Considering the socio-economics of resistance management decisions

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Waite Campus, Adelaide

SUSTAINABLE AGRICULTURE FLAGSHIP
www.csiro.au
What are farmers managing?

A weed

Dynamic multi-species weed populations

Herbicide resistance – plants / risks

A finite herbicide resource

A renewable herbicide resource – with herbicide gains and losses

A potentially exhaustible herbicide resource
What are farmers managing?

Farm businesses with crops, pastures, people and external forces

A weed

Dynamic multi-species weed population

Herbicide resistance

A finite herbicide resource

A renewable herbicide resource with gains and losses
Economics 101: Scarcity of effective new herbicides plus demand will lead to price rises?
No major increase in herbicide prices - unlike labour, fuel and fertiliser.

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No help from the ‘invisible hand’ of economics

The growing cost of herbicide resistance is not just about weeds

- Trend to earlier crop seeding times (dry) – need for flexibility
- Increasing cost of complexity for farmers (value of simplicity)
- Increasing importance of farm scale
- Increasing labour costs
- Widening crop row spacings
- Expanding no-tillage/conservation agriculture
- Increasing cropping intensity

- New regions facing resistance
And the cost of weeds is much more than yield loss (e.g. Western Australian ryegrass)

1998-2003:
Most common ryegrass density was <1 plant/m² (resistant or susceptible). 17% had >10 plants/m²

2010:
Only 5% paddocks with more than 10 plants/m²

In farmer fields (WA): no relationship between ryegrass resistance status and weed density at harvest

2014:
National farmer survey suggests only 16% with >10 plants/m² RG

(Owen et al 2013; Llewellyn et al 2001; 2009; Western Australian grain growers).
Optimal herbicide use in a period (myopic)

Adapted from: Miranowski & Carlson
Optimal pesticide use (considering longer-term resistance costs)

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Optimal pesticide use (considering longer-term resistance costs)

Selection pressure

Adapted from: Miranowski & Carlson

Laxminarayan (ed) 2002
So what are we expecting farmers to believe:

• Believe that resistance can happen and have a cost

• Believe that resistance can be delayed or prevented

• Believe that it is under their control

• Believe that conserved susceptibility will have a substantial value in the future
Perceived cost of resistance varies: reduction in willingness to pay for cropping land

Perceived cost of resistance varies: reduction in willingness to pay for cropping land (WTP) among WA grain growers. Llewellyn et al. 2002
Harrington weed seed destructor

$20/ha
Believe that resistance will happen (and when)

Lots of understanding of potential resistance
Lots of understanding about resistance mechanisms

Specifics Vs General Principles
Vs Empirical Probabilities

“Advisers are used to making do with incomplete information”
- Used on thousands of farmer paddocks
- Usually used to predict risk of applying extra N (probability of profit)
- Provides a forecast under highly uncertain variable scenarios
- Presents ‘best-bet’ recognises risk, uncertainty
RESISTANCE

PROPHET

- Hundreds of known field histories with measured resistance status
- Farmers familiar with probabilities
- Research models already exist
- Advisers and farmers using their own ‘rules of thumb’

What is the likelihood of resistance within X applications if I keep relying on this herbicide?
Believe that what they do will matter

Mobility – 42% of farmers expect glyphosate resistance to be gained by pollen or seed movement from neighbouring fields within 10 years

Technological optimism- confidence in new technology being available

In 2000: 52% expected new selective herbicide type in 5 years
In 2014: 69% expect new selective herbicide type in 10 years;
59% expect new knockdown able to control glyphosate resistant weeds in 10 years
Chance to reset resistance clock?

Photo: P. Newman
So when does investing in herbicide conservation look attractive?

