FINAL REPORT

GRDC Grains Research & Development Corporation

Risk assessment and preventive strategies for herbicide resistance in NR (phase III)

UQ00054

Project Details

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Summary

The threat and management of glyphosate# resistant weeds are major issues facing northern region growers. At present five weeds are confirmed glyphosate-resistant: barnyard grass, liverseed grass, windmill grass, annual rye-grass and flaxleaf fleabane. This project used 25 experiments to investigate the ecology of the grass weeds, plus new or improved chemical and non-chemical control tactics for them. The refined glyphosate resistance model developed in this project used the experiments' findings to predict the long-term impacts on evolution of resistance and on seed bank numbers of resistant weeds. These data led to revised management and resistance avoidance strategies, which were published in the Reporter newsletter, and via an on-line risk assessment tool.

Conclusions

Conclusions of this project drawn from trial data are listed by individual weed species, below.

Multiple weed species

- Persistence of the seeds of barnyard grass species, liverseed, sowthistle and wild oats in the soil was very short, with 99% of seeds losing viability within two years.
- Tillage, rainfall and cropping systems had a major effect on weed emergence, but the relative impact differed between species.
- Modelling showed that time to evolve glyphosate# resistance differed between species, taking approximately nine years to develop in sweet summer grass and 18 years in sowthistle in systems using high risk practices including intense use of glyphosate without control of survivors.
- It is more effective to start an intense preventive program for resistant weeds before the resistance level reaches 1% (approximately 10 summer fallows of high risk practices for barnyard grass).
- Modelling showed that prevention of resistance build-up in weed populations requires a two-year intensive program that must include non-glyphosate treatment of all cohorts in consecutive fallows. This strategy gave very good seed bank control, providing evidence that minimising seed set over a period long enough to nearly exhaust the seed bank is a powerful method for managing glyphosate-resistant or susceptible weeds.
- Simulation results demonstrated that rotating to summer cropping with non-glyphosate herbicides provided better seed bank control and extended the useful lifespan of glyphosate over winter cropping with glyphosate-only summer fallows, particularly for sweet summer grass and sowthistle.

Barnyard grass

- Glyphosate resistance did not appear to confer any fitness penalty, so glyphosate-resistant biotypes grow and reproduce similar to glyphosate-susceptible biotypes.
- Pre-tillering glyphosate-resistant populations growing under optimal conditions were able to be controlled with glyphosate, but not once stressed and/or at the tillering stage.
- The double knock tactic (glyphosate followed by treatment with paraquat#) was consistently highly effective on glyphosate-resistant and susceptible biotypes.
- Large glyphosate-resistant plants were controlled with very high rates of glyphosate followed by paraquat at robust rates.
- Large glyphosate-resistant plants were controlled by sequential applications of paraquat at robust rates.
- Glyphosate-resistant and susceptible biotypes were controlled effectively with a range of Group A herbicides, which are now registered for use with a WeedSeeker® sprayer in New South Wales (NSW), provided that survivors are controlled. The new double knock is Group A herbicide followed by paraquat.
- A glyphosate-resistant population was effectively managed at the field scale using a strategy of targeting each flush in two consecutive summer fallows with double knock, or using a residual followed up with paraquat on survivors, followed by rotation with broadleaf summer crop using a residual and Group A post-emergent herbicide.
- Metolachlor#, imazapic# or atrazine#+ metolachlor residual herbicides gave 90-100% control of barnyard grass for up to two months.

Wild oats

- Multiple resistant wild oats were effectively managed at the field scale using a strategy of targeting each flush in two consecutive winter fallows. This was followed by planting manure oats, Roundup Ready® (RR) canola or wide-row chickpea.

Liverseed and feather-top Rhodes grass

- Dense populations of early-tillering liverseed and feather-top Rhodes grass were controlled using double knock, with following flushes controlled by metolachlor and imazapic when added to the first or second knock.

- A range of Group A herbicides was highly effective on glyphosate-resistant liverseed grass when applied at robust rates.

Recommendations

An integrated weed management (IWM) strategy to prevent or delay evolution of glyphosate# resistance needs to ensure that all cohorts of glyphosate survivors in a given year are controlled with something other than glyphosate. Scenarios where some or most emergences are controlled only with glyphosate are predicted to be relatively ineffective in delaying resistance. This is especially crucial in weeds that can produce more than one generation per year, such as sweet summer grass in Central Queensland.

It is important to begin IWM practices as soon as possible, certainly before patches of resistant weeds become widespread or even noticeable in the paddock to slow the rate of evolution of resistance in weed populations. Theoretical simulations with IWM starting from the first use of glyphosate were the only situation to result in very large delays in the evolution of resistance (15+ years). Once some resistant patches are evident, little can be done to delay further resistance development unless non-glyphosate options are used until the seed bank is depleted of glyphosate-resistant seed.

