Risks and RATs: assessing glyphosate resistance risk in paddocks in north-eastern Australia

David Thornby[1], Jeff Werth[1], Matt Curr[2] and Steve Walker[1]
[1] Agri-Science Queensland, Department of Employment, Economic Development and Innovation, PO Box 2282, Toowoomba, Qld 4350, Australia.
[2] Strategic Communications and Marketing, Department of Employment, Economic Development and Innovation, GPO Box 46, Brisbane, Qld 4001, Australia
Corresponding author: david.thornby@deedi.qld.gov.au

Summary Glyphosate resistance has for a number of years been recognised as threatening the profitability of conservation farming practices in north-eastern Australia. Risk assessment and preventative management are a key part of the industry's response to the problem. We developed a risk assessment tool (RAT) to assess glyphosate resistance risk in cotton and grains systems in this region. This tool allows us to determine a risk score for weeds in varying crop rotations and herbicide use patterns. Through a fax survey, we estimated resistance risk levels for 21 cotton growers in north-eastern Australia. Several key weeds were identified as being particularly at risk, although the majority of weed species scored relatively low. A wide range of management risk levels was observed, but in general non-irrigated cotton crops and fallows were found to have the highest estimated resistance risk. Glyphosate-tolerant cotton crops scored higher for risk than conventional cotton crops. Fleabane, sowthistle and several summer grasses were estimated to be particularly at risk of resistance in non-irrigated glyphosate tolerant cotton crops, and winter and/or summer fallows. Online delivery of the RAT provides growers and researchers with several key features. Users can assess their current risk levels within minutes, and can also test likely risk for potential rotations and alternative herbicide usage patterns. Responses from the RAT are compiled to track changing risk levels through time and between regions. Inferences about the rate of uptake of herbicide use recommendations can therefore be made.

Keywords Herbicide resistance, risk assessment, weeds management.

INTRODUCTION

Glyphosate resistance is now acknowledged as a serious and long-term threat to the profitability and viability of cropping systems worldwide (Heap 2010). In particular, conservation tillage farming systems, which often require frequent application of broad-spectrum herbicides to ensure clean fallows and planting conditions, rely on glyphosate to provide effective weed control. Consequently, there is substantial selection pressure for glyphosate-resistant biotypes.

Reducing the rate and likelihood of glyphosate resistance evolving in any given weed population presents a substantial challenge to growers, who must weigh up current profitability against future sustainability. The risk and cost of developing a resistant population must be measured against the cost of taking action, and formal assessment of current risk must be the first step in developing plans to reduce that risk. To date, there have been few tools for estimating herbicide resistance risk directly, and existing tools focus on particular herbicide-tolerant crops or individual weed species (Stanton *et al*. 2008, PRAMOG, Monsanto 2009). We took a more holistic approach to glyphosate resistance risk assessment, and developed a method of assessing resistance risk according to inherent species characteristics and selection pressure applied by the weed management practices used to control the weed community in any given paddock.

MATERIALS AND METHODS

Our risk assessment tool was developed for use in survey form and online. The survey was sent out to cotton growers to investigate current herbicide use patterns and industry-wide resistance risks. The online tool is available to the whole industry, and similarly provides information for researchers, as well as for growers to assess their own risk and manage their herbicide use strategy.

We developed separate risk assessment procedures to estimate the risk associated with specific weed species (species risk) and with weed control tactics and crop sequences (management risk). Total population risk is the product of species and management risks.

Species risk We used an expert analysis approach to estimate the inherent resistance risk of different weed species by weighting biological factors that promote or mitigate against the evolution of glyphosate resistance. These factors include seed bank characteristics and reproductive characteristics (Table 1). Higher values are awarded to characteristics that are thought to have greatest impact on the rate at which gene frequencies in a population could shift in response to selection pressure. The scores for each factor were summed to give a total species score.

Table 1. Species risk scoring factors.

Factor	Scoring range
Fecundity	1–10
Emergence characteristics	0–10
Generation period	0–5
Reproduction method	0.5–1
Mating system	0.5–1

We assessed a wide range of species for inherent risk using the above analysis, including most species on Roundup Ready Herbicide® and Roundup® CT (Monsanto Australia Inc.) labels, plus other species of interest including flaxleaf fleabane (*Conyza bonariensis* (L.) Cronq.) and several species that have evolved glyphosate resistance in other parts of the world.

The potential maximum species score is 27. We indexed the species results against this maximum, to give each species a rating from one to ten.

Management risk A substantial part of the overall risk of a weed population evolving glyphosate resistance resides in the management history of that population (Powles 2008). Selection pressure for glyphosate resistance is a function of the frequency of glyphosate application, the frequency of other kill methods applied, and the competitive effects of crops affecting weed reproductive success.

