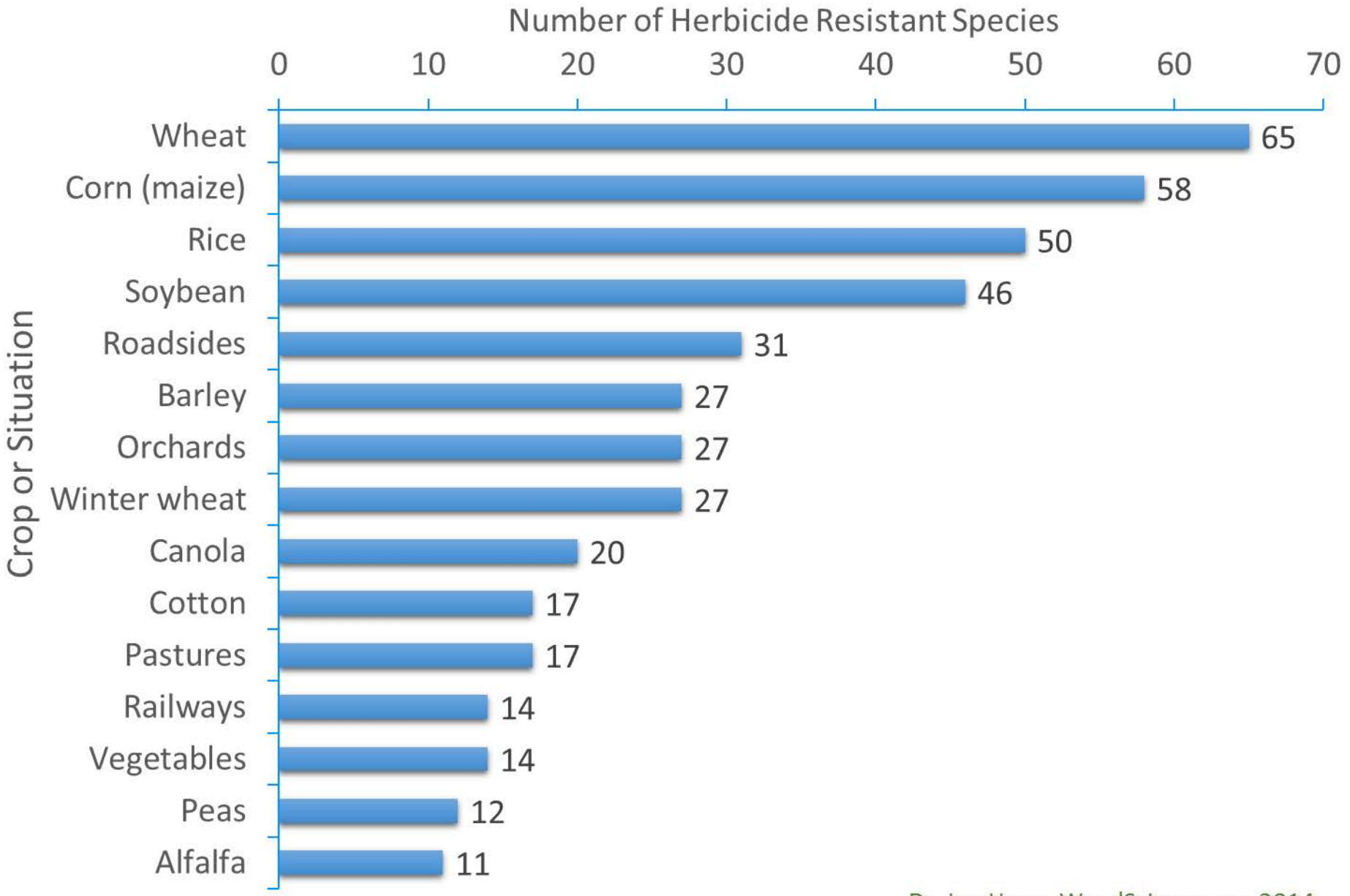
And Yet….


Global Increase in Unique Resistant Cases
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 2014

Resistant Species for Several Herbicide Sites of Action (HRAC Codes)

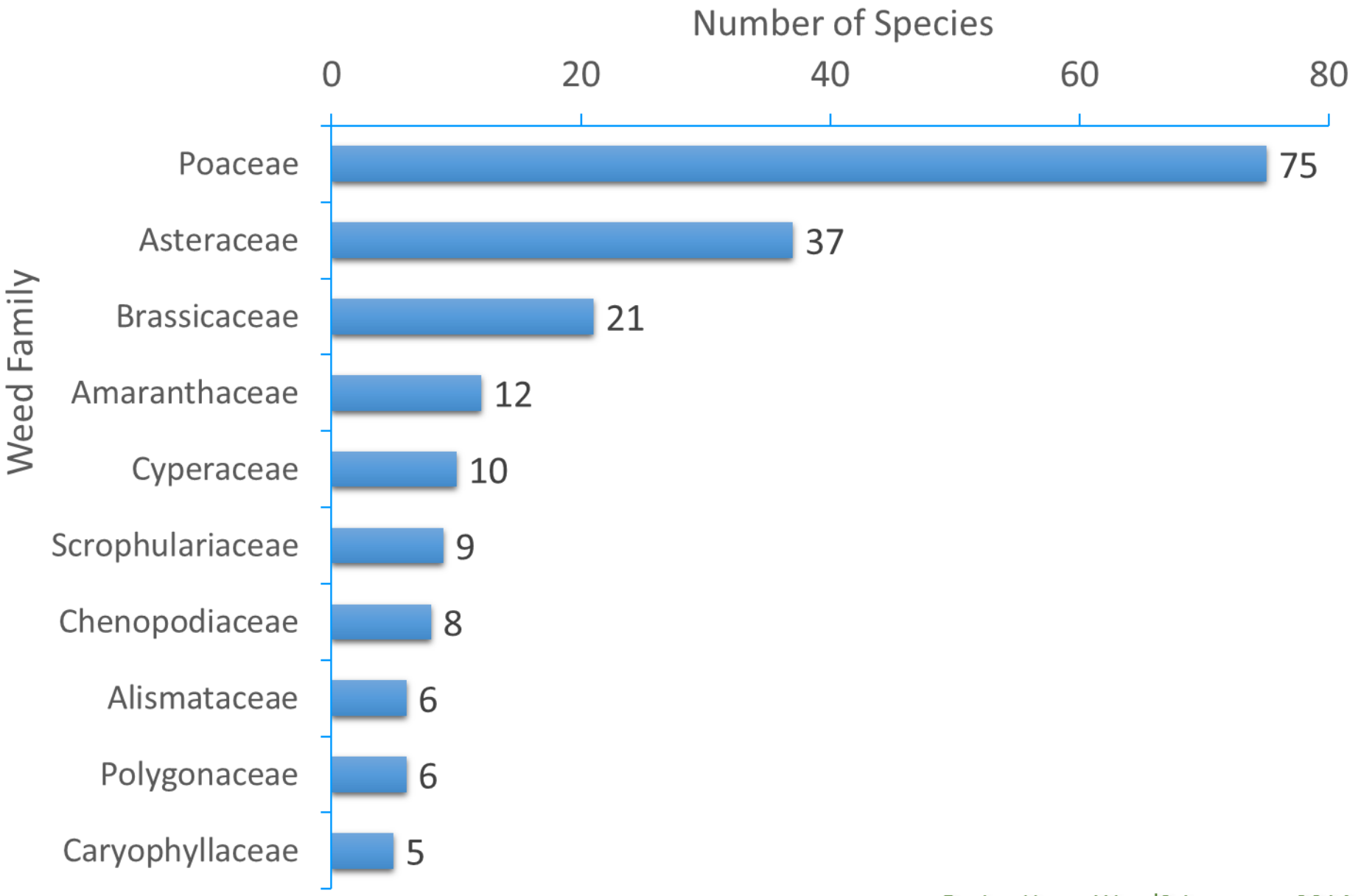


Number of Herbicide-Resistant Species by Crop



Dr. Ian Heap, WeedScience.org 2014

Number of Herbicide Resistant Weed Species by Weed Family (Top 10)



Weed Species Resistant to Multiple Herbicide Sites of Action

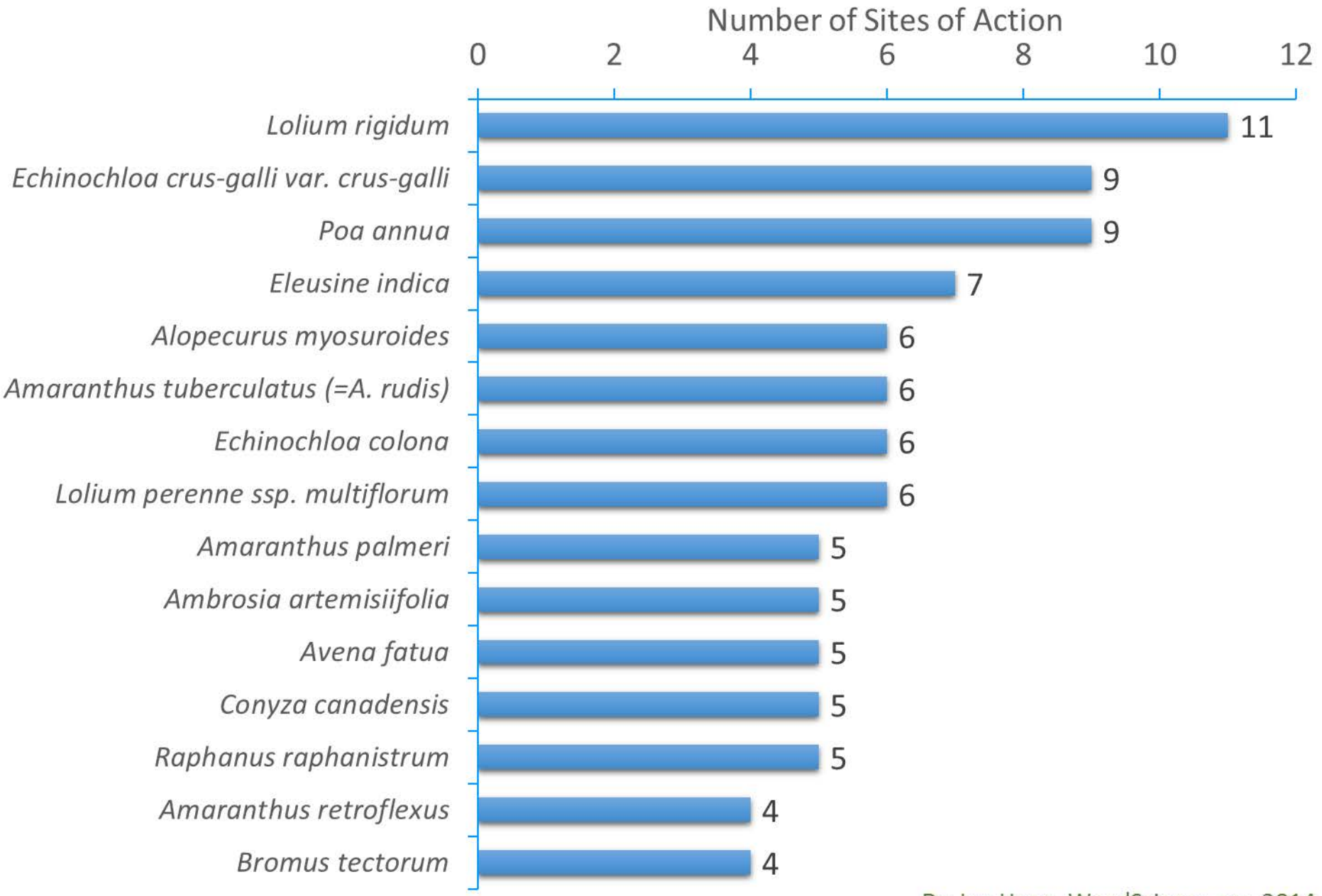


Photo Courtesy Stanley Culpepper

Photo Courtesy Larry Steckel

Photo Courtesy Stanley Culpepper


Photo by A.C. York 2010

Tillage is now a common scene

2004: 13% of cotton acres cultivated
2010: 32% of cotton acres cultivated

Photo Courtesy Stanley Culpepper

What's Next?

- We have to do something "different".
- Back to the definition of insanity.
- The human dimension MUST come into play, and be integrated with biology, to guide strategies from here forward.
- Considerations from a sociological, economic standpoint.

Agenda

- USDA opening remarks
- Understanding the decision process
- Economics of resistance management
- Community-based approaches
- Global perspective
- Diversifying tactics
- Education and outreach

Agenda

- Incentives and regulations
- EPA perspective
- Call to action!

What the 2nd Summit is NOT

- Not about reviewing BMPs
- Not about developing new BMPs
- Not about biology/physiology of the problem
- Not about pointing fingers!

What the 2nd Summit IS About

- Understanding the socio-economic dimensions of the problem
- Moving to more systems-based solutions
- Re-evaluate what we have been doing that has NOT worked
- Everybody has a role to play!

Concrete Outcomes of the 2nd Summit

- Everyone takes ownership
- Everyone commits to action
- Individuals and groups step forward to lead efforts
- Establish networks to communicate, coordinate, and plan for success

Today's Format

- Speakers will be brief and to-the-point
- Time allowed for dialog
- Questions posed to you during the day

The Goal

Cropping systems with diverse weed management tailored to farm and operator conditions

At the End of the Day

Resistance will only be managed through the **combined** efforts of ALL parties involved: growers, industry, universities, retailers, dealers, consultants, commodity groups, government, landowners, lending institutions, professional societies, press, non-governmental organizations….

YOU!

Larger Context

NRC is using this Summit to initiate a scoping meeting on pest resistance management – tomorrow

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Understanding the (Holistic) Decision Making Process in Weed Management to Better Effect Change

Raymond A. Jussaume Jr.
Michigan State University
&
David Ervin
Portland State University

September 10, 2014





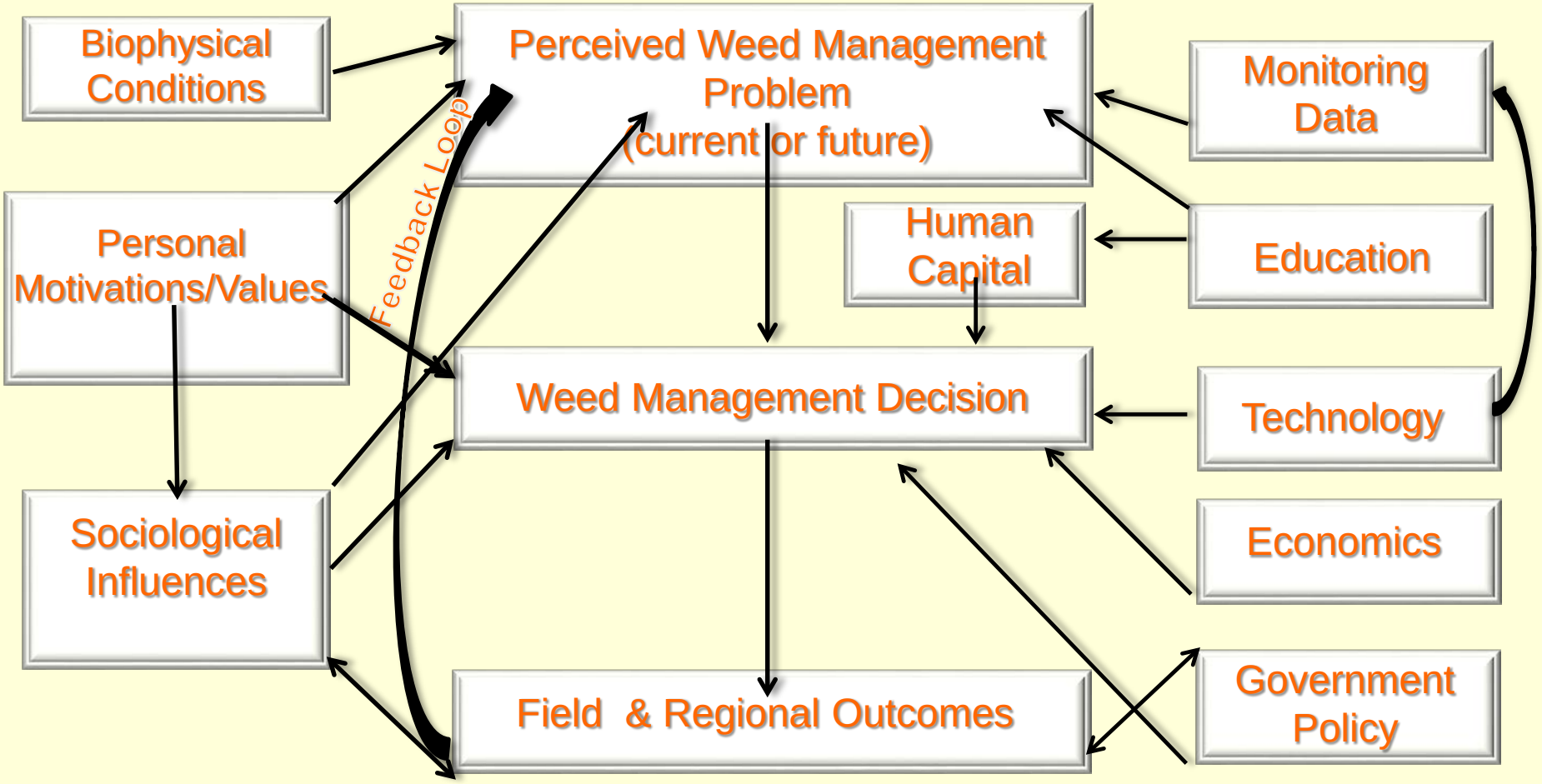
Today's Take Home Points

- There is no single "solution" to the problem of herbicide resistant weeds that can be placed in the hands of individual farmers.
- "Responses" will have to be complex, varied, community based and with roles for various actors. This will be a never-ending process of learning and adaptation.

