Modelling to estimate glyphosate resistance risk in barnyard grass in the northern Australian grain region

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Summary Conservation farming practices have resulted in increased use of herbicides, particularly glyphosate, resulting in the evolution of glyphosate-resistant populations of several species, threatening the sustainability of conservation farming systems. In order to determine the glyphosate resistance risk level of regional farming practices, we developed a model of glyphosate resistance evolution in the northern grains region, and evaluated the likelihood of resistance evolving under various currently used practices. Simulations, using barnyard grass as the test weed, showed that the risk of evolution of glyphosate resistance is relatively high in systems with no summer cropping, tillage, or use of alternative herbicides. Summer cropping with sorghum and strategic tillage in fallow reduced this risk. The addition of a double knock used as a 'resistance-busting' tactic reduced the risk of evolving glyphosate resistance significantly, depending on the state of the population when the tactic was introduced. Our predictions of risk for various farming practices are being used to assist growers in determining their own risk level, allowing them to make practical but worthwhile changes to avoid glyphosate resistance.

Keywords Modelling, weeds, barnyard grass, *Echinochloa*, glyphosate, herbicide resistance.

INTRODUCTION

Resistance to glyphosate in weed populations is an increasingly common phenomenon. Glyphosate's broad effectiveness, low cost, and relative safety have all contributed to its increased use (and hence increased selection pressure for resistance). The use of soil conservation practices has increased in Australian farming, and farmers have subsequently relied heavily on knockdown herbicides for pre-planting and fallow weed control, particularly glyphosate.

Glyphosate resistant weeds have been found to be present in the northern grain region (NR), though limited to northern New South Wales (NNSW) (Preston 2007). In cropping situations, glyphosate resistant annual ryegrass (*Lolium rigidum* Gaud.) and awnless barnyard grass (*Echinochloa colona* L.) populations have been identified.

Barnyard grass is one of the most significant weeds of cropping throughout the NR (Osten *et al*. 2007), and glyphosate resistant barnyard grass has the potential to reduce farming profitability significantly in both NNSW and Queensland.

In estimating the effects of the NR's variable farming systems, climate, and soil types on the rate of evolution of glyphosate resistance in barnyard grass, we elected to take a modelling approach as has been done successfully for other regions (for example Diggle *et al*. 2003). We developed a model of barnyard grass populations in NR farming systems (Thornby *et al*. 2006), and have used the model to assess a variety of different farming systems and weed control tactics. We have also evaluated the effects of the double knock tactic as a preventative measure.

MATERIALS AND METHODS

Software environment The model simulates a population with a single-gene glyphosate resistance mechanism (Thornby *et al*. 2006). It consists of a set of modules in the APSIM environment (Keating *et al*. 2003) that simulate weed and crop growth, including the effects of competition on seed production, soil and climate processes, and fertiliser applications. A connected set of equations model weed population factors. Scripting commands in APSIM's manager determine dates and effectiveness of weed control tactics used. Available tactics for barnyard grass control in the model include: glyphosate knockdown in fallow, pre-planting, and inter-row; non-glyphosate knockdown; residual herbicide used pre-planting or at planting; tillage at planting or used strategically in fallow; double knock (glyphosate followed by an alternative knockdown herbicide) and chipping/hand roguing. These can be triggered in the model by a combination of date, days since last application, crop sowing date, weed emergence, weed density, and multi-year herbicide rotation. Several tactics can be used in a single simulation. APSIM rules also define and control crop rotations. The model returns a range of variables concerning crop, weed, and soil status, yield, and proportion of resistance in the weed population.

Simulations We developed thirty-year simulations for a variety of NR farming systems. Results from simulations using Dalby (Queensland) historical climate and soil data are considered here. We assumed starting conditions for each simulation as shown in Table 1. Note that for barnyard grass, the resistance mechanism and initial gene frequency are estimates, since investigations into real glyphosate resistant barnyard grass have yet to provide this information.

We developed two sets of simulations from these starting conditions. The first set (A1–A5, Table 2) consists of a number of regionally typical farming systems, and includes the presumed highest risk scenario. The second set (B1–B4, Table 3) consists of a range of scenarios investigating the effects of a double knock tactic, with several permutations of frequency and starting time.

RESULTS

The NR farming systems studied in the first set of simulations (A1–A5, Figure 1) show that weed management and agronomic practices used on a paddock can have a significant bearing on the rate of evolution of glyphosate resistance.

In the highest risk conditions (A1), a serious glyphosate resistance problem is predicted to develop after 17 years from first use of glyphosate. Adding two summer crops with relatively poor efficacy of residual herbicides every five years has a minor, but insignificant, effect on the rate of evolution for glyphosate resistance (A2). Improving the efficacy of residual herbicides and crop competition in the same number of summer crops increases the time taken to develop a serious glyphosate resistance problem by four to five years (A3). Where some glyphosate survivors in fallows are controlled with other means before setting seed (A4), the useful lifespan of glyphosate is 11 years longer than for the highest risk system. System A5 shows that conventional tillage, which does not rely as heavily on glyphosate as the conservation tillage systems A1–A4, is not predicted to develop a glyphosate resistant weed population within the 30 years simulated here.