In many cases of common resistance (high risk weeds and herbicides):

- Incentive for long-term conservation as an objective is not clear (Pannell & Zilberman 2001)
- Exploit finite susceptibility to maximise Net Present Value before moving to next best option

As commonly practiced by farmers... *eg clethodim resistance*

1998 <1%; 2003 8%; 2010 65%

But economic cases for investment in conservation exist.
Where investment in conservation has been shown to pay:

- Where number of effective applications can be extended
- Where cost of conservation is low
- Where potential cost of resistance is high
- Where likelihood of resistance is high and certain if no action

Weersink et al 2005 / Mueller et al 2005 (glyphosate studies)
Where investment in conservation of susceptibility has been shown to pay:

- Where number of effective applications can be extended
- Where cost of conservation is low
- Where potential cost of resistance is high
- Where likelihood of resistance is high and certain if no action
A tool to evaluate the profitability of ryegrass control methods in the no-till broadacre cropping systems of the Southern Australian grainbelt, on the short, long-term and at paddock scale, in 3 simple steps:

1. Define your paddock  
2. Build your strategy  
3. Compare your results

START

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## 2. BUILD Strategy

### Choose enterprise and control options:

<table>
<thead>
<tr>
<th>Yr 1</th>
<th>Yr 2</th>
<th>Yr 3</th>
<th>Yr 4</th>
<th>Yr 5</th>
<th>Yr 6</th>
<th>Yr 7</th>
<th>Yr 8</th>
<th>Yr 9</th>
<th>Yr 10</th>
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</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Barley</td>
<td>Canola</td>
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<td>Wet</td>
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<td>Dry</td>
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</tr>
</tbody>
</table>

- **Time of sowing**
- **Soil preparation**
- **Knock-down / Double-knock**
- **Pre-emergent herbicide**
- **Establishment system**
- **Crop seeding rate**
- **Post-emergent herbicide 1**
  - Yr 1: Triaz + Gp A
  - Yr 2: Triaz + Gp A
  - Yr 3: Triaz + Gp A
  - Yr 4: Triaz + Gp A
  - Yr 5: Triaz + Gp A
  - Yr 6: Triaz + Gp A
  - Yr 7: Triaz + Gp A
  - Yr 8: Triaz + Gp A
  - Yr 9: Triaz + Gp A
  - Yr 10: Triaz + Gp A
- **Grazing intensity**
- **Spring options**
  - Swathe
  - Others
- **Harvest options - Crops**
  - Narr+B.
  - Narr+B.
  - Narr+B.
  - Narr+B.
- **Mature ryegrass setting seed**
  - Yr 1: 37
  - Yr 2: 13
  - Yr 3: 14
  - Yr 4: 25
  - Yr 5: 8
  - Yr 6: 9
  - Yr 7: 3
  - Yr 8: 1
  - Yr 9: 1
  - Yr 10: 1
- **Seeds in soil next autumn (m²)**
  - Yr 1: 160
  - Yr 2: 143
  - Yr 3: 94
  - Yr 4: 95
  - Yr 5: 86
  - Yr 6: 57
  - Yr 7: 25
  - Yr 8: 10
  - Yr 9: 6
  - Yr 10: 21
- **Gross margin ($/ha)**
  - Yr 1: $189
  - Yr 2: $207
  - Yr 3: $453
  - Yr 4: $247
  - Yr 5: $207
  - Yr 6: $445
  - Yr 7: $255
  - Yr 8: $232
  - Yr 9: $193
  - Yr 10: $490

### Weed Control Expenses

- **User's options**
- **Mechanical**
- **Herbicides**
- **Competition**

### Income

- **Fodder**
- **Crops**
- **Sheep**

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**GROSS MARGIN ($/ha)**

- **$308**
- **on average**

**MATURE RYEGRASS (plants/m²)**

- **100**

**INCOME**

- **$600**

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**SCALES**

- **Fixed**
A note on developing weed management decision support for advisers?

Perceived value of a tool that can:

- Predict how a new weed management practice will affect the number of herbicide applications before resistance is likely (81% high value)
- Predict what next year’s weed population will be if the weeds are allowed to set seed in the current crop (92% high value)
- Predict how far and how quickly a patch of resistant weeds will spread under different management strategies (57% high value)

100 Australian farm advisors (2012)
Llewellyn, Kragt et al 2013 JAEP
RIRDC
A note on developing weed management decision support for advisers

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Value of decision support tool attributes:

- Reducing ‘set-up’ time from 6 to 3 hours more valuable than increasing the ‘accuracy’ of the tool from 70 to 90%.
- 2 categories of advisers: those that want detail; those happy with generalities
Summary

- Cannot rely on herbicide price signals to drive conservation behaviour (often the opposite)

- Need to be realistic about the economics and risk of investment in conservation: specific cases

- Need better understanding of the true economic costs & risks: increasingly large

- The call for ecological complexity in weed management faces the rising value of management simplicity

- Farming systems trends increasingly favour ‘silver bullets’-embodied technologies

- But analysis of weed management systems in whole farm context increasingly important
Thank you
The costs of resistance

Resistance leads to mainly management cost increases not yield losses due to weed competition.