Question

- What single factor do you think exerts the greatest influence on farmers' herbicide resistance management decisions?
  1. Economic Conditions
  2. Extent of the Problem
  3. Available Technology
  4. Natural Resource Conditions
  5. Personal Values
  6. Neighbors/Community
  7. Government Programs
  8. Other

Weed Management Influences



Some Implications

- Weed management is a complex problem pervaded by uncertainty
- Biophysical, technological, economic and social influences ALL interact to affect decisions
- Weed scientists, social scientists, policy makers, private sector actors, etc. must work with farmers to understand the process and to develop approaches to address the issue

Examples of Influences

- Missouri farmers with higher education levels implemented more soil conservation
- Government cost-sharing increased soil conservation effort
- Farmers' values about their "downstream" neighbors influenced their pollution control decisions
- Kentucky farmers implementing sustainable agriculture practices used farmer networks for problem identification, but expert networks for possible approaches

Farm Level Issues

- Various farm level factors (ecology, climate, weed types, etc.) affect weed resistance and thus weed management approaches
- Various farm household level factors (financial conditions, grower knowledge, personal values, etc.) will influence weed management approaches
- Various community level factors (farm structure, retail environment, level of social capital) will influence degree to which community based responses are possible

A “Wicked Problem”

- The evolution of herbicide resistance is a “wicked problem” because of its complexity (involving multiple factors) and because there is no “optimal” solution
- Managing resistance involves managing a “common pool resource” because the susceptibility of weeds to a management strategy is a shared resource in an area
- No model can completely describe the evolution of herbicide resistance or provide a solution to the problem
- Decision making models are frameworks for understanding how people are responding to a problem, not a specific solution plan

Towards a Holistic Decision-Making Framework

- Problem must be (broadly) recognized by ALL actors
- Understand local natural resource conditions
- Recognize heterogeneity of farm households (mix of economic, social-psychological, socio-structural influences)
- Complexity of governmental policies and business practices
- Importance of social influences – responses of individual farmers crucial, but not sufficient

Question

Which of the following individuals/institutions do you think has the greatest influence on farm level weed management decisions?

1. Neighbors/Family Members
2. Crop Consultants
3. Extension Personnel
4. Federal Government
5. Financial Advisors
6. Chemical/Seed Company Representatives
7. Other

Conclusions: The Challenge of Understanding and Responding to Weed Resistance

- The spread of weed resistance is “global” but factors influencing spread are “local”
- There is no “magic bullet.” There is no answer or solution that can be “provided” to farmers
- Socio-economic factors are as important as biophysical and climatological factors
- All actors will need to partner with each other to develop approaches for addressing the problem at community and farm levels

Call to Action

- Develop a holistic interdisciplinary HRM management approach with scientific and stakeholder inputs
- Collect information from growers, farm managers, input suppliers and others to identify their thoughts on the strength of various influences affecting weed management in different settings
- Assess the potential for neighbor/community institution-building to address common pool problems associated with HRM

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Economics of Resistance Management

Terry Hurley, University of Minnesota
George Frisvold, University of Arizona

September 10, 2014





Managing Resistance: Two Economic Challenges

- Herbicide resistance management decisions depend on more than profitability.

- Managing herbicide resistance is a long-term problem.

Question

Of the following items, which one would you rank as the biggest barrier to farmer adoption of herbicide resistance management plans?

1. Lack of Information
2. They Are Too Complex
3. They Are Too Costly
4. Benefits Are Too Uncertain
5. Insufficient Management Time

Herbicide resistance management decisions depend on more than profitability

- Need to look at overall household income, goals, and constraints.
- Simplicity, flexibility, and convenience are valuable.
- Farm programs and government regulations matter.

Managing herbicide resistance is a long-term problem

- It is an investment problem:
  - Increased Costs Today ─ More Chemical, Equipment, Labor, Training
  - Delayed Benefits ─ More Effective and Flexible Control Options

- It is an insurance problem:
  - Cost Are Certain
  - Benefits Are Uncertain

Question

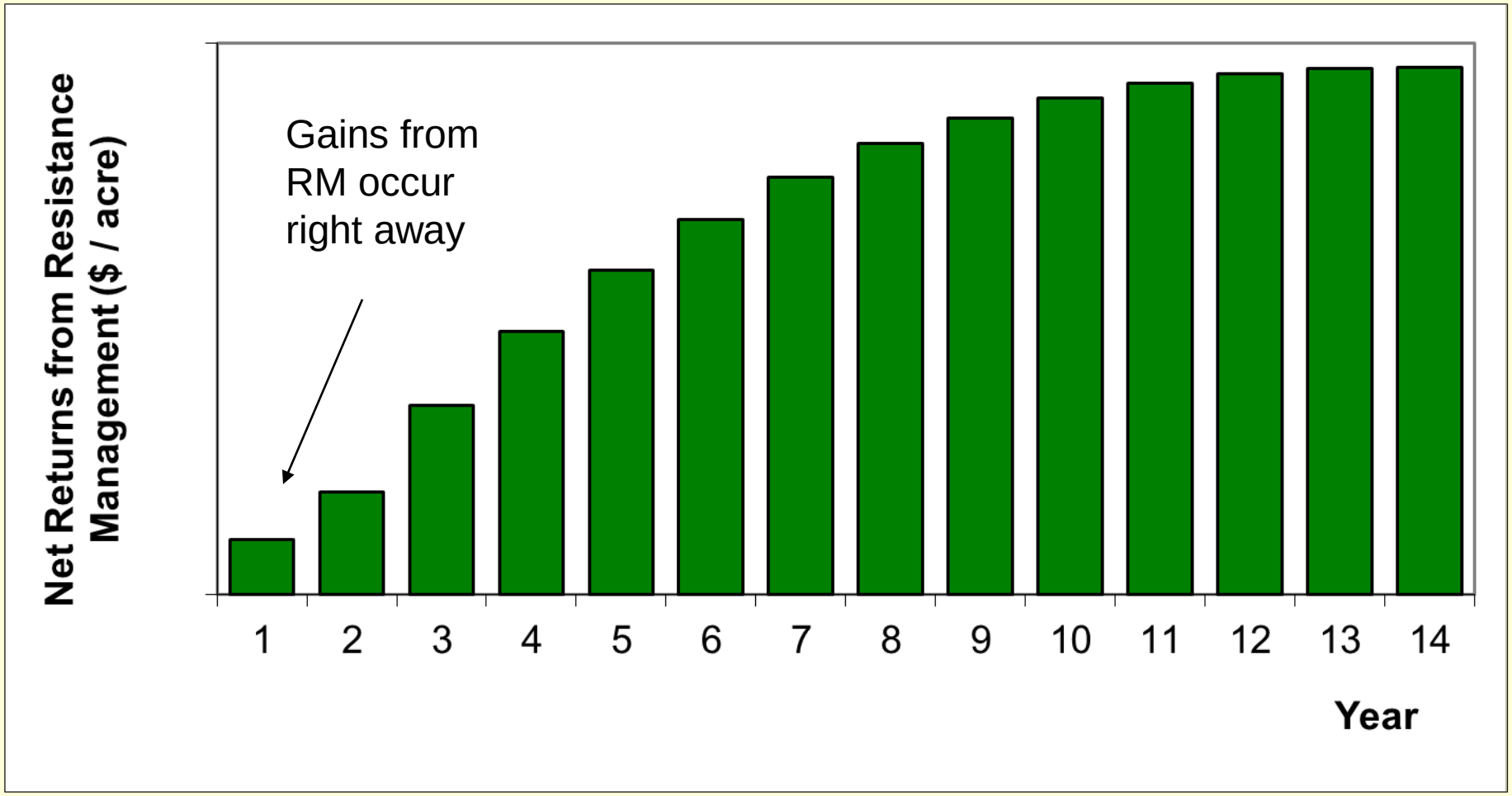
In your opinion, how likely is it that the discovery of new herbicides will solve current and future herbicide resistance problems?

1. High
2. Medium
3. Low

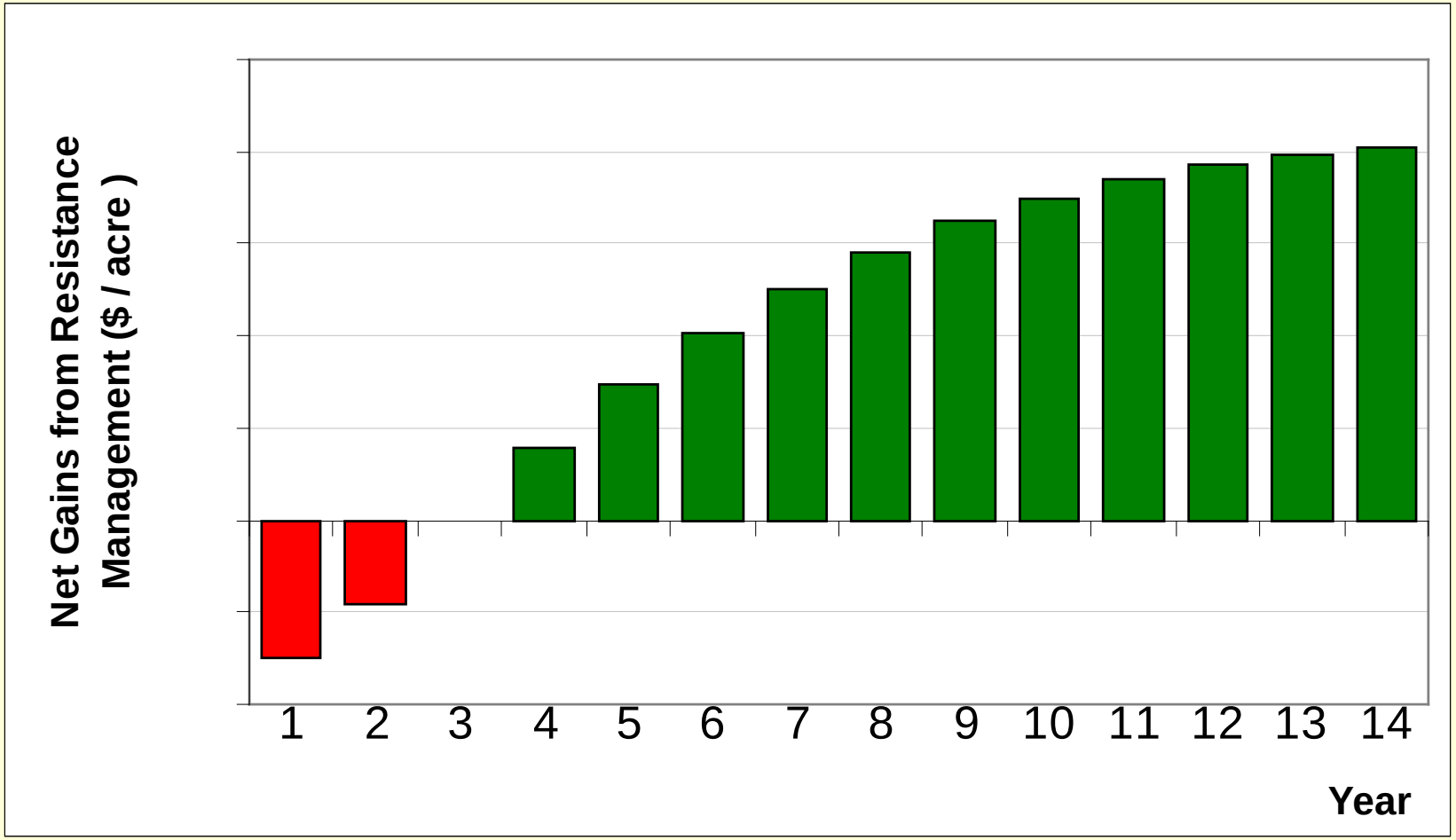
Example Long-Run Income With Resistance Management (RM)

- Case 1: Optimistic Case
  - RM more profitable even in the short-run.
  - Why wait?
- Case 2: Intermediate Case
  - Only takes a few years for net gains of RM to turn positive.
  - RM “pays for itself” after just a few years.
- Case 3: Pessimistic Case
  - RM less profitable for a number of years.
  - RM pays off only after a long time.

Case 1: Resistance Management Pays Right from the Start



Case 2: Resistance Management "Pays for Itself" Relatively Quickly



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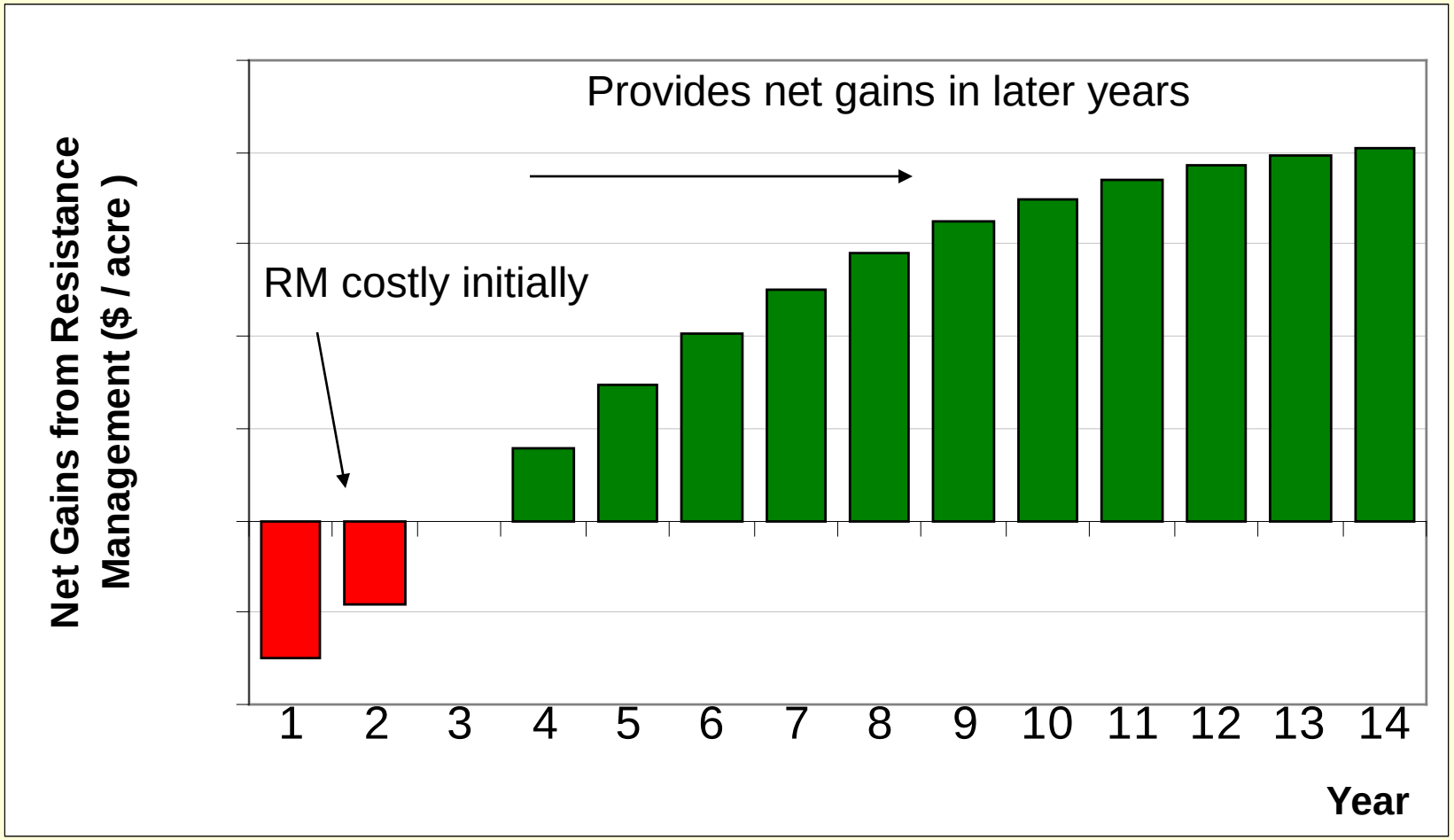