Intensive strategies used to drive down the weed seed bank over two years can provide excellent control of glyphosate-susceptible and glyphosate-resistant weed populations in the long-term. This is provided some or all of the non-glyphosate tactics are well-timed knockdowns (residuals used alone are not sufficiently effective) and the strategy is introduced early before more than one or two small patches of resistance are found.

Summer cropping with residuals may not provide many extra years of glyphosate susceptibility over glyphosate-only summer fallows unless well-timed non-glyphosate knockdowns are also used in the cropping phases. As few as two knockdowns or double knocks in a five-year rotation featuring frequent residuals appears to be sufficient to provide several extra years of glyphosate susceptibility. Depending on weed species, seed bank density of resistant populations can be at least halved by planting competitive summer crops (with residuals) two or three times in five years.

It is important to note that the proportion of resistant seeds in the seed bank is unlikely to reduce, even when glyphosate alternatives are used and/or glyphosate survivors are fully controlled because there is no fitness penalty associated with the resistant gene, at least in barnyard grass. Thus, the urgency to implement preventive strategies sooner rather than later, if the current practices are in the 'medium' to 'high' risk categories, needs to be reinforced.

Outcomes

Summer grasses, particularly barnyard grass, are prevalent across the whole of the northern region. It is highly likely that most of these populations have been subjected to several years of high-risk practices for evolution of glyphosate# resistance.

The number of paddocks with confirmed glyphosate-resistant populations of summer grasses is currently small in number in the northern region but extensive areas are likely to have weeds with some level of resistance. These areas could be undetectable, with only a few isolated resistant plants, or more extensive infestations that have not been tested for resistance, possibly because the weeds are thought to be difficult to control for other reasons.

Wild oats are also prevalent across much of the winter cropping areas of southern Queensland and northern New South Wales (NSW), and many of these populations have developed resistance to the Group A herbicides, with some exhibiting multiple resistance to all of the selective herbicides used in winter cereals and chickpeas.

This project developed and validated a range of chemical and non-chemical tactics to effectively manage these resistant weeds. These tactics have been integrated into strategic management packages that have been shown to effectively control these weeds and drive the seed bank down to extremely low densities. When these management packages are implemented in paddocks with very low levels of glyphosate resistance, they have the added benefit of extending the sustainable use of glyphosate for a number of years.

The management packages developed in this project will have substantial economic benefits to the grains industry across the northern region. The potential value has not been estimated. However, aspects of this will be explored as part of the new project 'Improving integrated IWM practices for NR'. A potential monetary cost could be estimated for each seed that enters the seed bank, based on expected seed viability, future costs and the effectiveness of management tactics. The values are likely to differ for each species and depend on whether the seed is glyphosate-susceptible or resistant. These values could then be compared to the additional costs of controlling glyphosate-sprayed survivors and using glyphosate alternatives. Thus, the economic benefits of IWM practices could be estimated and lead to increased adoption of these practices.

Achievement/Benefit

Background and issues addressed

The threat and management of glyphosate# resistant weeds and multiple-resistant wild oats are major issues facing northern region growers. At present, five weeds are confirmed glyphosate-resistant: barnyard grass (20 populations), liverseed grass (three), windmill grass (two), annual ryegrass (29) and flaxleaf fleabane (eight). These populations present major problems for management in fallows, most of which have traditionally relied on glyphosate. Group A resistance in wild oat populations is widespread in the northern region, with some populations exhibiting multiple resistance to Group A, B and/or Z chemicals. These populations present major problems for management in winter cereals and chickpeas.

The issues facing advisers and growers are:

- What are the risks of glyphosate resistance developing in weed populations?
- What preventive tactics need to be implemented, and how frequently do they need to be used?
- How can resistant weeds be managed in the short and long-term?

Project objectives

- Develop effective tactics for the prevention and management of glyphosate-resistant grasses and multiple-resistant wild oats.
- Improve the understanding of the ecology of these weeds.
- Expand the glyphosate resistance model to predict the long-term impact of current practices and preventive options on evolution of resistance and seed bank dynamics.
- Develop and refine weed prevention and management strategies.

Major achievements

Twenty-five experiments successfully investigated new tactics and weed ecology of barnyard grass, liverseed grass, feather-top Rhodes grass, annual ryegrass, wild oats and sowthistle. More than 250 scenarios were simulated using the refined glyphosate resistance model to evaluate the risks for evolution of glyphosate resistance for barnyard grass, liverseed grass, sweet summer grass and sowthistle weeds in diverse northern region cropping systems. The team made 55 presentations to industry and published 45 peer-reviewed papers, newsletters, fact sheets and articles.

