Comparing Roundup Ready and triazine tolerant canola in crop rotations accounting for variable conditions

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Summary Monté Carlo based risk analysis techniques have been employed to compare a crop rotation including Roundup Ready® (RR) canola to a rotation including triazine tolerant (TT) canola. Within these rotations, use of glyphosate as a knockdown herbicide has been compared with use of Spray.Seed®. Net returns were found to fall in the longer term in all rotations. Net returns were highest initially but fell more rapidly in the RR rotation where glyphosate was used as a knockdown herbicide. Where Spray.Seed® was used as a knockdown herbicide in the RR rotation the initial net return was lower, but the rate of fall in net return was reduced.

Keywords Herbicide resistance, genetically modified, risk, variability, wild radish, ryegrass.

INTRODUCTION

Weed control is risky. Selecting the best weed control strategy depends on a huge number of factors, and every situation is different. To make things more complex there are many things that are unknown in any particular case. In this study we have used Monté Carlo based risk analysis techniques to address this variability and uncertainty. We have simulated two possible crop rotations. One of these is wheat-lupin-wheat-triazine tolerant (TT) canola, and the other is wheat-lupin-wheat-Roundup Ready® (RR) canola, both located at Wongan Hills, Western Australia. Within each of these rotations we have examined the effect of using glyphosate every year as a knockdown herbicide versus using Spray.Seed® (paraquat-diquat) for the same purpose.

The analysis presented here is part of a larger analysis of the role of RR canola in farming systems (described in the Acknowledgments section below). This partial analysis has been presented here to illustrate the potential of the simulation methodology that has been employed, however some of the assumptions made here may be inappropriate in some circumstances. For a more complete assessment, please consult the full report.

MATERIALS AND METHODS

This analysis has been done using a model of weed population dynamics based on that described by Diggle and Neve (2001). The model calculates seed pool dynamics for ryegrass and wild radish and their effect on crop yield over a 30 year period. The model accounts for inter-species competition, the effects of all commonly practised weed control methods, the temporal pattern of germination of the weeds, the density of the crop, and the evolution of herbicide resistance to triazines and glyphosate in both weeds. Herbicides other than glyphosate and the triazines were presumed to have a fixed number of applications before the weed populations became resistant to them, as is done in the RIM weed management model (Pannell *et al*. 2001).

Routine management practices A knockdown herbicide, either glyphosate or Spray.Seed®, was always used prior to planting of the crop. In each simulated sequence of years the same knockdown herbicide was used every year. One of two tillage regimes was also practised in all years of each sequence. These tillage regimes were no tillage at seeding, or full-cut tillage as part of the seeding operation. Selective herbicides were applied as appropriate (see Table 1). Stubbles were always grazed.

Current costs and grain prices were used for all crops and all management practices. Grain prices were presumed to be the same for the RR and TT canola crops. The technology cost that may be charged for use of RR canola is unknown. A figure of $30 per hectare has been used in this analysis based on a hypothetical pricing policy that would result in a total herbicide cost for RR canola that was comparable to but somewhat less than that of a typical TT canola package.

Conditional management practices Additional weed control practices were employed when weed numbers exceeded nominated thresholds. These were:

- crop-topping with paraquat in lupins
- 2,4-D for extra control of wild radish in wheat
- high seeding rates of all crops
- seed catching as part of the harvest operation.

Table 1. Herbicides used in the canola phases, and their costs.

Herbicide	Rate ($L\ ha^{-1}$)	Cost ($\$\ ha^{-1}$) TT canola	Cost ($\$\ ha^{-1}$) RR canola
Glyphosate (knockdown)[A]	1.0	7.50	7.50
Spray.Seed® (knockdown)[A]	1.2	13.50	13.50
Simazine (pre-emergent)	2.0	13.50	
Atrazine (post-emergent)	2.0	13.50	
Select® (Clethodim) (post-emergent)	0.15	18.00	
Glyphosate (post-emergent)	1.0		7.50
Total (glyphosate knockdown)		52.50	15.00
Total (Spray.Seed® knockdown)		58.50	21.00

[A] One or the other of these is used.

Variability Variability and uncertainty were represented by defining probability distributions for key uncertain and variable model parameters. The model was run 9216 times, and in each run of the model parameter values were generated from the distributions. Variable parameters were:

- Starting point for the crop sequence – first wheat, lupin, second wheat, or canola.
- Paddock size – minimum, most likely, and maximum paddock sizes were presumed to be 50, 100, and 200 ha, respectively.
- Initial seed bank for weeds – initial ryegrass populations were assumed to vary between 0 and 3000 seeds m^{-2} with 1000 seeds m^{-2} being most likely. For wild radish minimum, most likely and maximum populations were 0, 50, and 500 seeds m^{-2}, respectively.
- Crop sowing rate – minimum, most likely, and maximum crop densities were presumed to be 100, 175, and 300 plants m^{-2} for wheat; 40, 60 and 90 for lupin; 40, 50, and 70 for canola.
- Initial frequency of genes for herbicide resistance in weeds – initial frequencies of Roundup resistance genes were presumed to vary between 10^{-9} and 10^{-5} for both ryegrass and wild radish, and between 10^{-7} and 10^{-3} for triazine resistance genes for both ryegrass and wild radish.
- Remaining applications of in-crop selective herbicides for both weed species – number of remaining applications for ryegrass selective herbicides was presumed to vary between 0 and 8, with 4 being most likely. For wild radish the range was 0 to 15, with 6 being most likely.
- Whether tillage was used as part of the seeding operation – full-cut tillage at seeding and zero tillage were equally likely.