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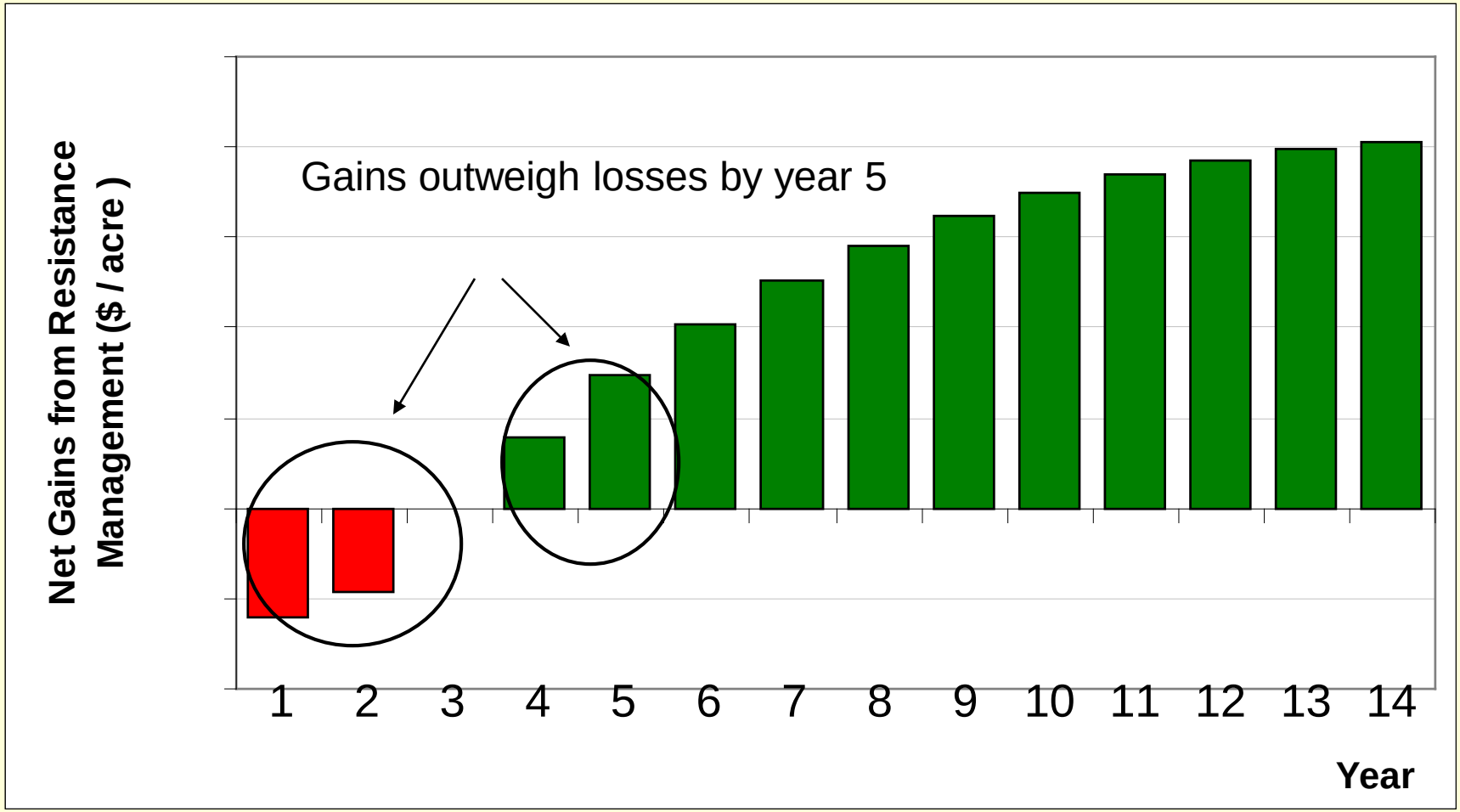
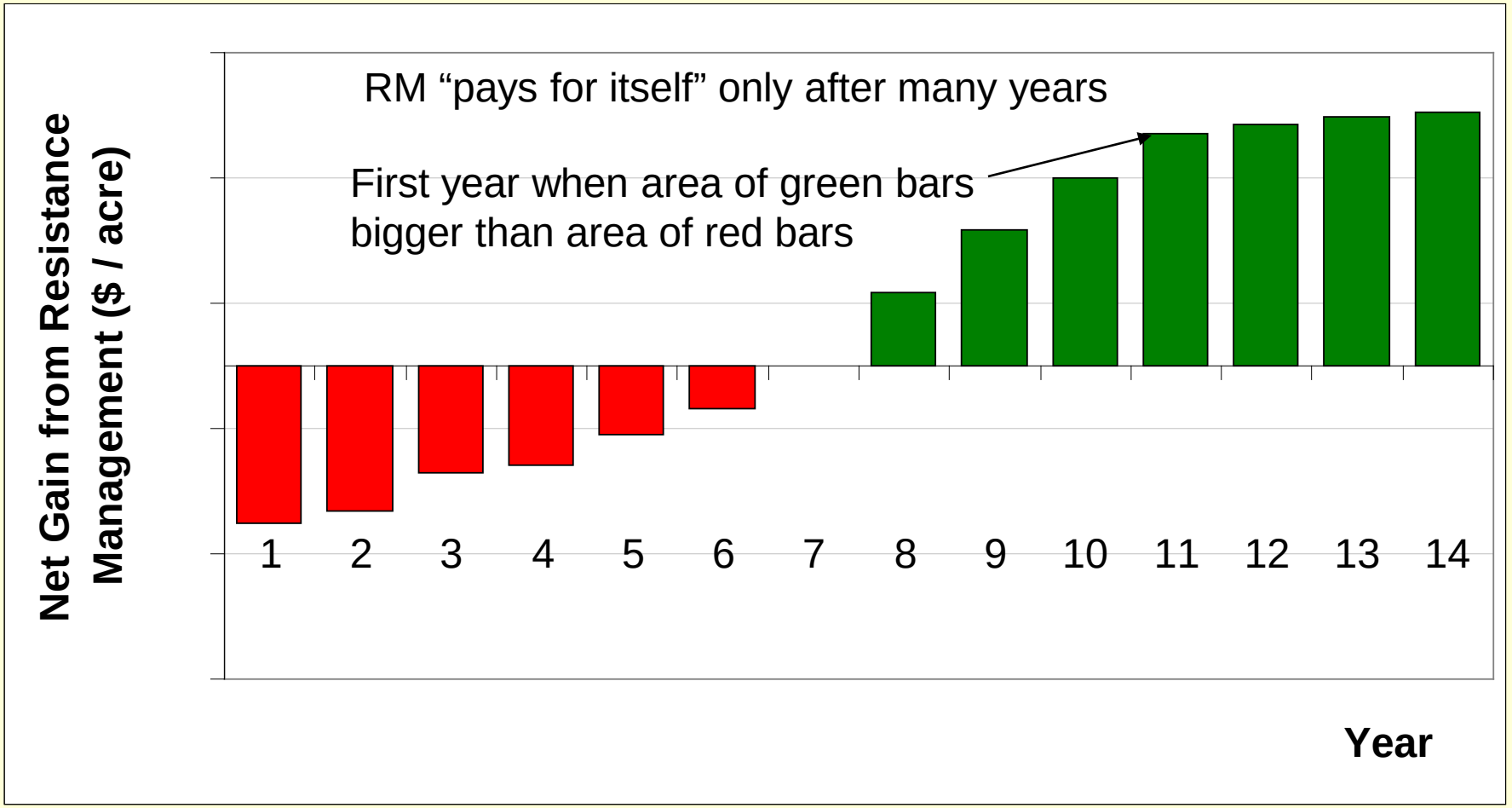


Case 3: Managing Resistance Takes Longer to Pay Off

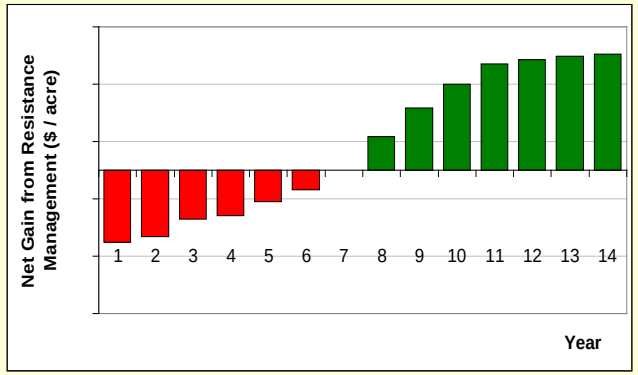


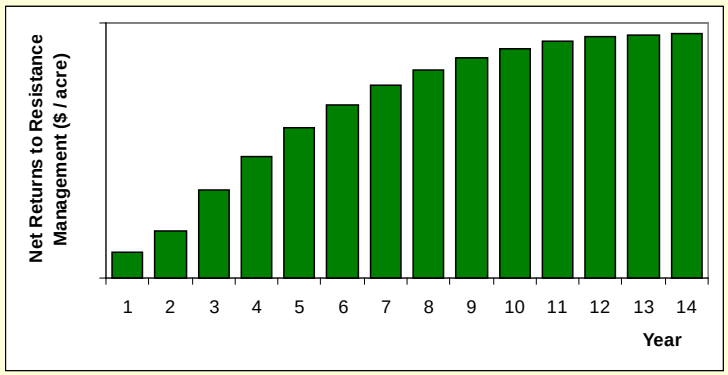
Policy Implications

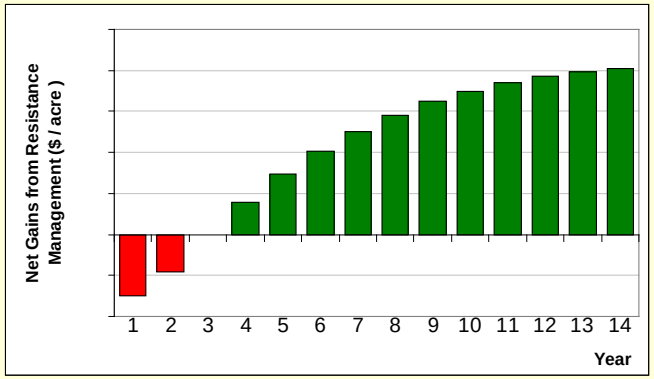
- Case 1: RM “pays for itself” right away
  - Traditional demonstration, education, extension may suffice
  - Results must still be clear and convincing
- Case 2: RM takes a few years to pay off
  - Simply providing information may be insufficient
  - Growers with (a) more short-run economic stress, (b) higher discount rates, (c) plans to sell for development less likely to adopt
  - Economic incentives may be needed to encourage adoption
- Case 3: RM takes longer to pay off
  - Messaging most difficult (longer time frame increases uncertainty of benefits)
  - Additional economic incentives may be needed to encourage adoption

Economics of Resistance Management: **Critical Need**

We need to know which crops and regions have which type of economic return profile







Call to Action

- Reduce regulatory barriers to herbicide resistance management
- Communicate the effect of herbicide resistance management on short and long-term farm profitability
- Provide short-term financial incentives to reduce the cost of developing and implementing field-by-field herbicide resistance management plans

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Community-Based Approaches

David Ervin, Portland State U. and
George Frisvold, U. Arizona

September 10, 2014





Outline

- Why community-based approaches?
- Design principles
- Lessons from community-based programs
  - Boll Weevil eradication
  - AZ Bt Cotton Working Group
  - Zero Tolerance
- Call to action items

Audience Question 1

How likely do you think it is that herbicide resistant weeds will spread from one farmer's fields to another farmer's fields?

1. Very likely -- greater than 80% probability
2. Likely -- more than 50% but less than 80%
3. Can't say either way -- even odds
4. Unlikely -- less than 50% and greater than 20%
5. Very Unlikely -- 20% or less
6. Don't know

Why Pursue Community-Based Approaches?

- Significant weed mobility across farms and the landscape
- Causes stem from natural processes, e.g., pollen, and mechanical, e.g., machinery.
- If farmers feel their actions will not be matched by their neighbors, they have less incentive to practice HRM.
- It's an assurance problem! (Individual decisions depend on those of the group)

Sizing up the Mobility Problem

- If herbicide resistance is mobile, the susceptibility of weeds to the herbicide is a resource shared across farms.
- That susceptibility is called a “common pool” resource.
- Dimensions of weed mobility need more research.

Why Prefer Community-Based Approaches?

- Top-down, command and control approaches usually achieve objectives, at much higher cost than necessary
  - Lack of flexibility increases expense
  - Prescriptive practices stymy innovation
  - High monitoring and enforcement costs

Why Prefer Community-Based Approaches?

- Top-down, technology / practice subsidies can have similar problems
  - Inefficiencies at taxpayer expense
  - Payments can end up just being income transfers without altering behavior

Design Principles

1. Clearly defined boundaries
2. Rules adapted to local conditions
3. Farmers using the resource must participate in decision-making
4. Effective monitoring that is accountable to farmers using the resource

Design Principles cont.

5. Graduated sanctions for rule violators
6. Conflict resolution mechanisms are cheap and easy
7. Community granted the right to determine program planning and implementation
8. Multiple layers of organizations, e.g., local, state and federal, may be required

Audience Question 2

As a general rule, what percentage of farmers in communities experiencing herbicide resistance do you think would participate in a community-based approach?

1. 20% or less
2. 21-40%
3. 41-60%
4. 61-80%
5. More than 80%
6. Don’t know

Lessons from Community-Based Approaches

- Boll Weevil Eradication
  - Support for cooperative programs was lower areas with less acute problems.
  - Larger-scale growers with more formal education were more likely to adopt pro-active measures.
  - The large-scale growers were less pleased with the program because they got less additional gain from the community-wide effort.
  - Smaller-scale growers favored community-based effort if it reduced complexity of management.
  - Government subsidies help.

Lessons from Community-Based Approaches

- AZ Bt Cotton Working Group:
  - History of area-wide approach (growers, university research & extension, USDA, EPA, industry)
  - Two-way flow of information to and from growers
  - Continued monitoring
  - Good data on gains from Bt also show benefits of managing resistance
  - Possible to increase effectiveness and lower costs of regulation at the same time through info sharing
  - Managing for resistance never ends!

Lessons from Community-Based Approaches

- Zero Tolerance for Palmer Amaranth
  - Importance of “rapid information exchange between the grower, extension personnel, and researchers.”
  - Continuous testing and evaluation
  - Science-based rules
  - Requires across-commodity approach
  - Looks beyond individual farm fields

Some General Lessons

- "If / then" statements based on scientific information, showing economic consequences more effective than exhortations of what people "should" do
- Exchange of information important
  - Multi-directional vs. uni-directional flow
  - Listening is underrated
- Building institutional capacity takes time and requires maintenance (even after crises subside)

Audience Question 3

Select the 5 options that you think will be the **most effective** at resistance management (RM)

1. Federal regulations directing how, when, & where herbicides may be used
2. Extension / grower education programs
3. Federal stewardship payments to encourage RM
4. Industry incentives programs providing rebates for RM
5. Reduced crop insurance premiums for adoption of RM practices
6. Grower-led, community-based RM programs
7. More informative herbicide labels
8. Increased research into non-chemical methods of weed control
9. Increased economic incentives or lower regulatory barriers to developing herbicides with new modes of action
10. Faster approval of seed varieties with multiple herbicide resistant traits

Calls to Action

1. Solicit recommendations for candidate community-based approaches to herbicide resistance.
2. Select one or two areas to initiate pilot community-based programs.
3. Document the successes and limitations of the pilot programs for wider application.

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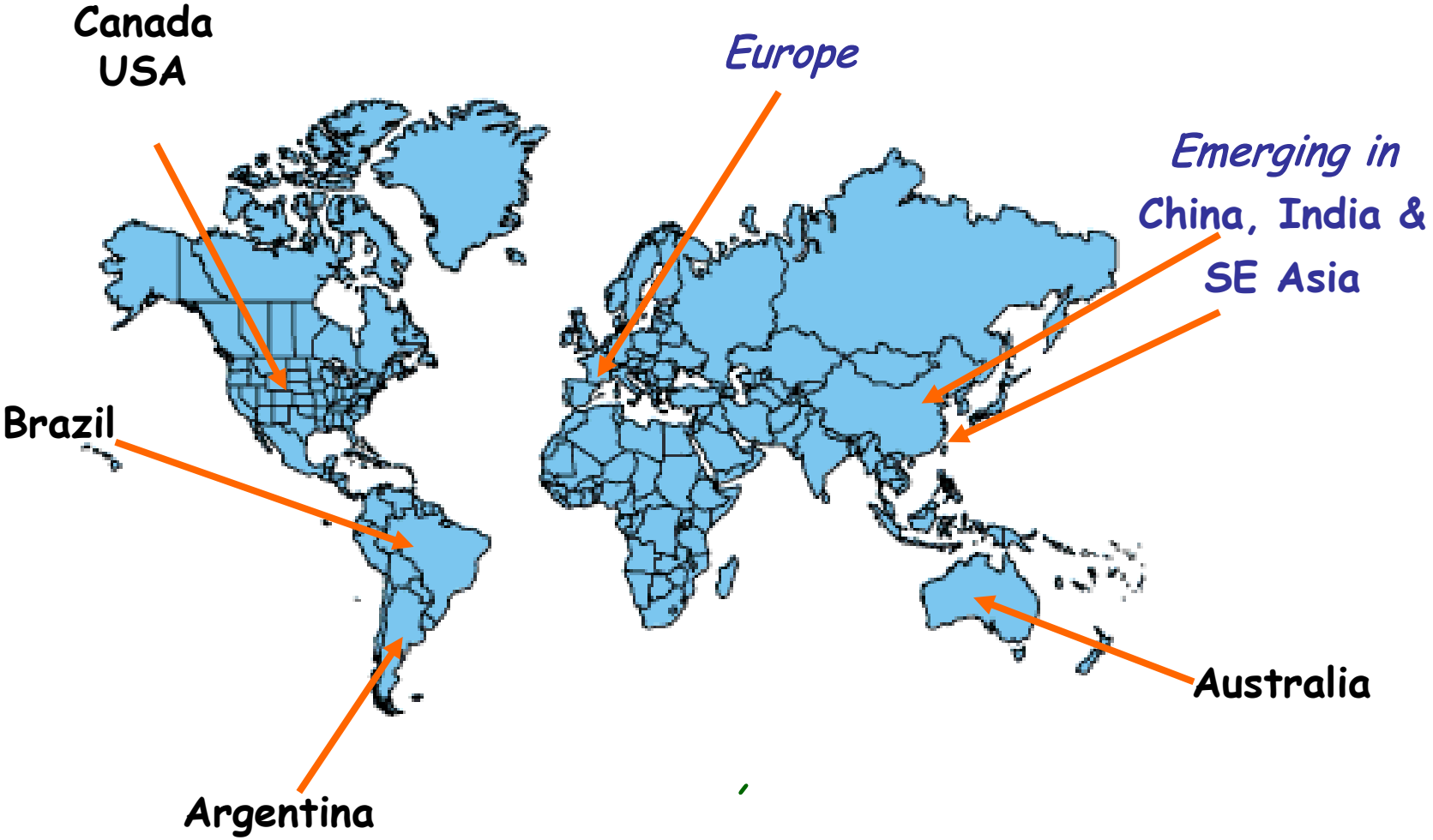
RESISTANCE GLOBALLY.