If we assume that a visibly noticeable resistance problem in an average paddock is somewhere between one and 30% of the population being resistant, depending on how clumped together the resistant weeds are and the vigilance of the observer, Figure 1 shows that very little time elapses between a noticeable problem and an unmanageably large problem. In the highest risk simulation the population jumps from 10% resistant to 80% within two years. Where there is much less selection pressure for glyphosate resistance (A4), the population shift from 'mostly

Table 1. Initial parameter values for simulations

Parameter	Value
Resistance gene frequency	1×10^{-8}
Weed seed-bank density	30 seeds m^{-2}
Paddock size	100 ha
Soil moisture	50% full profile

Table 2. Simulated farming systems, where high tillage refers to full disturbance before summer planting and once targeting the main weed flush in summer fallows, and better agronomy refers to improved efficacy of atrazine plus the use of more competitive crop agronomy.

System	Summer crops	Tillage	Control of glyphosate survivors
A1	None	None	None
A2	2 in 5 years	Minimal	None
A3	2 in 5 years, better agronomy	Minimal	None
A4	2 in 5 years, better agronomy	Minimal	100% of main flush in fallows
A5	2 in 5 years	High	None

Table 3. Double knock regimes, with all simulations done on minimum-till basis with no summer cropping and no other control of glyphosate survivors.

System	Flushes controlled	Years applied	Times applied
B1	Largest	1–30	30
B2	Largest	2, 4, 6…30	15
B3	Largest	4, 8, 12…28	7
B4	All	11, 12	8

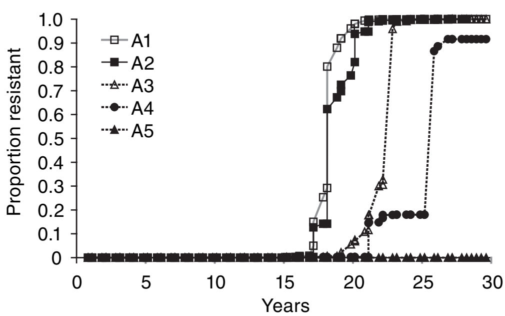

Figure 1. Predicted evolution rate of glyphosate resistance in barnyard grass in typical northern grains region farming systems.

not resistant' to 'mostly resistant' takes about eight years.

Double knock simulations based on an otherwise high-risk farming system (Figure 2) show that with increased intensity of intervention, the number of years to development of a significant glyphosate resistance problem increases. Annual double knock (B1), even on a single flush, is predicted to prevent the development of glyphosate resistance entirely within the 30 years simulated. Double knock every two years (B2) on a single flush is shown to delay the onset of a significant problem by more than ten years, compared to the highest risk simulation (A1, included for comparison). The application of a double knock strategy once every four years on a single flush (B3) is predicted to have only marginal benefit with regards to glyphosate resistance, although it increases the potential time between being able to spot resistance in the field, and the population being almost entirely resistant. In the case of two years of intensive intervention after ten years of high risk farming (B4, two years of double knock on every barnyard grass flush), the time to evolution of a severe resistance problem is increased, in comparison with the highest risk system, by five years.

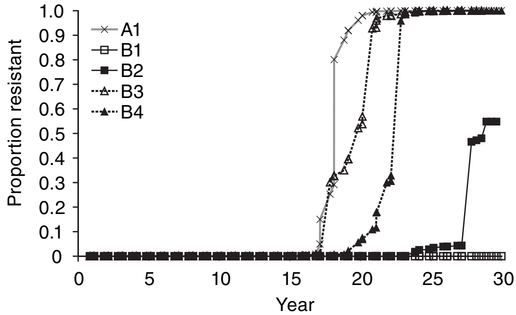

Figure 2. Predicted evolution rate of glyphosate resistance in barnyard grass under four double knock regimes.

DISCUSSION

Results from the simulations show that typical NR farming systems have a range of levels of risk of glyphosate resistance. Rapid selection for glyphosate resistance can occur where glyphosate is heavily relied upon in every year without the complementary use of alternative weed control tactics. The lowest risk systems are ones that include tillage, frequent summer cropping with good efficacy from residual herbicides, and control of the survivors of glyphosate applications. Double knock applications have been shown to be effective in extending the useful lifespan of glyphosate. Combining frequent, good quality summer cropping with occasional double knock that affects all flushes of barnyard grass, and attempting to prevent seed set in all survivors of glyphosate applications, is likely to provide the best chance of preventing glyphosate resistance in NR farming systems.

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