An example with wild oats:

Single year economic weed control density threshold: 39 plants/m²

Dynamic economic model with multi-year weed seedbank: 6 seeds/m²

(Jones & Medd 2000).

Estimates: $28-$64/ha p.a. Conyza/Amaranth/Waterhemp


$45/ha p.a. Ryegrass (Weersink et al 2005)
# 1. DEFINE Paddock

## Main parameters

<table>
<thead>
<tr>
<th></th>
<th>Wheat</th>
<th>Barley</th>
<th>Canola</th>
<th>Legume</th>
<th>Hay</th>
<th>Silage</th>
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<td>10%</td>
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<td>Average area cropped</td>
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<td>2000</td>
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</tbody>
</table>

## Control options

### Knock-down herbicides
- Glyphosate: 6, 6, 4, 95%, 95%, 95%
- Paraquat: 8, 8, 6, 95%, 95%, 95%
- Glyphosate/Paraquat: 12, 12, 10, 100%, 100%, 100%

### Pre-emergence herbicides
- Trifluralin: 12, 12, 70%, 70%
- Group B: 5, 85%
- Sakura: 35, 90%
- Boxer Gold: 30, 85%
- Triazine: 10, 5, 70%, 50%

### Post-emergence herbicides
- Group A: 18, 10, 10, 70%, 60%, 40%
- Triazine: 8, 70%
- Triaz + Gp A: 14, 80%
- Glyphosate: 8, 85%
- Group B: 12, 95%, 65%

### More options...

- More prices...
- More options...

## Save Profile

- Paddock name: Default
- Your name: Susceptible

- SAVE LOAD: Resistant, Non-selective
- SAVE LOAD: Resistant, Gp. A B C
- CLEAR LOAD: Susceptible, Default
### More Options...

#### Crops

<table>
<thead>
<tr>
<th>Wheat</th>
<th>Barley</th>
<th>Canola</th>
<th>Legume</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>70</td>
<td>3</td>
<td>100</td>
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<tr>
<td>90</td>
<td>100</td>
<td>5</td>
<td>125</td>
</tr>
</tbody>
</table>

**Seeding rate**
- Standard: kg/ha
- High: kg/ha

**Harvest index**
- Wheat: 0.40
- Barley: 0.40
- Canola: 0.40
- Legume: 0.30

% of fodder yield relative to the above harvest index: 80%

Pre-emergents loss of efficiency when dry seeding: 10%

#### Pastures - 3rd consecutive year of sub-clover

**Grazing intensity**
- When standard: 4.5 DSE/ha, 80% management
- When high in spring: 6.5 DSE/ha, 95% management
- When hay is planned: 4.0 DSE/ha, 100% management
- When hay only is planned (no grazing): 2.0 DSE/ha, 100% management

**Hay production**
- 1.0 t/ha

#### Ryegrass control

**Plants (in crop/pasture):**
- No-till (knife-point): 40%
- Full cut (direct drill): 80%
- Topping - Cereals: 75%
  - Canola/Legumes: 75%
  - Pastures: 90%
- Swathing: 40%
- Swathing + spray: 90%

**Plants (crop/pasture sacrifice):**
- Green / brown manuring, mowing: 100%

**Seeds (harvest weed seed control):**
- Catch & chaff tramlining: 85%
- Catch & HSD or BDS: 85%
- Catch & burn: chaff cart dumps: 85%
- Catch & burn: narrow windrows: 85%
- Whole-paddock burning (residues): 60%
## 2. BUILD Strategy