Stephen Powles

ahri.uwa.edu.au

Big HR issues are in the major, industrialised grain exporting nations:

Grains feed the world!



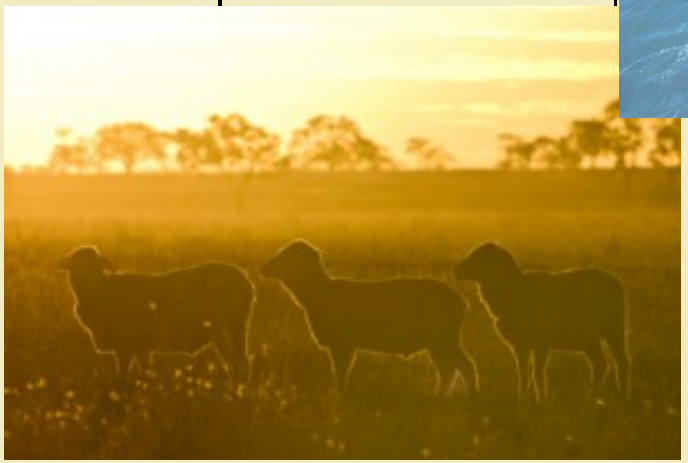
Diversity disrupts R evolution

- **R occurs in many places globally where there is minimal diversity**
- Diversity is common in agriculture in most parts of Asia & Africa and R is minimal.
- Europe has diversity and R only a major issue where there is minimal diversity
- USA, Brazil, Argentina, Canada, Australia are the big global grain exporters. Big farms, high herbicide reliance, low diversity, high resistance

A TALE OF TWO LANDS WITH BIG HR PROBLEMS.

South Land


Sitting in a 3.8-metre sea
kayak and watching
a four-metre great
white approach you is
a fairly tense experience

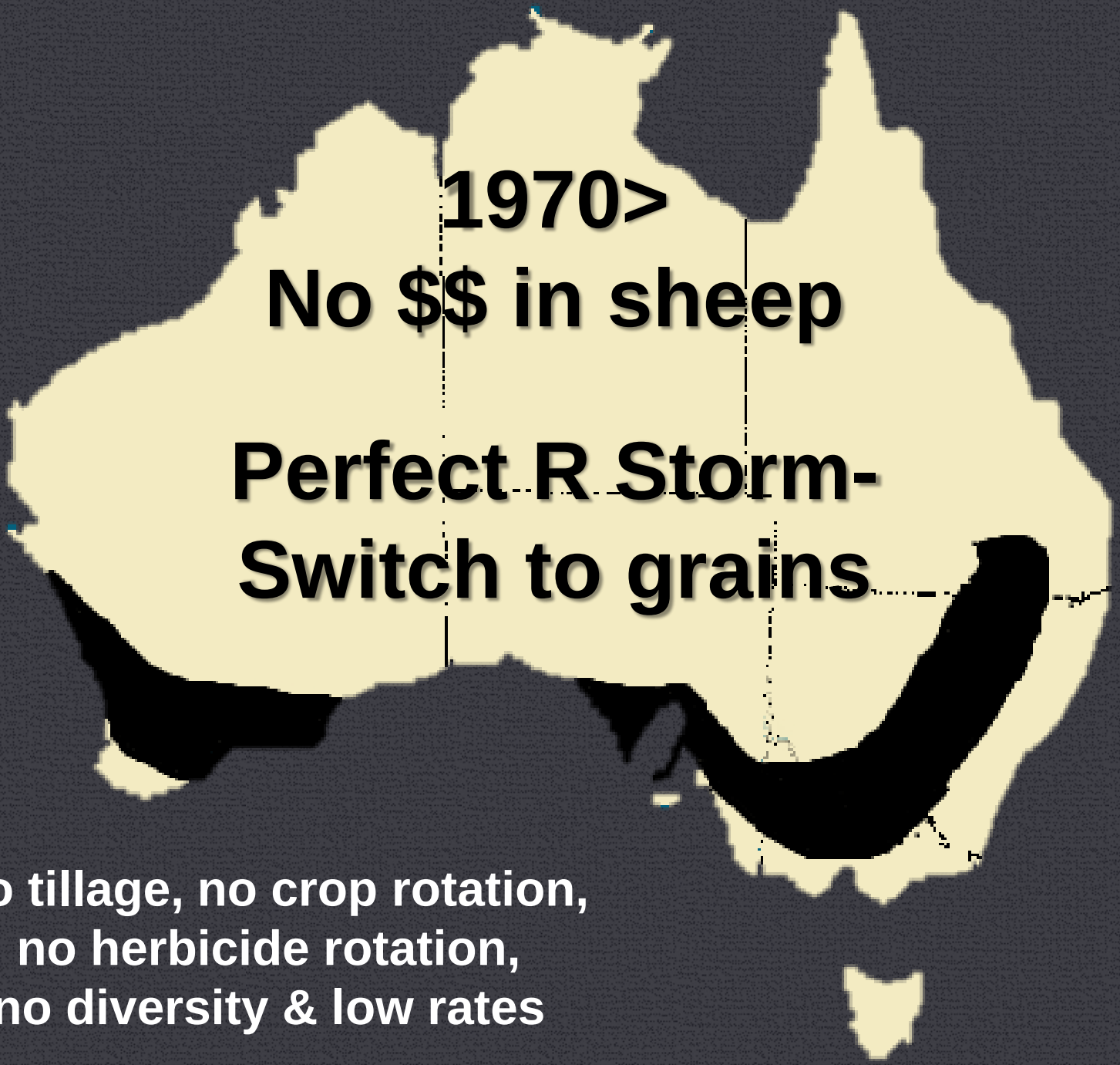


1850 onwards
140 million sheep
on Lolium pasture

- **Short seed bank life**
- **Huge pop's over vast areas**

Lolium seeded & nurtured across half a continent when the sheep was king

- **Genetically diverse**
- **Cross-pollinated (wind)**

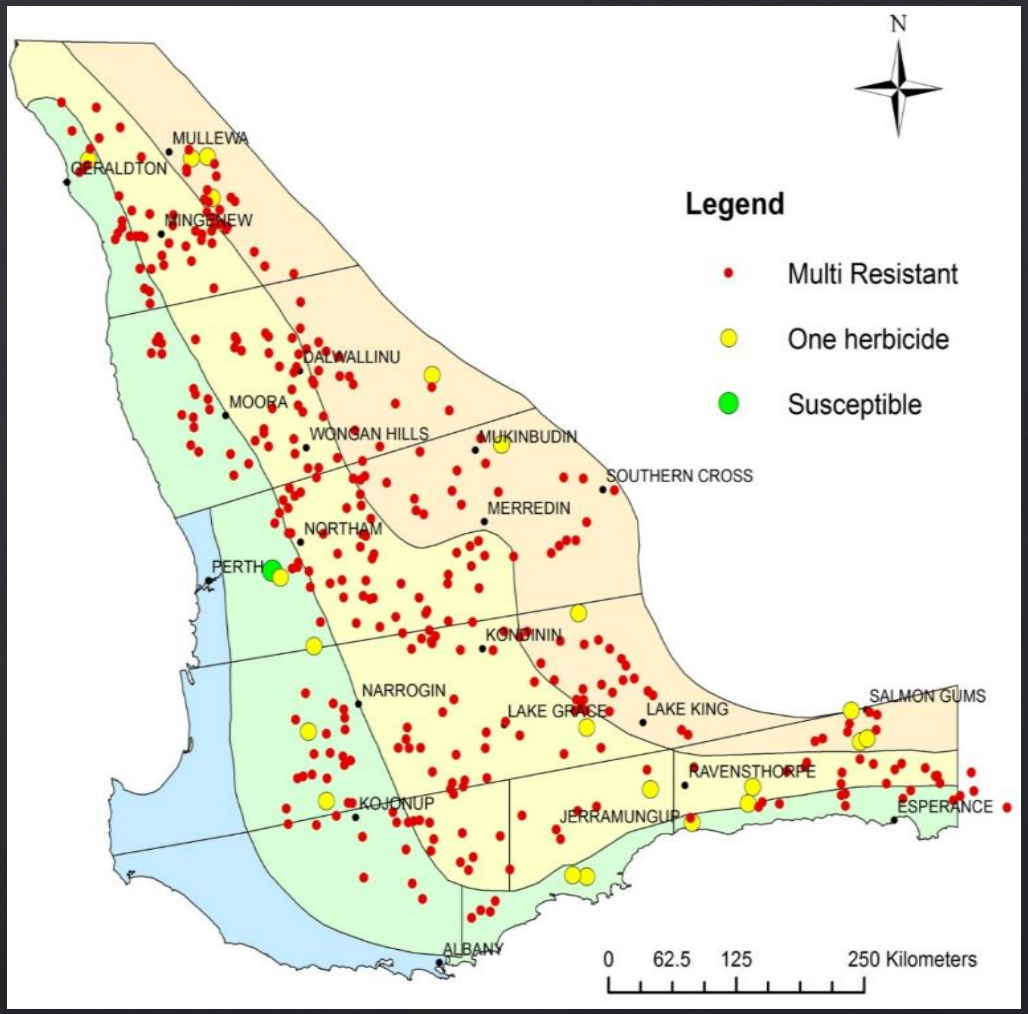


No tillage, no crop rotation,
no herbicide rotation,
no diversity & low rates

#1

Resistance from coast to coast

15 million acre random resistance survey (*Lolium*) in West Aust.