Tactics to manage glyphosate-resistant barnyard grass

A long-term field experiment infested with glyphosate-resistant barnyard grass evaluated the impact of different crop sequences and chemistry (knockdown, selective, residual) on seed set and run down of the weed seed bank over two years. The best control was in the fallow phase using either double knock (glyphosate followed by paraquat#) on each flush, or residuals metolachlor# or imazapic# followed with high rates of paraquat. These strategies gave excellent control and prevented seed bank replenishment, resulting in very low emergences of weeds the following season. These reduced populations could then be managed in a cropping phase. The best option in the cropping phases was mungbeans using pre-emergent imazethapyr# followed by post-emergent haloxyfop#. Good control in sorghum was achieved only when a residual was followed up with inter-row spraying with paraquat on survivors and escapes.

The double knock tactic (glyphosate followed by paraquat) was refined in four experiments. Duplicated pot experiments showed that double knock was equally effective on susceptible and resistant populations. Glyphosate provided some level of control on young resistant plants when treated with robust rates. Paraquat was equally effective on both populations, but needed to be applied at robust rates on late tillering plants. In a field experiment infested with large resistant barnyard grass (10-20 tillers), the most effective tactics were paraquat followed by paraquat at a robust rate and double knock with very high glyphosate rates (6-10L/ha) followed by paraquat. In a field experiment with a very dense infestation of susceptible barnyard grass (650 plants/m^2), double knock provided more than 99% control. When metolachlor, imazapic or atrazine# + metolachlor residual herbicides were mixed with the first or second knock, there was 90-100% control of new emergence for one month.

The impact of biotic and abiotic factors was quantified for glyphosate efficacy on susceptible and resistant populations in two glasshouse experiments. Glyphosate rate and weed size, and to a lesser extent moisture stress, greatly affected plant response. On pre-tillering plants, there was very little difference in glyphosate efficacy between susceptible and resistant populations. Glyphosate efficacy was poor on mid-tillering resistant plants at low rates, and on late-tillering plants irrespective of rates. When plants were moisture stressed there was very little difference in efficacy between susceptible and resistant populations.

In a pot and field experiment, high rates of Group A herbicides haloxyfop, fluazifop#, butroxydim#, sethoxydim# and clethodim# gave 96-100% control of tillering resistant barnyard grass. These products are registered now for use by Weed-Seeker® in NSW.

Tactics to manage resistant wild oats

A long-term field experiment infested with multiple-resistant wild oats evaluated the impact of different crops and chemistry (knockdown, selective, residual) in preventing seed set and running down the weed seed bank over three years. Two consecutive fallows reduced the seed bank to extremely low numbers. Best cropping options were brown manure oats, RR canola and wide-row chickpeas. In another field experiment, wild oats were effectively controlled in wide-row chickpeas using the combination of inter-row application of glyphosate or paraquat followed by use of a wick wiper to apply glyphosate to the survivors.

Tactics to manage other glyphosate-resistant weeds

A pot experiment demonstrated the effectiveness of a range of Group A products on glyphosate-resistant liverseed grass.

In areas with recent fallow and use of Group A herbicides, a pot experiment confirmed that populations of glyphosate-resistant annual ryegrass have developed multiple resistance to Group A products.

In a field experiment infested with susceptible liverseed grass and feather-top Rhodes grass, excellent knockdown was achieved with double knock. Subsequent flushes were effectively controlled for two months when metolachlor or imazapic was added to one of the knocks. Similar results were obtained in four field experiments in Central Queensland.

Ecology of resistant weeds

A 32-page review on seed bank ecology of sowthistle, wild oats, barnyard grass and liverseed grass was carried out as part of this project. The review assisted with developing relevant research questions for these problem weeds.

Consequently, six long-term field experiments were established to assess the impact of environment, cropping system and agronomic practices on the emergence patterns and seed bank dynamics of these weeds. Under the conditions of zero-tilled fallow with no replenishment of the seed bank, less than 1% of wild oats and barnyard grass seed remained viable after two years. Emergence accounted only for a relatively small component of seed loss, with 2-15% of summer grasses and 4-23% of wild oats emerging over two and three years, respectively. However, a number of practices and factors can greatly affect emergence numbers; wheat-summer fallow rotation, spring millet crop and tillage all reduced barnyard grass emergence by more than 50%; increased soil moisture increased barnyard grass emergence by approximately 50%; tillage reduced liverseed grass emergence by more than 75%. Intensive sampling of the seed bank will be undertaken in the new IWM project.

Glyphosate-susceptible and resistant lines for barnyard grass were identified and grown for seed increase. To develop parameters for the glyphosate resistance model, the competitiveness of these lines was measured. The results showed that, unlike other species, there was no apparent fitness penalty associated with the glyphosate resistance gene.