We calculate management risk Rm_i per phase i (for example, the average summer fallow or cotton crop) as:

$$Rm_i = G_i - (C_i{*}Ce_i) - (A_i{*}Ae_i) - K_i \quad (1)$$

where G_i is the number of glyphosate applications in phase i, C_i is the number of times the grower attempts to control glyphosate survivors in phase i, Ce_i is the factor for the average effectiveness of methods used to control survivors in phase i; A_i is the number of non-glyphosate kill methods used in phase i and Ae_i is the factor for the average effectiveness of those alternatives. The typical range of values for G_i, C_i, and A_i is from zero to five. The range of values for Ce_i and Ae_i is between zero and 0.95. K_i is a crop rating, allowing for reduction in weed seed set due to competitiveness of the crop used in phase i. K_i is determined as:

$$K_i = Kf_i{*}Kr_i{*}Kd_i \quad (2)$$

where Kf_i is a factor for the type of crop, Kr_i is a reducing factor for crop row spacing, and Kd_i is a reducing factor for crop density. Total values for K_i range between zero and 0.6. Kf_i values were determined by expert analysis of sparse data on weed seed production in stands of crop plants of varying densities.

In the offline version of the tool, we calculate Ce_i and Ae_i with regard to the nominated effectiveness the user states they obtain from these methods. In the online tool, only Ce_i is calculated in this way. For simplicity, Ae_i is given default values for different tillage types and alternative herbicides. Similarly, where the survey tool separates broadleaf and grass weeds for the purposes of determining effectiveness of alternative herbicides, the online tool simplifies by assuming that users who use substantially different amounts of herbicides selective for grasses and broadleaves will run the tool separately for each type.

Once risk scores for each phase have been calculated, summer and winter average scores (*Ss* and *Sw* respectively) are derived, and a year-round average (*Sy*) is also calculated.

Total risk Overall risk is determined by both a species' inherent risk and the level of selection pressure exerted by the cropping system. Thus, a total risk score Rt_w for a weed w can be calculated simply by multiplying the weed's species score by the appropriate seasonal average. For summer weeds this is *Ss*; for winter weeds *Sw*; and for weeds that may appear at any time of the year, *Sy*. A total risk score for a weed in any individual phase can similarly be derived from the species risk score and the management risk score for that phase, either from an individual's response or as an average of several users' responses.

Risk assessment survey We sent a fax survey out to a number of cotton growers in New South Wales and southern Queensland. We received 21 responses, and these comprised our initial dataset.

RAT construction The online tool (the RAT) was programmed in Flash 10 (Adobe Systems Inc.) and actionscript 3.0. There are some simplifications compared to the paper-based survey version. Notably, the user can only select weeds of interest from a shorter list of 30 key species, and the RAT does not distinguish between non-glyphosate herbicides specifically active against only broadleaf or grass weeds.

RESULTS

Species risk Indexed species risk scores for our weeds of interest ranged between 0.2 (nutgrass, *Cyperus* spp) and 8.1 (sweet summer grass, *Brachiaria eruciformis* (Sm.) Griseb.). A list of the ten highest-scoring weeds is shown in Table 2. The majority of species were found to be at relatively low risk: out of

63 species assessed, 39 scored lower than two points out of the indexed rating of ten.

Management risk Using the offline risk assessment tool, we estimated glyphosate resistance risk values for rotations and herbicide use patterns specified in the fax-out surveys. Average scores per phase are shown in Table 3. Fallows and non-irrigated cotton scored as the highest-risk phases. The maximum score for management risk is five, though the survey allows for higher scores.

Total risk scores We analysed the 21 responses to the survey as a preliminary dataset to test the effectiveness of the risk assessment tool. Where fax-out survey respondents indicated a weed was present in a particular phase of their cropping system, we determined a total risk score for that weed population as the product of the species risk and the management risk for that respondent's weed management system.

Total risk scores for each weed were generated both as a mean predicted risk using the average phase scores, and on an individual response basis as shown in Table 4. Across our analyses, several summer grass species, fleabane, and sowthistle appear to be at greatest risk of evolving resistance (Tables 2 and 4). Similarly, the phases in which the most risky activity was reported were found to be non-irrigated Roundup Ready Flex® cotton and winter and summer fallows (Tables 3 and 4). Irrigated cotton crops were predicted to be at substantially lower risk of glyphosate resistance than non-irrigated crops. This is the case for both herbicide-tolerant and conventional varieties, and is consistent across specific and average risk scores. Herbicide-tolerant crops were predicted to be at consistently greater risk than comparable conventional crops.

Table 2. Species risk scores for ten north-eastern Australian cropping weed species. Increasing score implies higher risk of resistance.

Species	Common name	Score
Brachiaria eruciformis	Sweet summer grass	8.1
Conyza bonariensis	Flaxleaf fleabane	7.6
Urochloa panicoides	Liverseed grass	7.2
Chloris virgata	Feathertop Rhodes grass	7.0
Sonchus oleraceus	Sowthistle	6.9
Echinochloa colona	Awnless barnyard grass	6.9
Phalaris paradoxa	Paradoxa grass	6.3
Dactyloctenium radulans	Button grass	5.9
Chloris truncata	Windmill grass	5.9
Cirsium vulgare	Spear thistle	4.8

Table 3. Management risk scores by phase from fax-out surveys as measured by the risk assessment tool. Increasing score implies higher risk of resistance. Scores are means followed by range in parentheses.