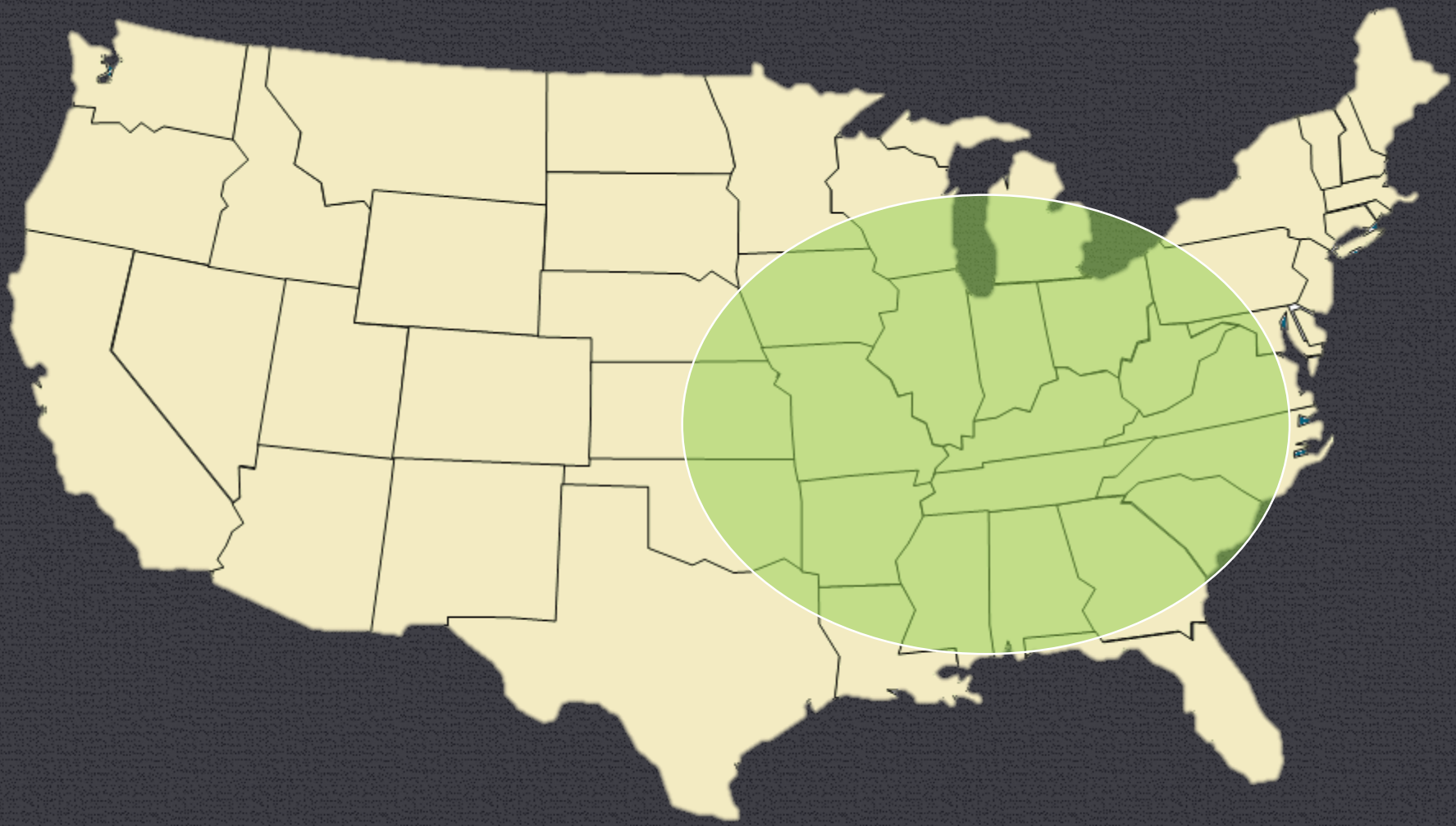


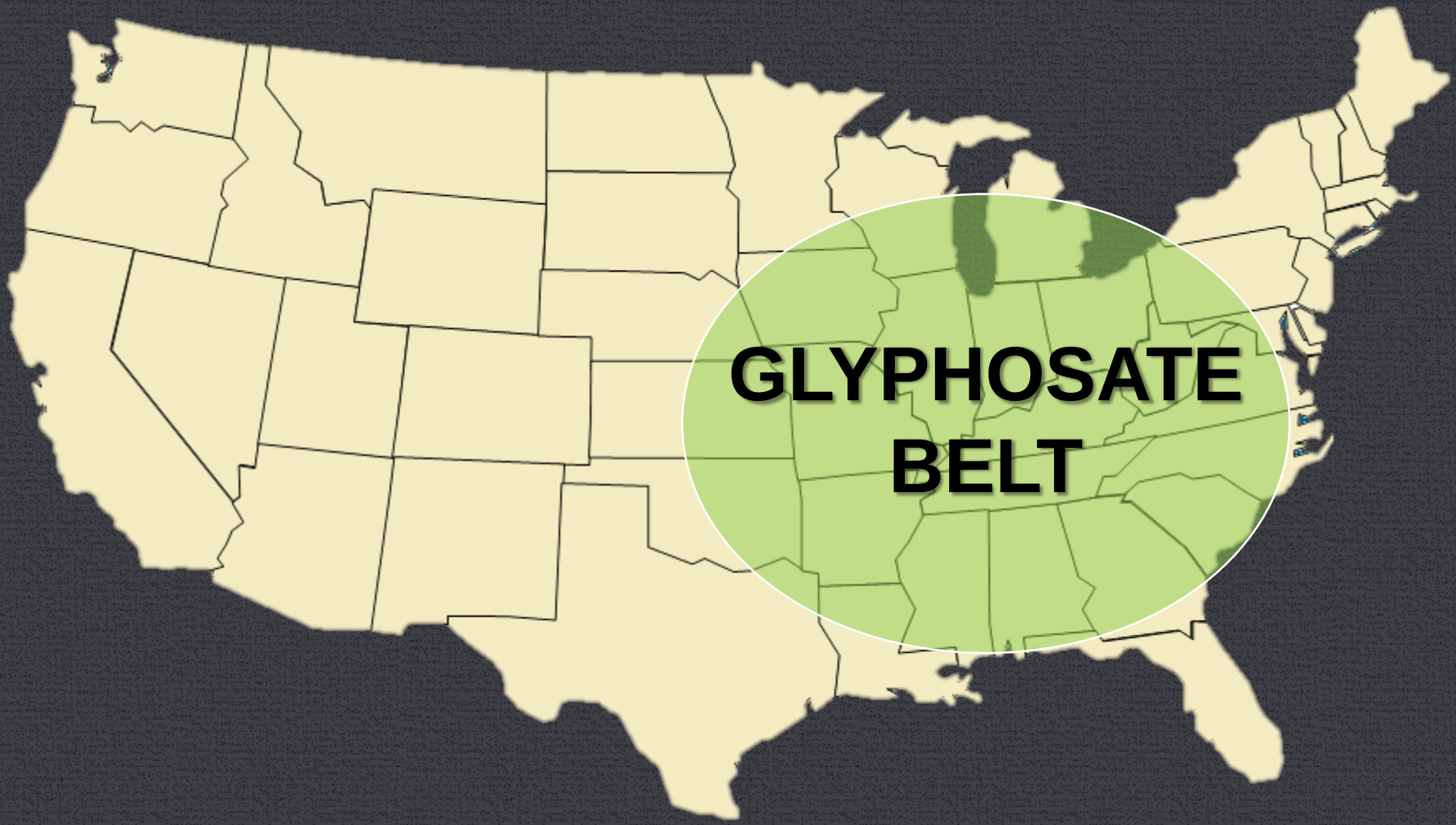
Owen et al. (2014) Weed Res

North Land

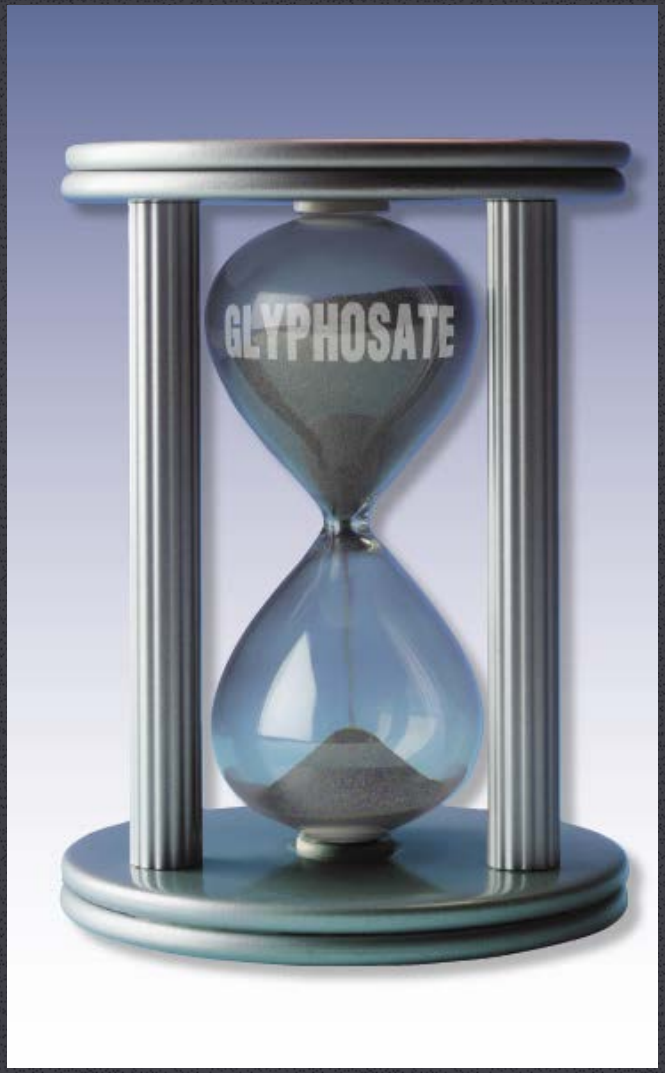
- GR Corn, GR Soybean, GR cotton, GR canola, beets …
- Cheap, simple, convenient weed control, no worries!






GLYPHOSATE
BELT

Time is running out



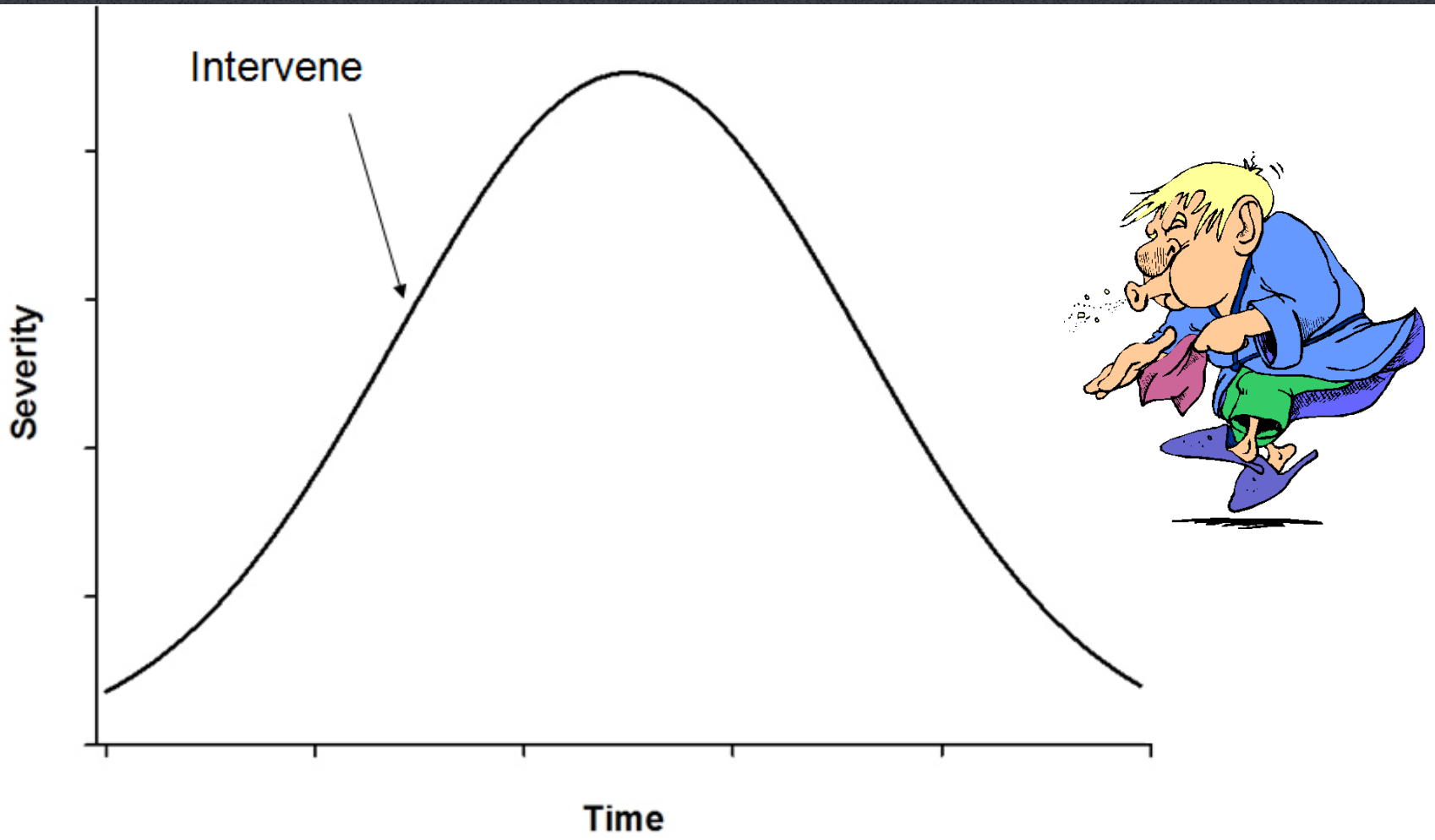
Glyphosate:

The world's greatest herbicide.

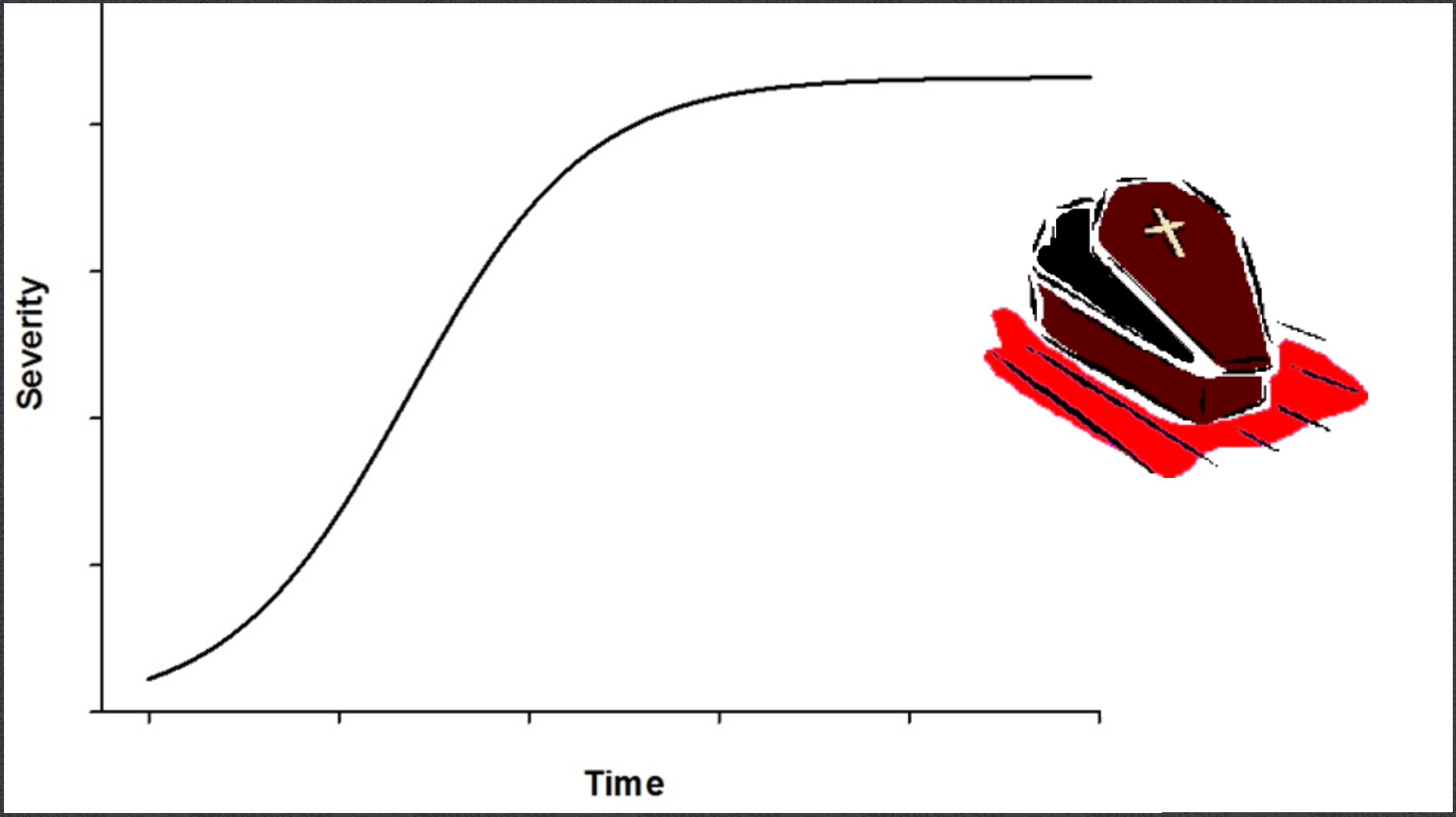
So good.

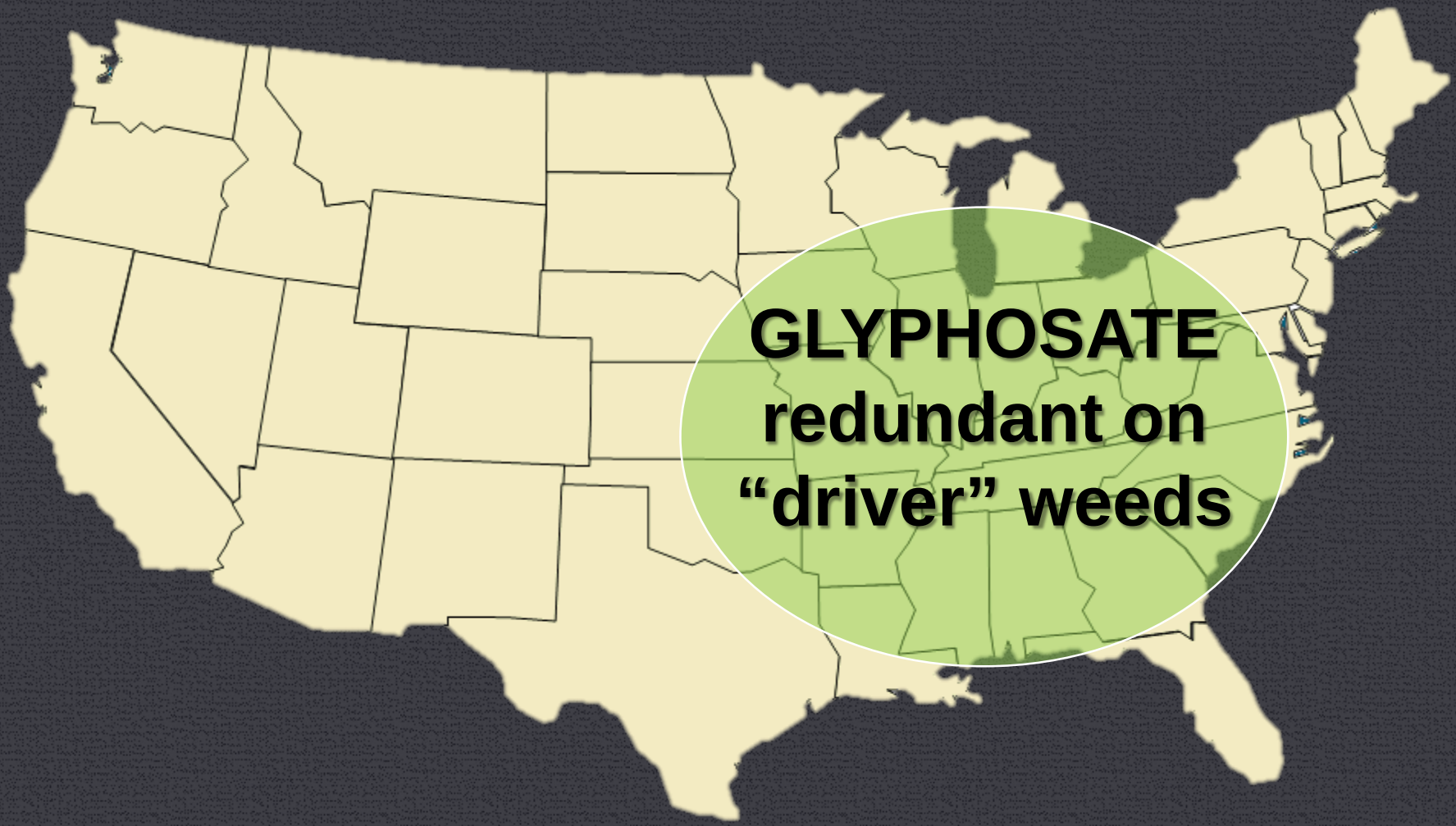
So easy to over-use.

What happens if you intervene in an epidemic?



What happens if you don’t?




GLYPHOSATE
redundant on
“driver” weeds

Chemical industry responses

- Add pre-em herbicides
- Increase herbicide discovery effort (no new herbicides imminent)
- Add trans-genes for existing herbicides (glufosinate, dicamba, 2,4-D, HPPD)

All are logical –BUT-resistance has,can,will occur to these herbicides. How they are used is critical.


Silver Bullet
Glyphosate
+++++++

Logical but R has, can, will evolve

HR gene traits

Glyphosate ++

Glufosinate

Dicamba

2,4-D

HPPD

DOES THERE HAVE TO BE A TRAIN WRECK BEFORE CHANGE OCCURS?

CHANGE
IS
DIFFICULT

My pessimistic list leading to a “train wreck”

- History of successful herbicide weed control.
- Strong belief that new herbicide solutions imminent
- Strong industry signals of pipeline of new herbicide/gene solutions
- Short term $$$$$ driven decision making
- High % of rental crop land
- Upcoming period of lower grain prices
- Generic herbicide suppliers

- Generation used to easy herbicide weed control
- Diversity tactics perceived to be too difficult
- Growers do not “fear the weeds”

AIDS,
SARS,
MERS,
HOS

HOS: A condition to be overcome in the US

HOS

Herbicide Only Syndrome

HOS

Herbicides are superb weed control tools, BUT multiple herbicide resistant weeds are telling us that herbicides ALONE are not sustainable.