Modelling

The glyphosate resistance model, previously restricted to wheat and sorghum rotations, has had sunflower, mungbean and conventional and glyphosate tolerant cotton added so that the diverse cropping systems of the northern region can be evaluated. To complement these crop additions, a full range of weed control options for these new crops was also added. These options are glyphosate, non-glyphosate knockdown, double knock, residual herbicide in crop or fallow, lay-by residual, tillage in fallow or inter-row, shielded applications and glyphosate over-the-top on a glyphosate tolerant crop.

Three new weeds have been added to the model: sweet summer grass, liverseed grass and sowthistle. A fleabane module has also been added, but may need to be modified when the genetics of resistance is determined.

Over 250 scenarios were used to simulate the evolution of resistance in different farming systems for different weeds and the impact of preventive approaches on delaying resistance evolution and depleting the seed bank. In a high risk situation, resistance is likely to develop in barnyard grass after 13 summer fallows, 11 fallows for liverseed grass, nine for sweet summer grass (in Central Queensland) and 18 for sowthistle. Implementing limited preventive actions (targeting one flush in two of five summers) had minimal or no impact on delaying resistance, although the seed bank was in some instances reduced substantially. However, targeting all flushes in two of five summers delayed resistance by more than five years if this tactic was implemented when resistance was at low levels. Irrespective of the resistance level when implemented, the barnyard grass seed bank was driven down from more than 2,000 to less than 10 seeds per square metre by this tactic. Changing the rotation to increase frequency of summer crops that included a mungbean rotation extended the useful life of glyphosate by several years, allowing the use of several non-glyphosate tactics (apart from rotations with a glyphosate tolerant crop).

A large data set on emergence patterns and seed persistence has been compiled from the long-term seed bank dynamics experiments. These data will be used to validate the revised Wizard model for some key northern region weeds when revisions to the model's methods for dealing with sub-tropical weeds have been completed.

Communication and strategies

The project team has actively communicated research findings and modified strategies to the industry through 45 publications and 55 presentations. The annual Reporter newsletter summarised the project findings, and the current edition has 16 pages on strategies to manage multiple-resistant wild oats, glyphosate-resistant barnyard grass and fleabane, and the impact of preventive strategies for barnyard grass, liverseed grass, sweet summer grass and sowthistle.

Outputs from the glyphosate resistance model were used to develop a Risk Assessment Tool in collaboration with a Cotton Cooperative Research Centre (CRC) project. This tool is now available online for growers and advisers to assess the risks for glyphosate resistance for their individual rotations and practices.

Benefits to industry

This project has provided the growers and advisers of the northern region with a new suite of chemical and non-chemical tactics that have been integrated into strategies to prevent or manage the important issues of glyphosate-resistant grasses and multiple-resistant wild oats.

The following key findings will have substantial economic benefit for the grains industry:

- Growers and advisers can now assess their individual risks of developing glyphosate resistance and implement a more targeted preventive strategy.
- A range of chemical and non-chemical tactics has been refined to ensure maximum effectiveness on glyphosate-susceptible and glyphosate-resistant grasses and multiple-resistant wild oats.
- The optimum times to implement preventive strategies have been determined to maximise the effective life of glyphosate.
- Ecological and field studies have validated that the seed bank of annual grass weeds can be successfully manipulated to very low numbers within a period of two years.

Consequently, the grains industry will benefit substantially from undertaking a risk assessment of their weeds and practices, then incorporating the appropriate IWM practices. This will help to minimise the replenishment of the seed bank into their weed management plan, maintain the effective use of glyphosate and minimise weed problems in the future.

Other Research

The new GRDC funded projects 'Improving IWM practice in the Northern Region' and 'Understanding and management of resistance to Group M, Group L and Group I Herbicides — a national project' and the Cotton Research and Development Corporation (CDRC) project 'Improved IWM systems in transgenic farming landscapes' will address many of the current priority research needs for the northern region. Collaborative links have been developed with other key weed researchers in Australia and contact made with overseas researchers who are undertaking basic research on issues that may be relevant for the northern region. The GRDC initiative to improve and formalise the weeds research, demonstration and extension framework for the northern region will greatly improve the flow of information to end users. The recent appointment of a weeds extension specialist, a joint initiative of GRDC and CRDC, and formation of adviser learning groups will greatly increase grower adoption of IWM practices.

Key weed research areas still to be addressed include:

1. An in-depth understanding of the ecology of the related weeds feather-top Rhodes grass and windmill grass is needed for the development of IWM strategies for these relatively new weeds.
2. How does the glyphosate# resistance gene move in seed and pollen in key northern region weeds? This will improve our understanding of the movement pathways for glyphosate-resistant weeds within and between farms. Improved knowledge about gene movement of these species will lead to better strategies and recommendations for preventing the spread of herbicide resistance.