### Choose enterprise and control options:

<table>
<thead>
<tr>
<th>Year</th>
<th>Yr 1</th>
<th>Yr 2</th>
<th>Yr 3</th>
<th>Yr 4</th>
<th>Yr 5</th>
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<th>Yr 7</th>
<th>Yr 8</th>
<th>Yr 9</th>
<th>Yr 10</th>
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<td>Canola</td>
<td>Wheat</td>
<td>Barley</td>
<td>Canola</td>
<td>Wheat</td>
<td>Wheat</td>
<td>Barley</td>
<td>Canola</td>
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<tr>
<td>Time of sowing</td>
<td>Delayed</td>
<td>+Delayed</td>
<td>Dry</td>
<td>Wet</td>
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<td>Wet</td>
<td>Dry</td>
<td>+Delayed</td>
<td>Dry</td>
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<td>Phosphate</td>
<td>Paraquat</td>
<td>Glyphosate</td>
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<tr>
<td>Knock-down / Double-knock</td>
<td>Triazine</td>
<td>Trifluralin</td>
<td>Triazine</td>
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<tr>
<td>Pre-emergent herbicide</td>
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<td>Trifluralin</td>
<td>Triazine</td>
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<td>2</td>
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<tr>
<td>Mature ryegrass setting</td>
<td>37</td>
<td>13</td>
<td>14</td>
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<td>8</td>
<td>9</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Seeds in soil next autumn (mt/ha)</td>
<td>160</td>
<td>143</td>
<td>94</td>
<td>95</td>
<td>86</td>
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</table>
## 2. BUILD Strategy

**Choose enterprise and control options:**

<table>
<thead>
<tr>
<th>Yr</th>
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</tr>
</tbody>
</table>

**Soil preparation**

- Glyphosate
- Trifluralin
- No-till
- Standard
- Narr+B.

**Knock-down / Double-knock**

- Glyphosate
- Triazine
- No-till
- Standard
- Narr+B.

**Pre-emergent herbicide**

- Glyphosate
- Triazine
- No-till
- Standard
- Narr+B.

**Establishment system**

- No-till
- No-till
- No-till
- No-till
- No-till
- No-till
- No-till
- No-till
- No-till
- No-till

**Crop seeding rate**

- Triaz + Gp A
- Triaz + Gp A
- Group B
- Group B
- Triaz + Gp A

**Post-emergent herbicide**

1. Triaz + Gp A
2. Triaz + Gp A
3. Group B
4. Group B
5. Triaz + Gp A

**Grazing intensity**

- 1
- 2
- 3

**Spring options**

- Swathe
- Others

**Harvest options - Crops**

- Cut+B.
- Narr+B.

**Mature ryegrass setting seed**

<table>
<thead>
<tr>
<th>Yr</th>
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**Seeds in soil next autumn (lm²)**

<table>
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<tr>
<th>Yr</th>
<th>Yr 2</th>
<th>Yr 3</th>
<th>Yr 4</th>
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<th>Yr 8</th>
<th>Yr 9</th>
<th>Yr 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>143</td>
<td>94</td>
<td>95</td>
<td>86</td>
<td>57</td>
<td>25</td>
<td>10</td>
<td>6</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

**Gross margin ($/ha)**

<table>
<thead>
<tr>
<th>Yr</th>
<th>Yr 2</th>
<th>Yr 3</th>
<th>Yr 4</th>
<th>Yr 5</th>
<th>Yr 6</th>
<th>Yr 7</th>
<th>Yr 8</th>
<th>Yr 9</th>
<th>Yr 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$207</td>
<td>$453</td>
<td>$247</td>
<td>$207</td>
<td>$445</td>
<td>$255</td>
<td>$232</td>
<td>$193</td>
<td>$490</td>
<td></td>
</tr>
</tbody>
</table>
### 2. BUILD Strategy

**Choose enterprise and control options:**

<table>
<thead>
<tr>
<th>Yr 1</th>
<th>Yr 2</th>
<th>Yr 3</th>
<th>Yr 4</th>
<th>Yr 5</th>
<th>Yr 6</th>
<th>Yr 7</th>
<th>Yr 8</th>
<th>Yr 9</th>
<th>Yr 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Barley</td>
<td>Canola</td>
<td>Wheat</td>
<td>Barley</td>
<td>Canola</td>
<td>Wheat</td>
<td>Wheat</td>
<td>Barley</td>
<td>Canola</td>
</tr>
<tr>
<td>Delayed</td>
<td>Wet</td>
<td>Dry</td>
<td>Wet</td>
<td>+Delayed</td>
<td>Dry</td>
<td>Wet</td>
<td>Dry</td>
<td>+Delayed</td>
<td>Dry</td>
</tr>
</tbody>
</table>