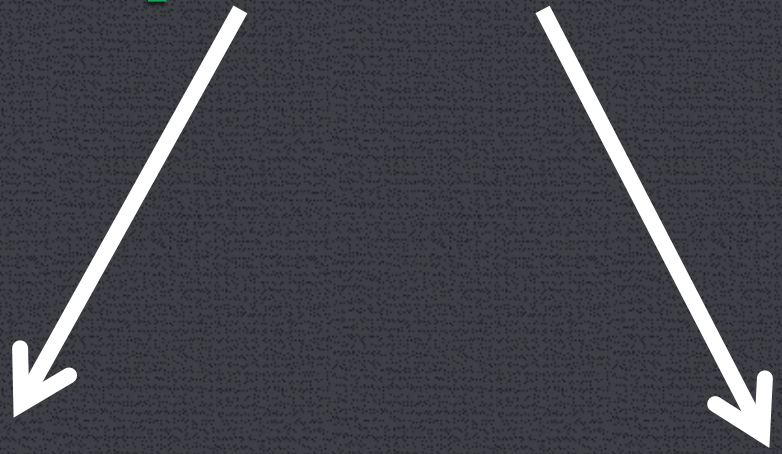
DIVERSITY is the only sustainable way forward.

The good news:

Herbicides much more sustainable IF HOS replaced by diversity.

Diversity

disrupts R evolution



Herbicides

Non-herbicide tools

Diversity

disrupts R evolution

=

Good agronomy
Low weed populations
New tools

Herbicide diversity & technology can disrupt R evolution

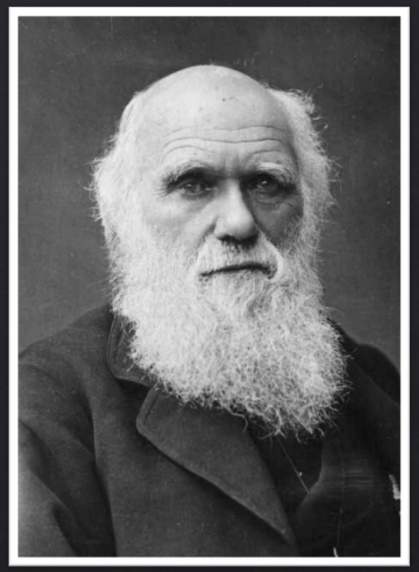
New herbicides (non-metabolisable)

Herbicide synergists & safeners

Smart full-dose mixtures, sequences

- Genetic herbicides (RNAi)

- Herbicide restraint



Harvest weed seed control

Harrington Seed Destructor

Will DIVERSITY replace HOS any time soon?

- No question that multiple herbicide resistant weeds will force change
- A strong role for all sectors of our industry:
  - Agro-ecologists, Agronomists,
  - Advisers & Growers
  - Scientists, incl. social scientists
  - Economists,
  - Communicators
  - Government
  - INDUSTRY

Weed biology

$$ Modelling

RIM
Ryegrass Integrated Management

Seedbank know-how

WEED smart
every weed every seed
every farm every year

R champion farmers

SOA labelling

AHRI
AUSTRALIAN HERBICIDE RESISTANCE INITIATIVE

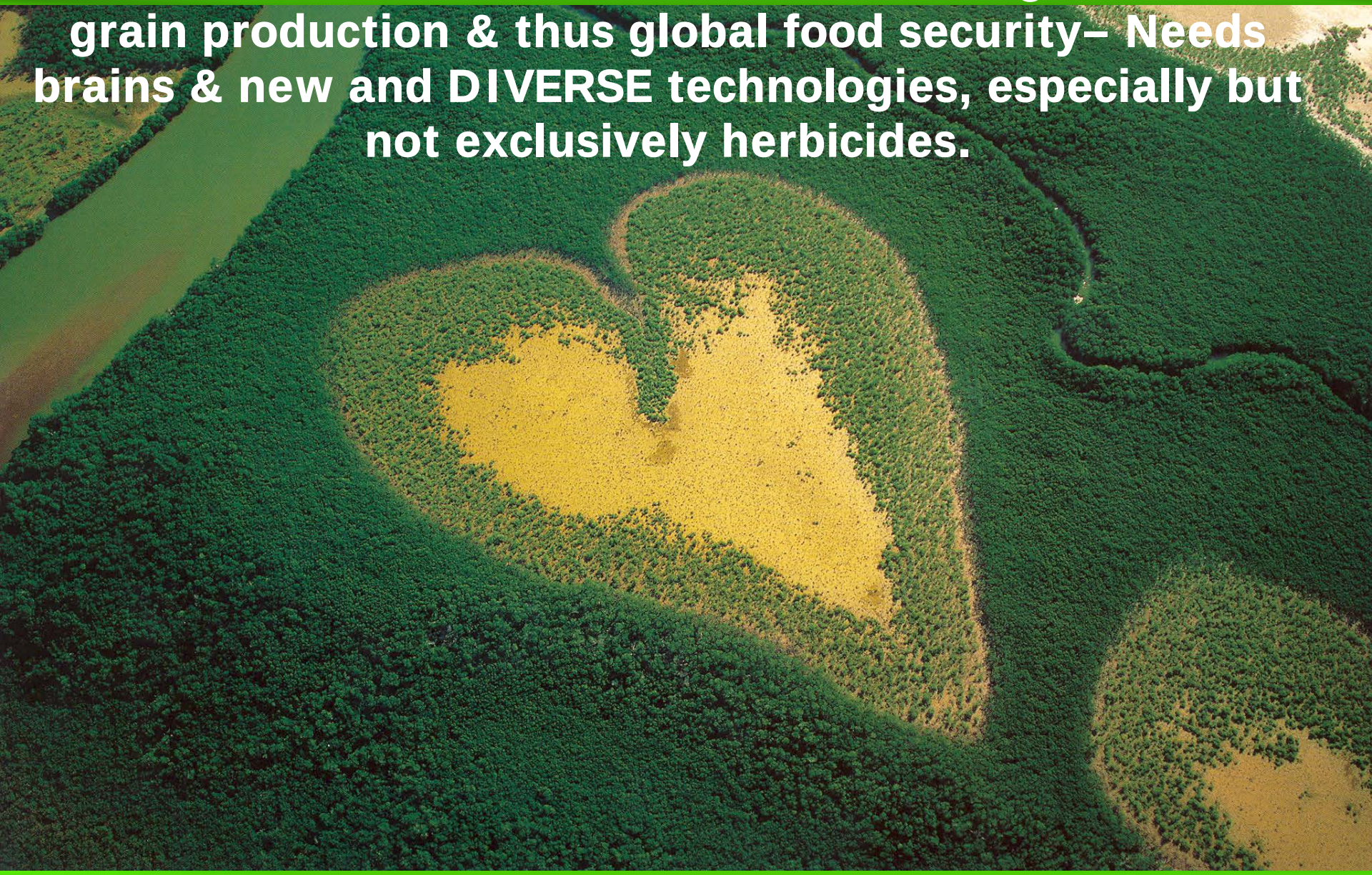
Workshops

Multi-disciplinary research

Print Media

Media

The Future: HR weeds are a HUGE challenge to world grain production & thus global food security– Needs brains & new and DIVERSE technologies, especially but not exclusively herbicides.



Ode to diversity

Americans all let us rejoice,
for we are proud & free.

We’ve golden soil & crops for toil,
And now we’ve got diversity.

Resistant weeds will not be our fate,
crops, chemicals & tools we will rotate.

Thus in joyful strains let us PLEA,
long live DIVERSITY

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September 10, 2014





Diverse Approaches to Herbicide-Resistant Weed Management

Micheal D.K. Owen
Iowa State University

September 10, 2014





Introduction

- Weed management tactics, in a general sense, have not changed appreciably in several decades
  - Tactics include cultural, mechanical and herbicidal
- Specific tactics however have seen many changes reflecting not only technological improvements but also addressing social and economic considerations

Introduction

- Despite the fact that evolved resistance to herbicides has been a concern for four decades, new resistances have tipped the cart
- There are a number of problems in managing herbicide resistant weeds
  - Grower knowledge
  - Time management
  - Economic concerns
  - Lack of new herbicides

Question

The current problems with herbicide resistant weeds increases the likelihood that growers will diversify weed management programs beyond simply changing herbicide programs.

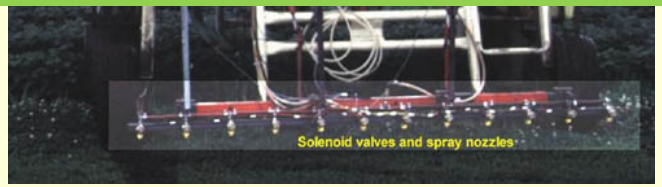
1. Yes
2. No

Grower perception of herbicide resistance

The reality of herbicide resistance

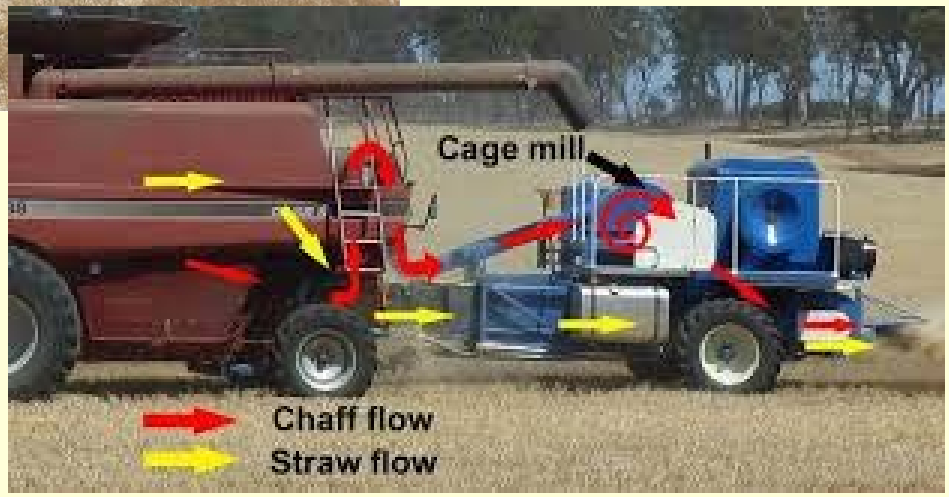
Site-specific weed management

Scouting is needed to provide the best tactics for individual fields



Mechanical tactics

Weed seedbank management



PAGMan – USDA-ARS & SDSU

Four-row grit applicator has 8 nozzles, one for each side of four rows
Grit application rate is about 500 kg/ha
Air is pressurized at about 500 kPa

Before & after grit application

(note level of in-row control)

Weedy V3

Treated at V1 (June 15) + V3 (June 23)

Cultural tactics

- Increase crop rotation complexity
- Temporal changes in crops
  - summer annuals (corn and soybean) vs. spring grains
- Date of planting
- Row spacing to improve crop competitiveness
- Inclusion of perennial forages

Better cover crops and their management

Soybean row spacing

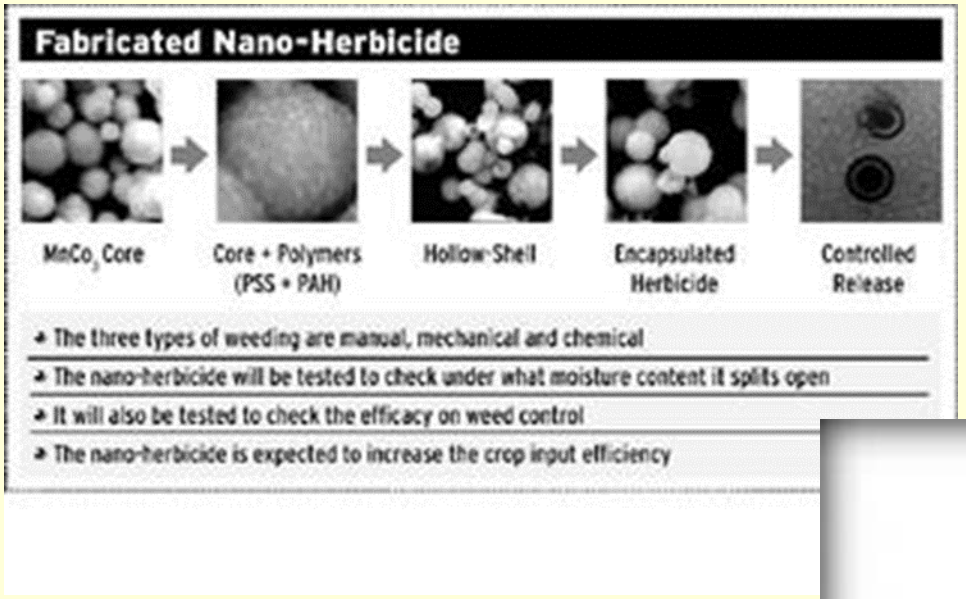
30” rows V2

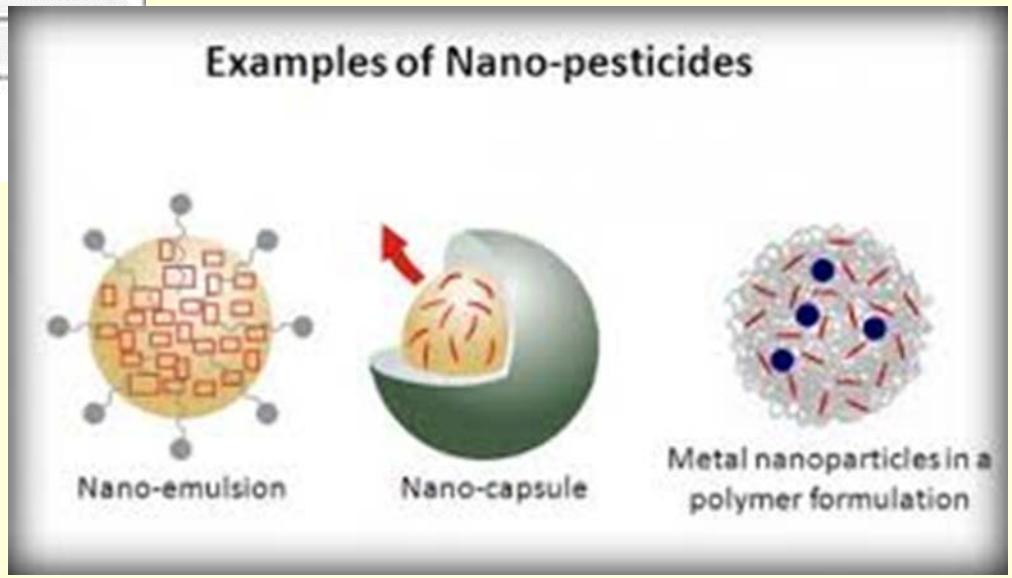
15” rows V2

Biological control tactics

Robotics

Nanotechnology in weed management





‘Omics’ in weed management

the plant journal

SEB Society for Experimental Biology

The Plant Journal (2014) 78, 865–876 doi: 10.1111/tpj.12514

RNA-Seq transcriptome analysis to identify genes involved in metabolism-based diclofop resistance in *Lolium rigidum*

Todd A. Gaines[1,2,*], Lothar Lorentz[2], Andrea Figge[2], Johannes Herrmann[2,3], Frank Maiwald[4], Mark-Christoph Ott[4], Heping Han[1], Roberto Busi[1], Qin Yu[1], Stephen B. Powles[1] and Roland Beffa[2]

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Received 15 October 2013; revised 10 March 2014; accepted 13 March 2014; published online 22 March 2014.

*For correspondence (e-mail todd.gaines@colostate.edu).

SUMMARY

Weed control failures due to herbicide resistance are an increasing and worldwide problem that significantly affect crop yields. Metabolism-based herbicide resistance (referred to as metabolic resistance) in weeds is not well characterized at the genetic level. An RNA-Seq transcriptome analysis was used to find candidate genes that conferred metabolic resistance to the herbicide diclofop in a diclofop-resistant population (R) of the major global weed *Lolium rigidum*. A reference cDNA transcriptome (19 823 contigs) was assembled and assigned putative annotations. Global gene expression was measured using Illumina reads from untreated control, adjuvant-only control, and diclofop treatment of R and susceptible (S). Contigs that showed constitutive expression differences between untreated R and untreated S were selected for further

diclofop resistance.

Keywords: transcriptomics, next-generation sequencing, herbicide metabolism, diclofop-methyl, herbicide resistance, transcriptional markers, *Lolium rigidum*.