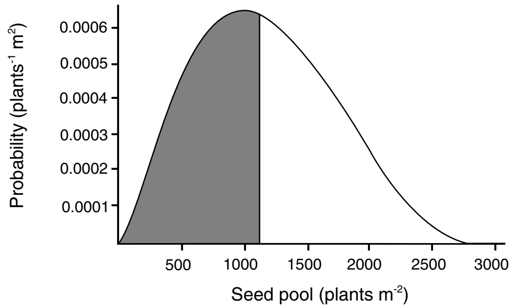

Figure 1. Probability density function for initial ryegrass population divided into two subsections with equal probability (low density – grey, high density – white).

Combinations of parameters were selected for each run using Latin Hypercube sampling (Vose 2000). Latin Hypercube sampling entails dividing the probability distributions for each of the variable parameters in sections, and selecting values from each of the subsections at random in all combinations with values from all subsections from the other distributions. This process results in a more complete representation of the possible combinations of parameters than would be obtained by completely random sampling. The probability distribution used for initial seed bank of ryegrass is shown as an example in Figure 1.

Seasonal variability in crop yield and competitiveness was represented using output from the APSIM crop growth model (Carberry *et al.* 1996). The APSIM model was run for 40 historical seasons at Wongan Hills, WA, for all crops grown both in monoculture and in competition with weeds. Crop yield and weed competition parameters for each year of each 30 year sequence were chosen at random from these 40 historical seasons. Genes for triazine resistance carry a yield penalty, so RR canola is presumed to have a yield advantage in the order of 6%.

RESULTS

All figures presented are means of all four rotational phases.

In the RR rotation where glyphosate was used as a knockdown herbicide, the average proportion of resistance in the ryegrass population reached nearly 40% by year 30. Where Spray.Seed® was used, the final fraction was under 0.3 (Figure 2). The fraction of glyphosate resistance in wild radish was much lower, 3% and 2% for glyphosate and Spray.Seed® knockdowns respectively.

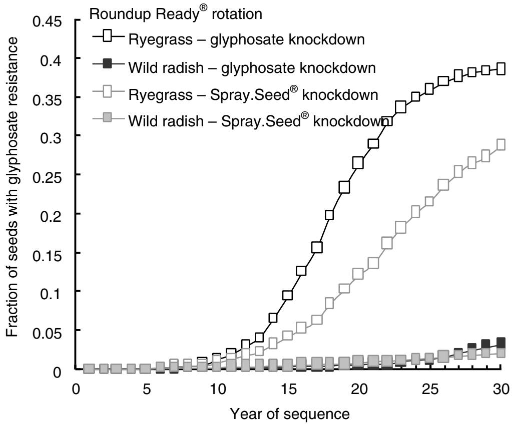

Figure 2. Average fraction of glyphosate resistance through time in ryegrass and wild radish for the RR rotation where either glyphosate or Spray.Seed® was used as a knockdown in all years.

The final levels of triazine resistance in the TT rotation were higher, 60% in ryegrass and 27% in wild radish. There was no effect of knockdown herbicide (Figure 3).

The average numbers of ryegrass plants at maturity fell in all cases for the first five years of the sequence. In the TT rotation the average ryegrass population increased steadily from that point on, finally reaching levels of approximately 500 plants m^{-2}. Average final levels were lower in the RR rotation, reaching nearly 270 plants m^{-2} with a glyphosate knockdown and under 70 plants m^{-2} where Spray.Seed® was used (Figure 4).

The average numbers of wild radish plants at maturity was higher in the RR rotation than in the TT rotation. (Figure 5). Populations were similar for both knockdown herbicides.

For both rotations the average net return tended to rise for the first five years of the sequence and then to fall beyond 15 years (Figures 6 and 7). With both knockdown herbicides the RR rotation had greater returns than the TT rotation in the first five years of the sequence. For the early years of the RR rotation and for all of the TT rotation the returns were higher where glyphosate was used as the knockdown herbicide due to its lower cost. In the later years of the sequence where glyphosate was the knockdown herbicide the returns from the RR rotation fell below the TT rotation and also below the returns for the RR rotation with Spray.Seed®. Where Spray.Seed® was used the returns from the RR rotation did not fall below the TT rotation at the end of the sequence.