**Soil preparation**
- Glyphosate
- Paraquat
- Triazine

**Knock-down / Double-knock**
- Trifluralin
- Triazine

**Establishment system**
- Standard

**Crop seeding rate**
- Standard

**Post-emergent herbicide 1**
- Group B
- Group A
- Triaz + Gp A

**Post-emergent herbicide 2**

**Grazing intensity**
- W/o Spray
- W/o Spray

**Spring options**
- Swathe
- Others

**Harvest options - Crops**
- Others

**Mature ryegrass setting seed**
- 10
- 11
- 10
- 17
- 12
- 9
- 15
- 6
- 3
- 3

**Seeds in soil next autumn (m²)**
- 106
- 153
- 354
- 154
- 138
- 319
- 139
- 55
- 32
- 118

**Gross margin ($/ha)**
- $197
- $209
- $500
- $246
- $205
- $482
- $247
- $229
- $192
- $484

---

**GROSS MARGIN ($/ha)**

- $317

**MATURE RYEGRASS (plants/m²)**

**WEED CONTROL EXPENSES**

- User's options
- Mechanical
- Herbicides
- Competition

**INCOME**

- Fodder
- Crops
- Sheep

---

**SCALES Fixed**
3. COMPARE Results

SUMMARY & ECONOMICS  POPULATION & SEED BANK  YIELDS & COMPETITION  DATA TABLES

Current $308 /ha /year

Susceptible, Default - with B

Current paddock and strategy

<table>
<thead>
<tr>
<th>Crops</th>
<th>Yields (t/ha)</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>2.0</td>
<td>-2%</td>
</tr>
<tr>
<td>Barley</td>
<td>2.2</td>
<td>-10%</td>
</tr>
<tr>
<td>Canola</td>
<td>1.3</td>
<td>-4%</td>
</tr>
<tr>
<td>Legume</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

Effect of weed density on crop yields

Average yield penalty on crops because of ryegrass:

-1%  -2%
RIM
- Assumes ‘average’ years and ‘average’ weed
- Focused on primary grass weed only
- Does not optimise

LUSO (Land Use Systems Optimiser)
- Based on RIM
- Optimises
- Can include variability of seasons and weed characteristics etc
1. Understand the biology of the weeds present.
2. Use a diversified approach toward weed management focused on preventing weed seed production and reducing the number of weed seed in the soil seedbank.
3. Plant into weed-free fields and then keep fields as weed free as possible.
4. Plant weed-free crop seed.
5. Scout fields routinely.
6. Use multiple herbicide mechanisms of action (MOAs) that are effective against the most troublesome weeds or those most prone to herbicide resistance.
7. Apply the labeled herbicide rate at recommended weed sizes.
8. Emphasize cultural practices that suppress weeds by using crop competitiveness.
9. Use mechanical and biological management practices where appropriate.
10. Prevent field-to-field and within-field movement of weed seed or vegetative propagules.
11. Manage weed seed at harvest and after harvest to prevent a buildup of the weed seedbank.
12. Prevent an influx of weeds into the field by managing field borders.
WSSA Recommendations 2012 (Norsworthy et al 2012)

1. Reduce the weed seedbank through diversified programs that minimize weed seed production.
2. Implement a herbicide MOA labeling system for all herbicide products and conduct an awareness campaign.
3. Communicate that discovery of new, effective herbicide MOAs is rare and that the existing herbicide resource is exhaustible.
4. Demonstrate the benefits and costs of proactive, diversified weed-management systems for the mitigation of HR weeds.
5. Foster the development of incentives by government agencies and industry that conserve critical herbicide MOAs as a means to encourage adoption of best practices.
6. 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.
7. Identify and promote individual BMPs that fit specific farming segments with the greatest potential impact.
8. Engage the public and private sectors in the promotion of BMPs, including those concerning appropriate herbicide use.
9. 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.