INTRODUCTION

Weed control in modern cropping systems is vital to protect crop yields, maintain profitable farming, and meet global food demands. Herbicides are major tools to control weeds and weed control failure caused by herbicide resistance is an increasing and significant problem worldwide (Heap, 2013). The evolution of herbicide resistance has rapidly occurred when large and genetically variable weed populations have been subjected to intensive herbicide selection (reviewed in Powles and Yu, 2010). While in many cases target-site-based herbicide-resistance mechanisms endow resistance only to a selecting herbicide chemistry/mode-of-action, the greatest threat is posed by metabolic resistance mechanisms, as there can be resistance across diverse herbicide classes. Metabolic resistance, while evident in several species, has been documented repeatedly in the important grass weed *Lolium rigidum*. Since first apparent (Heap and Knight, 1986), subsequent studies have established that herbicide cross-resistance in *L. rigidum* involves enhanced rates of herbicide metabolism that can be reversed *in vivo* by known

RNAi technology is an example

The key to herbicide resistance management: Many little hammers

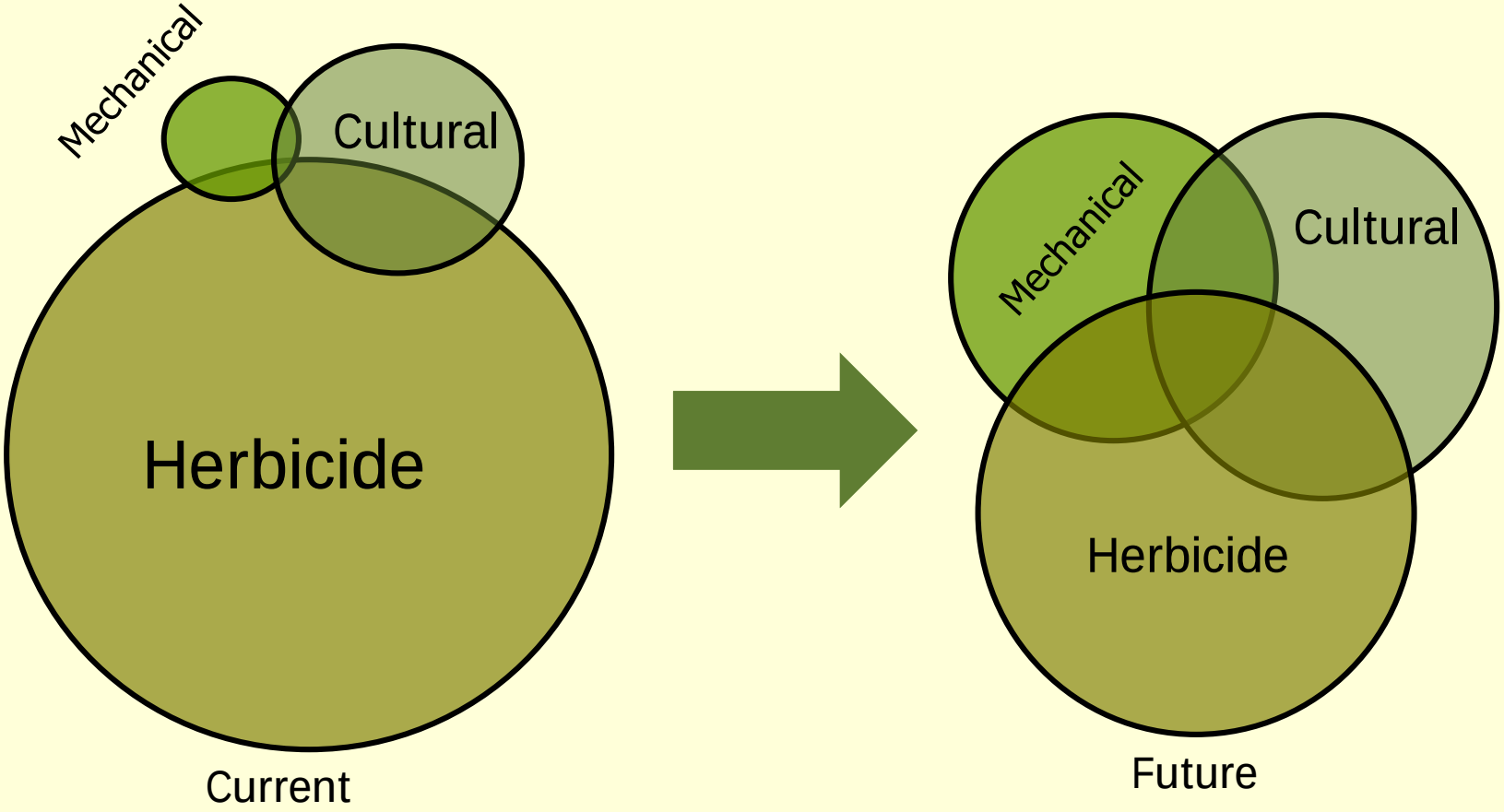

Seedbed prep tillage


Cover crops

Post-plant tillage


Field border management

“Ideal” Integrated Weed Management



Question

Will growers adopt more diversity in herbicide-resistant weed management programs **before** resistance in fields reaches levels that decrease farm profits?

1. Yes
2. No

Conclusions

- Diversity means adopting weed management tactics designed to address field-specific problems
- Diversity means that weed management must include long-term planning using many tactics based on field scouting
- Diversity means that individual growers recognize weed escapes and use multiple tactics to achieve control
- Diversity means that action is taken immediately

Call to Action

- Use scouting of individual fields to integrate biological, mechanical and cultural tactics to increase weed management diversity
- Develop public and private programs to control weed escapes prior to seed maturity thus improving weed seedbank management and reducing herbicide-resistant weed population densities
- Incentivize innovation in non-chemical weed management practices

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Rethinking Education and Outreach for Successful Herbicide Resistance Management

Amy Asmus and Jill Schroeder

Asmus Farm Supply, Inc and USDA/ARS/OPMP

September 10, 2014





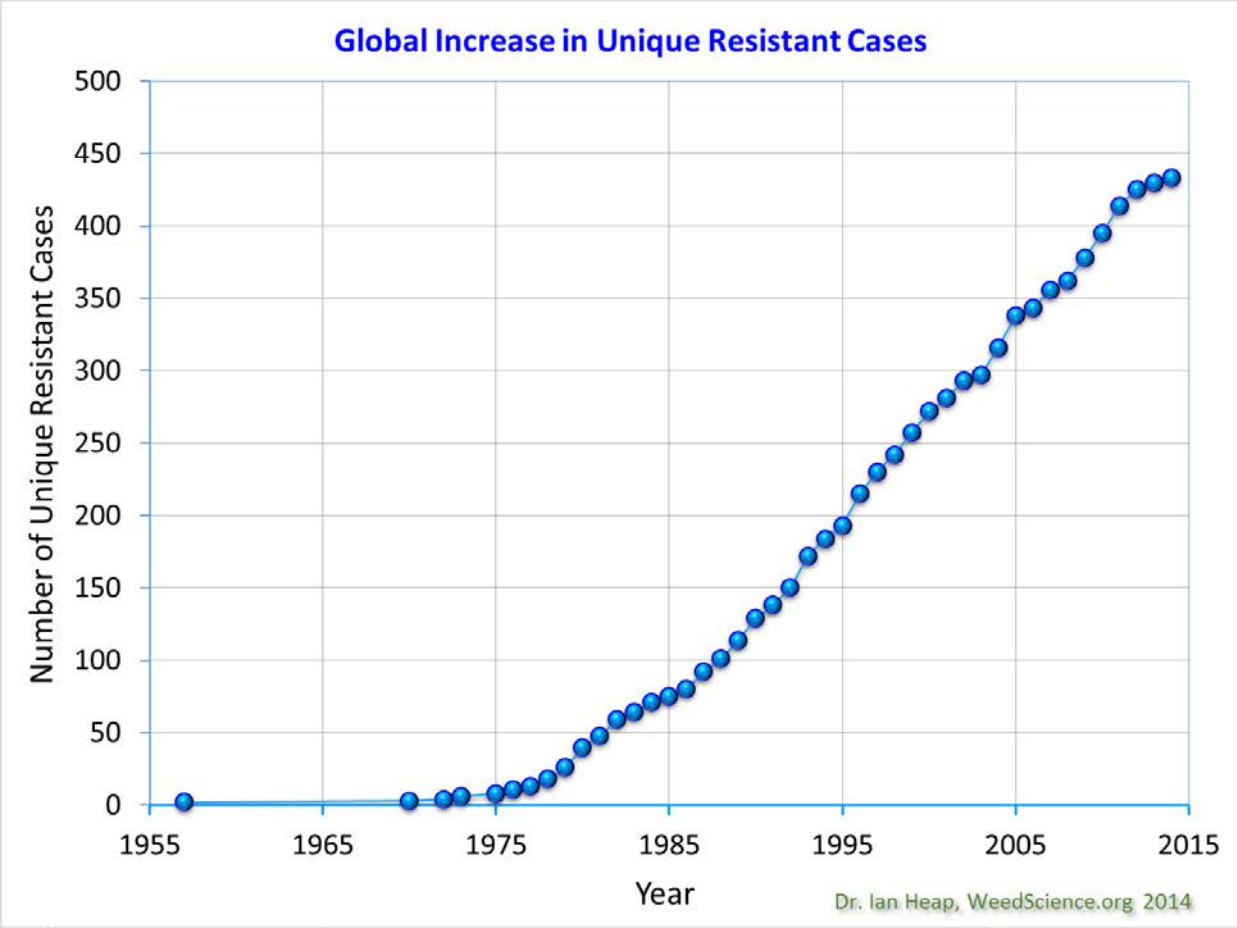
What is needed for success?

- Recognize that producers have intimate knowledge of their operation.
- Recognize that operations and issues vary greatly
  - Across management systems
  - Across land ownership
  - Across funding of operation (self vs bank loans)
  - Across regions (climate zones)

What is needed for success?

- Clear communication
  - Producers/advisors have access to many information sources.
    - Whose message is best for my operation?
    - How do I sift through all that internet content?
  - Communication is a two-way street!

Current approaches are not working!



Goals for education

- Need to consider goals for what must be tackled
  - Nationally
  - Locally

Action Item - Nationally

- Credible, science-based information on herbicide resistance MUST be delivered by all.
- ***OUR MESSAGE MUST BE CONSISTENT AND SCIENCE BASED!***

Question

- Should WSSA coordinate any/all of these programs to identify consistent messaging of HRM that would serve all commodities including aquatics and non-crop environments?

  1. Branded marketing program for HRM
  2. Endorsement for marketing programs already in place
  3. Endorsement for advisors trained in RM
  4. All of the above
  5. None of the above

Action Item - Nationally

- **Certification programs, licensing organizations, industry, associations, and ANY individual who provides information to decision makers must complete HRM training.**

Proposed Actions

- Establish partnerships to include HRM training materials by groups offering certification or licensing.
- Establish partnerships to develop a web portal for REVIEWED science based materials.
- Establish partnerships to TRAIN advisors throughout industry.

Question

What is your primary source of information on HRM?

1. University extension
2. Certified advisors/retailers
3. Manufacturers
4. Internet and/or media
5. Other

Question

Who is the primary source of information on HRM for growers?

1. University extension
2. Certified advisors/retailers
3. Manufacturers
4. Internet and/or media
5. Other

We are ALL educators!

- **Growers**
- Consultants
- Retailers
- Industry representatives
- Pesticide applicators
- Commodity organizations
- Environmental organizations
- Press
- Federal and state government agencies
- University research, teaching and extension
- ……

What is needed for success locally?

- Critical evaluation of traditional education
  - Understand audience
    - Communication must be clear and two-way!
  - What communities influence the decisions made by growers and how can they be engaged in solutions?
  - Consider ALL technologies for HRM
    - How do they fit with local production practices
    - How do they address specific weed problems
  - What are the costs vs. benefits for implementing HRM?

Action Items - locally

- **All** advisors will acquire and document training in HRM
- Advisors will make use of only science-based information.
- The production community will collaborate to adapt BMPs for local production systems.
- Economists and Extension specialists will collaborate to develop local cost/benefit information.

Please pause and consider

- What is YOUR role and obligation in education and outreach?
  - Who is your community and collaborators?
  - How can you improve your message?

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Carrots and Sticks: Incentives and Regulations for Herbicide Resistance Management and Changing Behavior

Michael Barrett, John Soteres and David R. Shaw
University of Kentucky, Monsanto (retired) and Mississippi State University

September 10, 2014





Question

Who should offer incentives for diversifying weed management programs and practicing HR BMPs??

1. Federal government agencies
2. Industry
3. Commodity Organizations
4. Someone else, not the above
5. Incentives should not be offered for this

Why Incentives?

- Because they can work!
- Because they can move the needle on adoption of BMPs

http://edcohealthinfosolutions.com

Why Incentives?

- Examples already given of successful programs (Boll weevil) where incentives helped
- Adoption of soil conservation practices clearly tied to incentives
- The Monsanto “Roundup Ready Plus” program has encouraged the use of soil applied herbicides

Incentive Caveats

- Temporary – not a subsidy
- Do not guarantee adoption – It is important to target to those farmers where an incentive will make a difference

Action Item: Government should promote:

- Non-chemical weed management
  - Cover crop use
  - Appropriate tillage
- Monitoring
  - Scouting before and and after application
  - Reporting and mitigation of resistance
- Diversity of Herbicide Use
  - Weed management plans
  - Herbicide use patterns?

Action Item: Government should:

- Ensure conservation compliance requirements minimize unintended disincentives to manage resistance
- Adapt crop insurance programs to incentivize adoption of HRM
- Incorporate HRM into good farming practice requirements for crop insurance claims

Action Item: Industry should:

- Use incentive programs that encourage diversity
  - Expand rebate programs to include other HRM practices such as rotating MOAs
- Use incentives with effective premixes – overlapping spectrum of MOAs at effective and full rates of application
- Incentivize staff and the entire supply chain to promote resistance management – both train and reward

Action Item: Commodity Groups

- Should help organize and incentivize the development of area-wide grower directed resistance management programs.

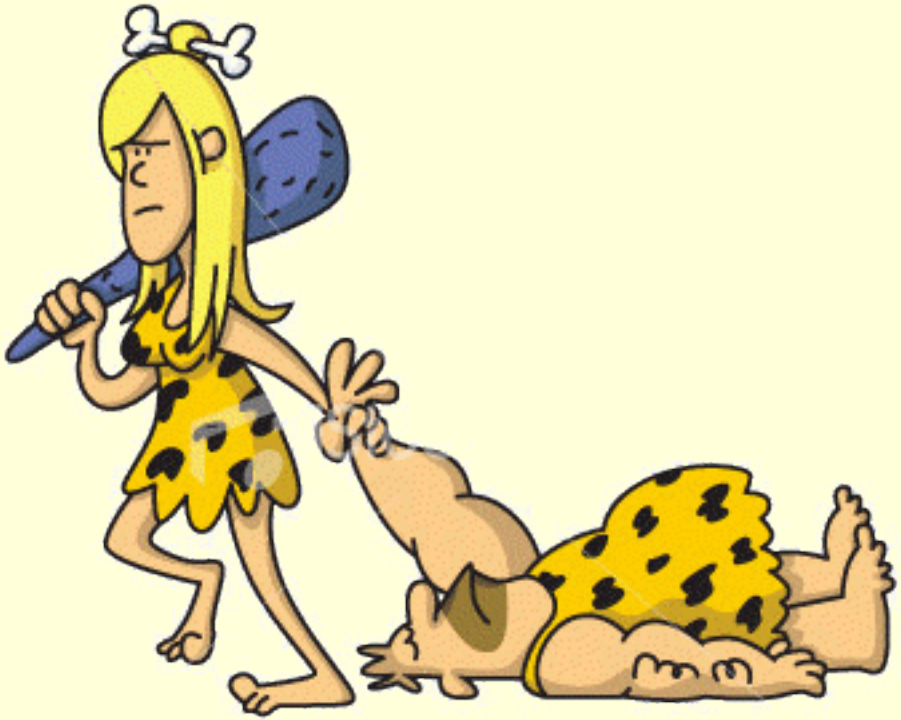
How much will it cost?

http://news.softpedia.com

- Incentives must be temporary – demonstrate the advantages to overcome “hurdles’
- But, must be a strong enough inducement
- Must have clear rules for participation
- Impact needs to be measured

The Big Gorilla

- Regulation to force behavior!



http://www.manataka.org

http://www.thesun.co.uk

Federal Agencies

- USDA – Animal and Plant Health Inspection Service
- EPA – Office of Pesticide Programs

EPA-OPP is Already Involved in Pest Resistance Management

- Insect refuges in BT crops
- Monitoring and surveying for BT lack of performance
- Herbicide resistance reported to agency under FIFRA section 6(a)(2) – “Adverse Effects Reporting”

Question

Could EPA-OPP dictate herbicide use for proactive herbicide resistance management, restricting the use of products – rates or frequency of application?

1. Yes
2. No

I am no lawyer but, yes - of course!

- Herbicides and other pesticides have these restrictions on their labels already for environmental or other reasons.

Why not do this?

- Difficult and/or expensive to enforce
  - And, it only applies to new labels and registration review
- Reduces local adaption and flexibility – there is no universal solution
- Could remove an otherwise effective weed management tool
- Growers do not like to be told what to do – this approach could be counterproductive

But, EPA-OPP can take proactive measures by insuring that the MOA and resistance management information are included on labels

- These are voluntary now – but EPA-OPP could move to make them mandatory if needed for full compliance

EPA-OPP Action Items:

- Require uniform MOA and resistance management labeling (the community needs to take this on as an action item too)
  - There are ways to indicate MOA on containers outside of the label – advertising and informational material.
- Use of full label rates
- Educational programs to explain effective MOAs and chemistries in mixtures
  - Is there a way to easily communicate this?