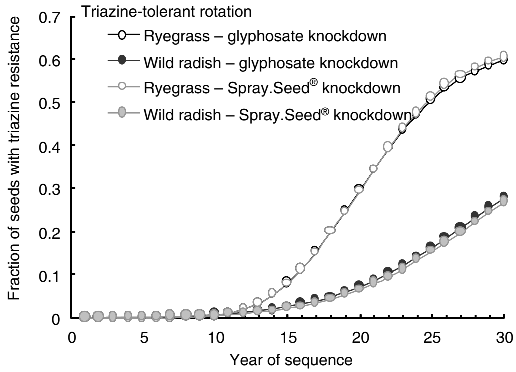

Figure 3. Average fraction of triazine resistance through time in ryegrass and wild radish for the TT rotation where either glyphosate or Spray.Seed® was used as a knockdown in all years.

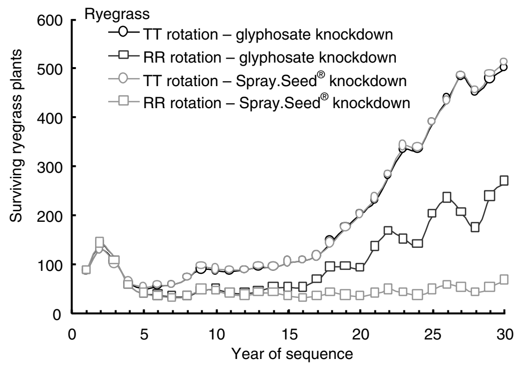

Figure 4. Number of surviving ryegrass plants at maturity through time for the RR and TT rotations where either glyphosate or Spray.Seed® was used as a knockdown in all years.

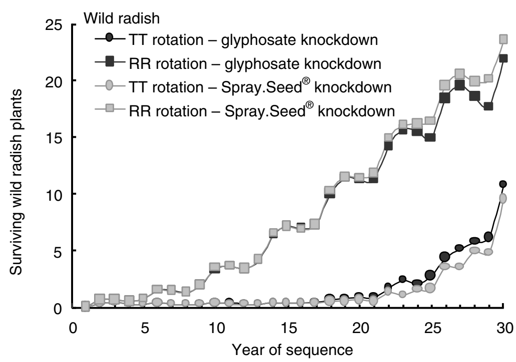

Figure 5. Number of surviving wild radish plants at maturity through time for the RR and TT rotations where either glyphosate or Spray.Seed® was used as a knockdown in all years.

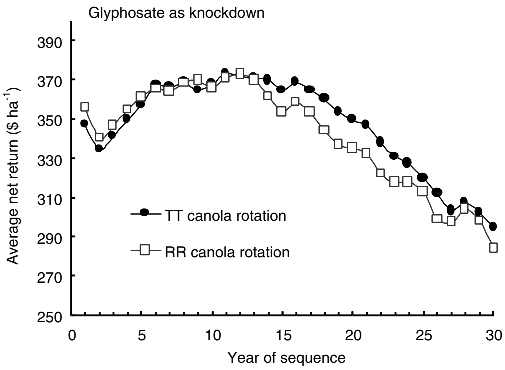

Figure 6. Average net return through time for the RR rotation and the TT rotation where glyphosate was used as a knockdown in all years.

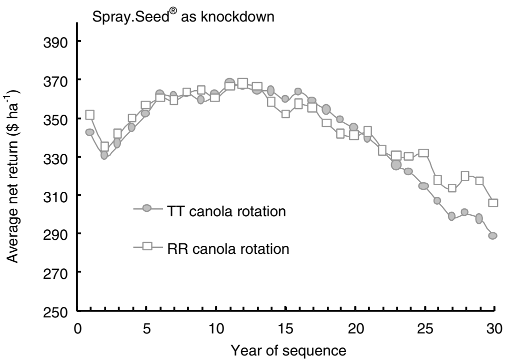

Figure 7. Average net return through time for the RR rotation and the TT rotation where Spray.Seed® was used as a knockdown in all years.

DISCUSSION

According to this analysis, the major problem that is encountered in a TT rotation is a large buildup of ryegrass numbers in the second half of the simulated 30 year sequence. This buildup occurs through a combination of increasing levels of triazine resistance in the ryegrass population, and the progressive failure of other selective herbicides. A secondary problem is a buildup of the wild radish population in the last 10 years of the sequence that occurs for the same combination of reasons.

In the RR rotation the major problem is a steady increase in the population of wild radish. This increase does not occur because of a buildup of glyphosate resistance in wild radish, but because of an assumed moderate level of innate tolerance of glyphosate by wild radish that results in poor control of wild radish in the RR canola year. This assumption of innate tolerance is based on observations of the level of control of wild radish by glyphosate in fallow conditions. It is possible that the level of control of wild radish by glyphosate in RR canola may be higher than assumed here. If so, a reduction in the rate of buildup of wild radish numbers and an increase in the rate of buildup of glyphosate resistance in wild radish would be expected.

A secondary problem in the RR rotation is a buildup of Roundup resistant ryegrass in the last 15 years of the sequence where glyphosate is used as a knockdown herbicide in addition to its use as a selective chemical in RR canola. Where Spray.Seed® is used as a knockdown, this buildup does not occur, though substantial levels of glyphosate resistance are still occurring in the ryegrass population and a buildup of resistant ryegrass beyond the simulated time period seems likely.

ACKNOWLEDGMENTS

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