Phase	Grass score	Broadleaf score
Other summer crop	0.5 (0–1.7)	0.4 (0–1.7)
Irrigated cotton	0.4 (0–0.9)	0.5 (0–1.8)
Barley	0.6 (0–2.5)	0.8 (0–2.5)
Wheat	0.7 (0–3.6)	0.8 (0–3.6)
Irrigated RF* cotton	1.2 (0–3.9)	1.1 (0–4)
Sorghum	1.3 (0–3)	1.1 (0–3)
Other winter crop	1.3 (0–3.1)	1.1 (0–4)
Non-irrigated cotton	1.0 (na)	1.9 (na)
Summer fallow	1.5 (0–4)	1.4 (0–4)
Winter fallow	1.7 (0–5)	1.6 (0–4.1)
Non-irrigated RF* cotton	1.6 (0.5–4)	2.1 (1.1–4.1)

*RF refers to Roundup Ready Flex cotton varieties.

DISCUSSION

A wide range of total risk scores was estimated from the survey responses, as shown in Tables 3–4, and it was also observed that a wide range of inherent risk levels is predicted to exist among the weed species for which glyphosate is registered (Table 2).

Irrigated cotton crops in general were predicted to be at relatively (perhaps surprisingly) low risk. The higher inputs available to irrigated growers appear to include a wider variety of herbicide types and a greater ability to follow up glyphosate sprays with other methods to prevent seed set. The data in Table 4 suggest that risks associated with herbicide-tolerant technologies can be reduced substantially if appropriate non-glyphosate control methods are incorporated.

Some species were predicted to be at high risk for glyphosate resistance, but no actual populations of these weeds were reported in the survey, e.g. sweet summer grass, which grows mainly in central Queensland, outside the survey area.

Although our dataset is limited, the preliminary risk assessment results show that our tool can analyse rotations and herbicide use strategies effectively, and predict resistance risk for particular weed species. At the time of writing, the RAT had not yet been released to the public, so no RAT data were available for inclusion. However, running the survey responses through the RAT returns the same results as shown here.

Individual risk assessments allow the user to determine what practice changes might be needed

Table 4. Mean total risk scores for highest risk weeds and phases, and range of total risk scores per individual grower. Single dashes in predicted total risk scores indicate an unlikely combination for which no estimate was made. Double dashes in actual response ranges indicate no responses were received for that combination of phase and weed. Numbers in brackets indicate how many responses were received for each phase × species combination.

Species	Non-irrigated RF* cotton	Winter fallow	Summer fallow	Non-irrigated cotton	Sorghum	Irrigated RF* cotton	Wheat	Irrigated cotton
	Predicted total risk (mean management risk per phase × species risk)							
Flaxleaf fleabane	16	12	11	15	8	8	6	3
Sowthistle	15	11	10	13	8	7	5	3
Sweet summer grass	13	14	12	8	10	10	–	3
Liverseed grass	12	–	11	7	9	9	–	3
Feathertop Rhodes grass	11	12	10	7	9	8	–	3
Awnless barnyard grass	11	12	10	7	9	8	–	3
	Range of responses from survey (management risk per response × species risk)							
Flaxleaf fleabane	9–15 (2)	0–23 (6)	0–30 (15)	15 (1)	7–17 (3)	0–21 (10)	0–0 (4)	0–14 (3)
Sowthistle	8 (1)	0–28 (11)	0–27 (9)	–	6 (1)	0–14 (7)	0–14 (11)	–
Sweet summer grass	–	–	–	–	–	–	–	–
Liverseed grass	7 (1)	–	0–22 (5)	–	0–16 (3)	0–21 (4)	–	0–2 (2)
Feathertop Rhodes	7 (1)	11–15 (2)	0–22 (2)	–	6 (1)	0–0 (2)	–	–
Awnless barnyard grass	7–27 (2)	11–21 (2)	0–27 (13)	–	0–15 (3)	0–27 (10)	–	0–2 (3)

*RF refers to Roundup Ready Flex cotton varieties.

to reduce resistance risk. They can also be pooled to develop strategies or suggest practice changes for industry sectors or smaller groups.

The management and total risk scores obtained from both the survey and the RAT are stored in databases that will, over successive seasons, be able to demonstrate changes in estimated risk levels. This information will be valuable in determining both industry-wide risk exposure to glyphosate resistance, and the rate of uptake of recommendations designed to extend the useful life of this valuable herbicide.

ACKNOWLEDGMENTS

This work was funded by the Cotton Catchment Communities CRC, Cotton Research and Development Corporation and Monsanto Australia.

REFERENCES

Heap, I. (2010). The international survey of herbicide resistant weeds. www.weedscience.org (last accessed Jan 2010).

Monsanto (2009). Roundup Ready® canola 2009 crop management plan. (Monsanto, Australia Ltd).

Powles, S.B. (2008). Evolved glyphosate-resistant weeds around the world: lessons to be learnt. *Pest Management Science* 64, 360-5.

Stanton, R.A., Pratley, J.E., Hudson, D. and Dill, G.M. (2008). A risk calculator for glyphosate resistance in *Lolium rigidum* (Gaud.). *Pest Management Science* 64, 402-8.