What about actions on other proactive label instructions?

- EPA-OPP could question:
  - Multiple (3-4) applications of a single product.
  - Reduced rates in mixtures compared to those in single products.
  - Use of less than full label rates. Should full rates be required?

What about reactive regulations?

EPA-OPP Action Items:

- Require scouting before and after herbicide application
- Require a registrant to establish an active monitoring and mitigation program for new resistance cases

Regulation can be a Good Thing

- Regulatory actions by EPA-OPP show it is serious about HRM and is willing to take steps to combat its evolution and spread.
- The threat of **credible** regulatory action has been shown to encourage participation in voluntary programs.

Other Regulation Action Items:

- A requirement for weed management plans drawn by certified advisors for participation in Federal Programs.
  - USDA conservation programs such as the Environmental Quality Incentive Program (EQIP) and Conservation Stewardship Program (CSP) should provide stronger herbicide resistance management plan development and implementation incentives
- Regulations to prevent the movement of resistant weeds across state borders.
  - National Plant Board, Seed Laws, Noxious Weed Lists

Question

Would regulations have made a difference in preventing, or at least slowing, the development of widespread ALS-inhibitor or glyphosate resistance?

1. Yes
2. No
3. I don’t know

Comments?

EPA's Perspective on Resistance

Herbicide Resistance Summit II

Jack Housenger
Director, Office of Pesticide Programs
U.S. Environmental Protection Agency

Palmer amaranth infesting cotton. Photo credit: Larry Steckel, UT

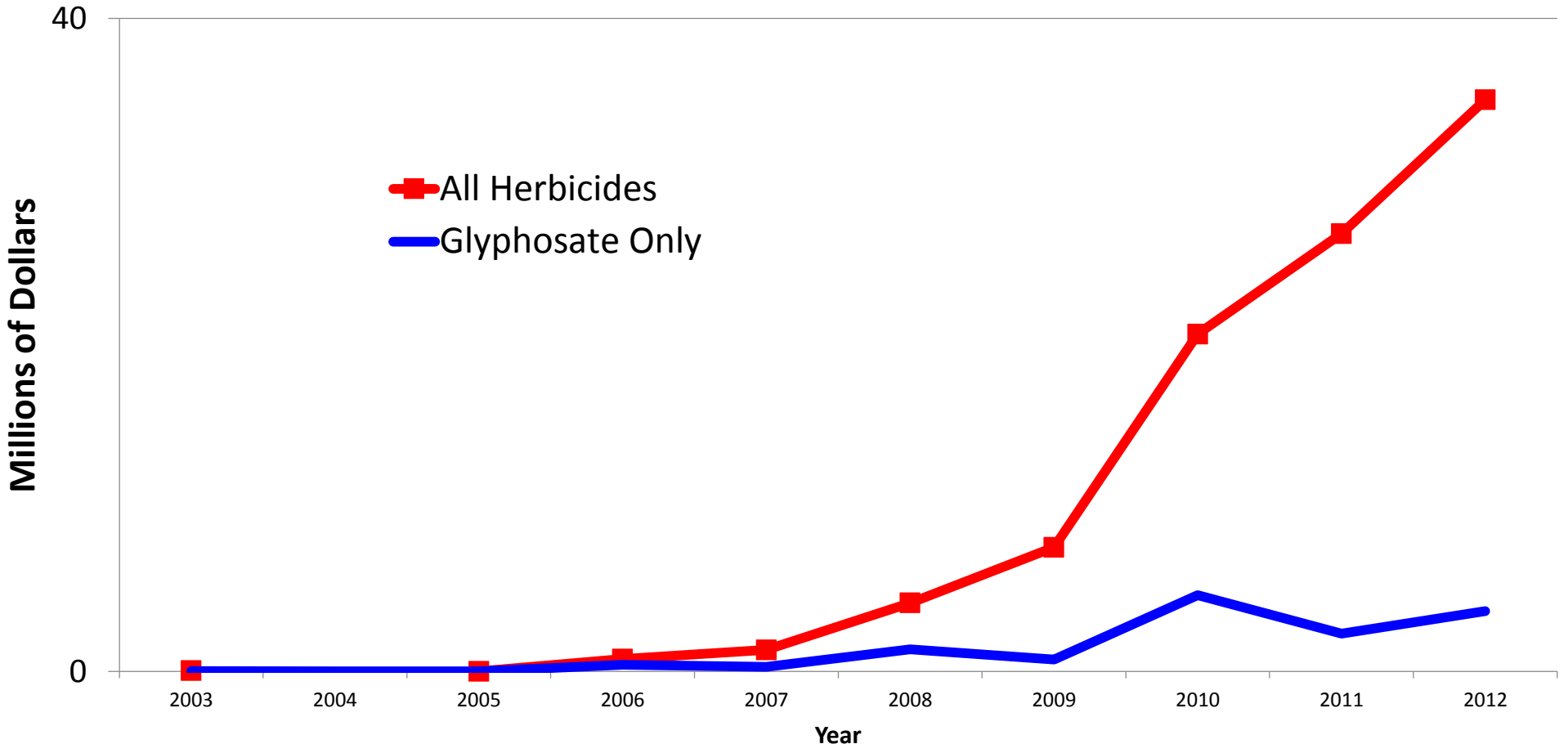
Outline

- Introduction
- Impacts
- Different Approaches to Managing Resistance
- Legal Authority Under FIFRA
- Aspects for Consideration in Successful Weed Resistance Management Framework
- Aspects for Consideration in Growers and Consultants Roles in Resistance Management
- Aspects for Consideration in Registrants Roles in Resistance Management
- Some Roles for Other Stakeholders
- EPA's Developing Role
- Label – Proposed Resistance Management Elements
- Terms of Registration - Proposed Resistance Management Elements
- Next Steps

Introduction

- EPA's goal is to extend the useful life of chemicals used for pest control by slowing the development of resistance to fungicides, herbicides, and insecticides
- Weed resistance is a complicated issue
  - Competing interests and multiple stakeholders
  - Economic issues
  - Social issues
  - Everyone is a stakeholder, including EPA, and part of the solution

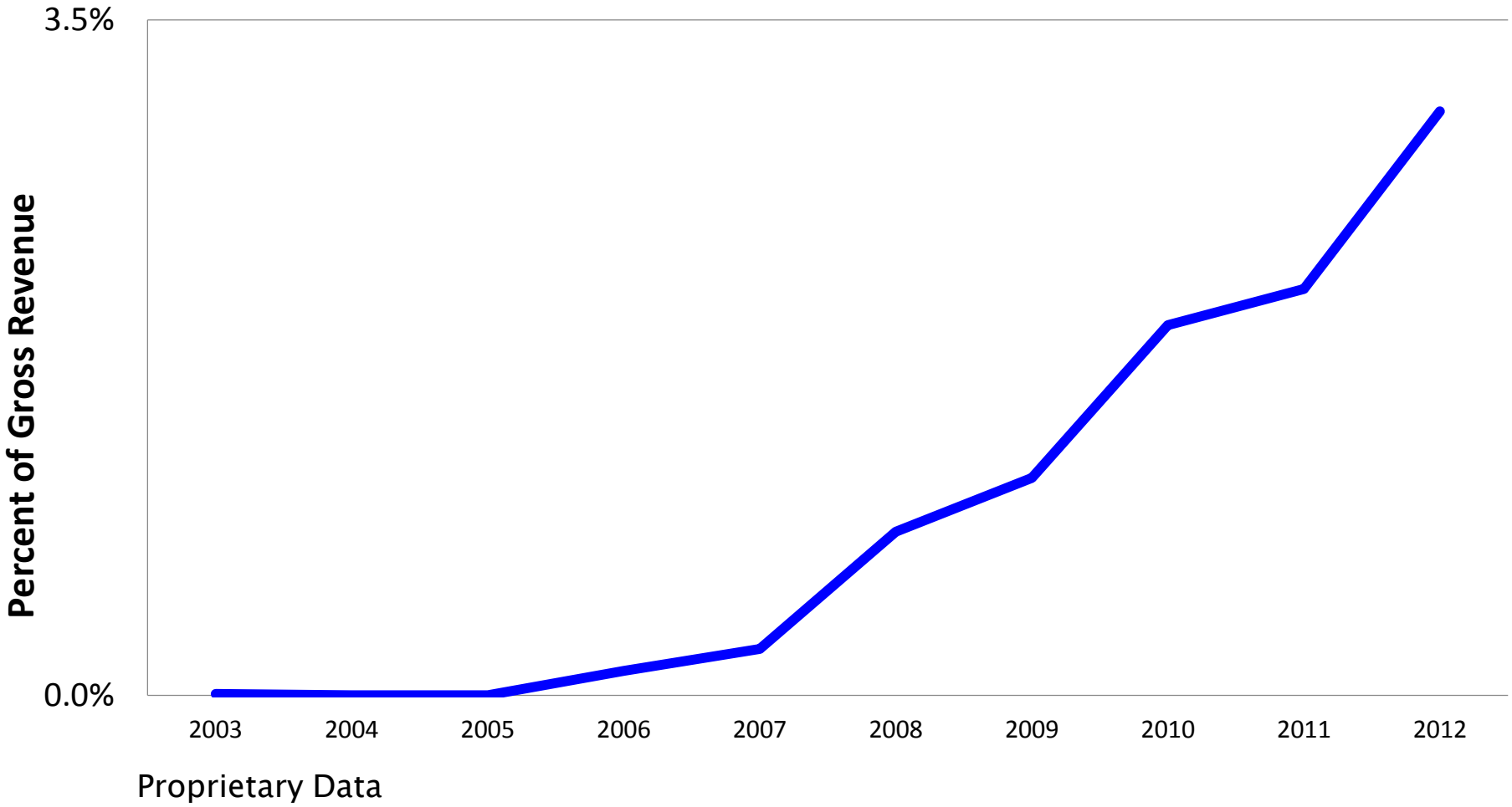
Control of Palmer amaranth in Georgia Cotton Increased Cost



Proprietary Data

Control of Palmer amaranth in Georgia Cotton

Herbicide Costs as Share of Gross Revenue Expenditures



Different Approaches to Managing Resistance

- Fungicides and Insecticides Registrants - resistance requirements
  - Registrants have specified the number of applications and require rotation to a different MOA to manage resistance
- Plant Incorporated Protectants Agency and Registrants - resistance requirements
  - Monitoring and reporting are required of grower/consultant and company
  - IPM stewardship plans are required
  - Thresholds of damage trigger a remediation plan
- Herbicides - no resistance requirements on labels and multiple resistance problems
  - Some companies have voluntary programs to promote resistance management
- Goal is to have effective resistance management and maintain flexibility for growers

Legal Authority Under FIFRA

- USDA/APHIS/Biotechnology Regulatory Services makes deregulation decision on genetically modified crops
- FIFRA is a risk and benefit statute
  - Risk of resistance may be considered as part of the regulatory decision
- OPP licenses the pesticide for use on genetically modified or conventionally bred crops
  - Establishes terms and conditions of the registration with the registrant
  - Approves product label for users (growers, applicators, and consultants)

Aspects for Consideration in a Successful Weed Resistance Management Framework

- Involves all stakeholders
- Allows flexibility to local conditions
- Growers utilize Best Management Practices, e.g. those developed by WSSA and HRAC
- Promotes early detection and containment
- Involves open communication among all parties
  - Education and training programs are readily available to growers
  - Materials provide a consistent approach that reflects the latest information
  - Communication about where resistance is occurring
- Extends the useful life of the pesticide and preserves the technology

Aspects for Consideration in Growers' or Consultants' Roles in Resistance Management

- Growers and consultants must be proactive
- Identification of "likely resistance"
  - Scouting before application for identification and growth stage
  - Scouting after herbicide application to look for poor performance or likely resistance
- Investigation and follow up for cases of "likely resistance"
- Remediation of the problem
- Communication to registrant or representative when problems are found
- Utilize education and training materials (e.g. from registrant, WSSA, Extension, etc)

Aspects for Consideration in a Registrants' Roles in Resistance Management

- Registrants must be proactive
  - Registrant must follow terms and conditions of registration
- Labels must include MOA and generally agreed upon best practices
- Establish and implement stewardship plan which includes resistance management elements designed by the registrant
- Communication to growers/stakeholders when problems are found
  - Report to growers/stakeholders (facilitate behavior change)
  - Report to EPA (are regulatory actions working)
- Develop educational materials and promote adoption of BMPs
- Develop and implement remediation plan when likely resistance is found
- Work to develop rapid diagnostic tests for resistance

Some Roles for Other Key Stakeholders

- Some other key stakeholders include
  - HRAC
  - WSSA
  - Consultants
  - Grower groups
  - NGOs
  - Research and Extension
  - Federal and State Partners
- Key Activities
  - Education and promote adoption of BMPs
  - Develop diagnostic tests
  - Alternative methods of weed control including non-herbicidal methods
  - Provide independent assessments
    - Occurrence of resistance
    - Success of remediation plan

EPA's Emerging Role

- EPA seeks more collaborative interactions on resistance management with societies, RACs, consultants, extension, NGOs, registrants, researchers, state and federal partners
- Gain an understanding of resistance management that can be applied to insects, plant pathogens, and weeds
- Common understanding of resistance and its causes
  - For example a better appreciation what each group can contribute towards managing resistance
- EPA will require specific measures to address weed resistance on all new registration actions for herbicide resistant crops
- Utilize the registration review process to strengthen resistance management for pesticides including glyphosate

Label – Proposed Resistance Management Elements

- Because early identification of problems is critical to managing resistance the following items will be placed with the directions for use so that they are clearly visible
- User or consultant:
  - Scout before application to identify weed and size
  - Scout after application determine if application was effective
  - Report of poor performance / likely resistance to registrant or their representative

Terms of Registration - Proposed Resistance Management Elements

- Develop a Stewardship Program
- Develop Training and Education materials
- Investigate cases of non-performance
  - Use Norsworthy et al. criteria for determining likely herbicide resistance
- Develop a Remediation Plan for use if resistance is suspected
  - Registrant must take immediate action to control likely resistant weeds
  - Thorough follow up to make sure problem is addressed
- Annual reporting of likely and confirmed resistance to EPA
  - Enough information to describe nature and extent of infestation
  - Early notification is important
  - Separate from 6(a)(2) reporting (adverse effects) but this would report confirmed resistance - too late
- Reporting of likely and confirmed resistance to other stakeholders
- Work to develop a rapid diagnostic system for resistance

Next Steps

- EPA will require specific measures to address weed resistance on all new registration actions for herbicide resistant crops
- Pending registration actions
  - 2,4-D resistant corn and soybean
  - Dicamba resistant soybean and cotton
- Pending registration review
  - Glyphosate

Herbicide Resistance Summit II

September 10, 2014





Call to Action

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To My Fellow Farmers

- Center of weed management community
- Final decision of programs implemented
- More to gain/more to lose than anyone
- Get information from a variety of sources

To My Fellow Farmers

- Increase our understanding of resistance
- Carefully select information sources
- Pay more attention to details
  - Post treatment monitoring
  - Controlling escapes
  - Post harvest control when needed
- Take a more long-term view of operations

University Scientists

- Continue work on causes and remedies
  - We still have a growing problem
- Work on message delivery
  - Work with social scientists
  - Particular attention to economics
- Think outside the box
  - Non chemical approaches

Government Agencies

- ARS – area-wide programs
- APHIS – resistant species = new pest
- NIFA – grant programs not one-time need
- ERS – long-term profitability – urgent need
- NRCS – conservation program incentives
- RMA – crop insurance incentive?
- OPMP – organization and communication
- EPA – regulatory challenges

Consultants

- Stay current
  - New technology
  - Local trends in resistance problems
- Lead local educational efforts
- Growers need long-term plans
- Independence is important
- Certification also important

Commodity/Farm Organizations

- Form strategic alliances
  - Across commodities and regions
  - Influence on legislation and ag agencies
- You can make things happen
- Help organize grower communities

Input Supply Network

- Final and most influential information
  - Current
  - Credible
  - Scientifically sound
  - Non-biased
- Stay current on technology and local pests
- Maintain access to all products

Industry

- Continue technology development
- Integrate more diversity into marketing
  - Cannot do the same thing every year
- Industry-wide educational efforts
- Incentives for good stewardship
- Consider partnering with government on incentive programs

Professional Societies

- Provide overall organization
- Make appropriate information available
  - Ensure validity of messages
- Ensure platform for diverse opinions
- Encourage open and full discussion

Public Interest Groups

- Consider all sides of the issue
- Offer positive input
- Stay engaged

Agricultural Press

- Provide information from diverse sources
- Fact check sources
  - Scientifically sound and accountable
- Help educate farm community
- Publicize successes

We have an Opportunity

- An opportunity to work together to get HR under control
- May be the Opportunity of a Lifetime

We have an Opportunity

- An opportunity to work together to get HR under control
- May be the Opportunity of a Lifetime
- To take advantage of the opportunity of a lifetime, we must act during the lifetime of the opportunity