Understanding the economic trade-offs in resistance management

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Understanding the economic trade-offs in resistance management

Russell Gorddard
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Focal question

How much should producers spend to delay the build up of resistance?
Resistance management presents complex economic trade-offs

- Economic intuition may be too simple and miss important trade-offs

- Optimisation models may mislead
  - black box complex relationships
  - include poorly understood and uncertain relationships

- Need simple models that guide intuition
A steady state model of the benefits and costs of a resistance management (RM) with resistance build up.

Annual Returns $/yr

\[ NPV = (V - c(T)) \times T \]

Time to resistance build up
Benefits and costs of a delaying resistance one year

\[ NPV = (V - c(T))T \]

\[ \frac{\partial NPV}{\partial T} = (V - c(T)) - c'(T)T \]

Marginal Cost = \( c'(T)T \)

Marginal Revenue = \( V - c(T) \)

Annual Returns $/yr

V

no resistance

with resistance

T

Time to failure

Time to resistance build up
Simple economic logic drives the optimal delay time ($T$)

$mc = T \cdot c'(T)$

$mr = V - c(T)$

With $c'(T) = \text{a constant (k)}$

$$c(T) = (0, k(T - t_0))$$
Should we apply more or less RM effort?

\[
MR = MC \\
(V - c(T)) = c'(T)T
\]

Need estimates of:

- \(V\): value of the crop relative to the best option under resistance
- \(c(T)\): the annual cost of resistance management
- \(T\): the expected time to resistance build up
- \(c'(T)\): the annual cost of delaying resistance an extra year
How to identify all direct and indirect effects of RM on profit in 5 easy steps!

\[ NPV(x_h, x_r) = [V - c(x_h, x_r, n_{sus})]T(x_h, x_r, \ldots) \]

1. Specify detailed objective function

\[ n_{sus} = n(x_h, x_r) \]

2. Specify steady state functions of intermediate variables

\[ x_h = x_h^*(x_r, \ldots) \]

3. Specify other choice variables as a function of resistance management

4. Sub 2&3 into 1 and take derivative with respect to a change in RM

\[ \frac{\partial NPV(.)}{\partial x_r} = -T(.) \left[ c_1 \frac{\partial x_h}{\partial x_r} + \frac{\partial c^y}{\partial x_h} \frac{\partial x_h}{\partial x_r} + c_2 + \frac{\partial c^y}{\partial x_r} + \frac{\partial c^y}{\partial n} \left( \frac{\partial n}{\partial x_r} + \frac{\partial n}{\partial x_h} \frac{\partial x_h}{\partial x_r} \right) \right] \]

\[ + [V - c(.)] \left[ \frac{\partial T}{\partial x_h} \frac{\partial x_h}{\partial x_r} + \frac{\partial T}{\partial x_r} + \frac{\partial T}{\partial n} \left( \frac{\partial n}{\partial x_h} \frac{\partial x_h}{\partial x_r} + \frac{\partial n}{\partial x_r} \right) \right] \]

5. This is the complete set of ways in which resistance management affects returns
Example of indirect effects

\[
\frac{\partial c^y}{\partial n} \frac{\partial n}{\partial x_h} \frac{\partial x_h}{\partial x_r}
\]

Change in optimal herbicide use
With a change in resistance management

Change in weed population
with the change in herbicide use

Change in revenue (yield) due to change in weed population
## Importance of different effects of resistance management on profitability

<table>
<thead>
<tr>
<th>Effect of resistance management (RM)</th>
<th>( \frac{\partial NPV(.)}{\partial x_r} )</th>
<th>Moth resistance to Bt toxins in Cotton</th>
<th>Ryegrass resistance to herbicides in Wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>The cost of change in purchases of RM inputs.</td>
<td>(-T(.)c_r)</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>The cost to production from change in RM</td>
<td>(-T(.) \frac{\partial c^y}{\partial x_r})</td>
<td>★★★</td>
<td>★★</td>
</tr>
<tr>
<td>The cost of change in purchases of pest control input with a change in RM</td>
<td>(-T(.) \frac{\partial x_h}{\partial x_r})</td>
<td></td>
<td>★</td>
</tr>
<tr>
<td>The costs to production due to change in pest control inputs with a change in RM</td>
<td>(-T(.) \frac{\partial c^y \partial x_h}{\partial x_r})</td>
<td></td>
<td>★</td>
</tr>
<tr>
<td>The cost to production due to changes in pest population due to changes in RM</td>
<td>(-T(.) \frac{\partial c^y \partial n}{\partial n \partial x_r})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The cost to production with changes in pest populations due to changes in pest control use made in response to changes in RM</td>
<td>(-T(.) \frac{\partial c^y \partial n \partial x_h}{\partial n \partial x_h \partial x_r})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The value of delay in time to resistance due to the change in pest control use with RM.</td>
<td>[1 - c(.)] [\frac{\partial T \partial x_h}{\partial x_h \partial x_r}]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The value of delay in time to resistance due to the direct effect of RM</td>
<td>[1 - c(.)] [\frac{\partial T}{\partial x_r}]</td>
<td>★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>The value of delay in time to resistance due to RM influencing pest control and therefore pest populations</td>
<td>[1 - c(.)] [\frac{\partial T \partial n \partial x_h}{\partial n \partial x_h \partial x_r}]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The value of delay in time to resistance due to the effect of RM on susceptible pest populations</td>
<td>[1 - c(.)] [\frac{\partial T \partial n}{\partial n \partial x_r}]</td>
<td>★</td>
<td></td>
</tr>
</tbody>
</table>
Criteria for optimal refuge for insect resistance management

\[ [1 - ax] = aT(x)\Delta\bar{x} \]

- \( a \) relative cost of refuge
- \( x \) proportion of land in refuge
- \( \Delta\bar{x} \) increase in refuge required to delay resistance one year
- \( T \) time to resistance build up
The marginal increase in refuge to delay resistance one year is relatively constant.
Optimal annual expenditure on resistance management with linear annual costs $c(T)$

\[ c(t) = 0.5(1 - bto) \]

![Graph showing the relationship between annual cost of RM and annual cost of extra year delay for different values of to (5, 10, and 20).](image-url)
Optimal control of resistance in weeds

\[
MR = MC
\]

\[
[V - c(T)] \left[ \frac{\partial T}{\partial x_r} \right] = T(T) \left[ c_r + \frac{\partial c^Y}{\partial x_r} + \left( c_h + \frac{\partial c^Y}{\partial x_h} \right) \frac{\partial x_h}{\partial x_r} \right]
\]

Need estimates of:

- \( V \): value of the crop relative to the best option under resistance
- \( c(T) \): the annual cost of resistance management
- \( \frac{\partial T}{\partial x_r} \): change in \( T \) with an increase in resistance management
- \( T \): the expected time to resistance build up
- \( c_r \): cost of extra resistance management
- \( c_h \): savings from reduced herbicide use
- \( \frac{\partial c^Y}{\partial x_r} \), \( \frac{\partial c^Y}{\partial x_h} \): cost of direct yield losses from RM / herbicide
- \( \frac{\partial x_h}{\partial x_r} \): decrease in herbicide use with increase in RM
Marginal costs and benefits of increasing steady state weed control (no resistance)
Summary

• Modelling the pre-resistance crop as a steady state reduces complexity and reveals the economic trade-offs in RM

• Basic economic logic drive an interior solution

• The analysis can be simplified on a case by case basis as appropriate

• The method can be generalised to consider more complexities
  • effect of spray on insect predators or other beneficial insects

• Simplicity enables incorporation into integrated analysis of rotations
Acknowledgements

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