The risks of resistance evolving to glyphosate in Australian non-agricultural weed management systems

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Summary Glyphosate is the world's most widely used herbicide with global sales exceeding $50 billion in 2009. Western agricultural systems have become reliant on glyphosate as it has enabled the widespread adoption of reduced or no-tillage farming systems.

The development of weeds with resistance to glyphosate has paralleled the increasing reliance on this herbicide. The world's first case was found in 1996 in annual ryegrass (*Lolium rigidum* Gaudin) in no-till small grains farming in Australia. At the time of writing there are 23 species that have developed resistance to glyphosate, of which Australia has 6.

While most cases of glyphosate resistance have been confirmed in agricultural environments, the number of glyphosate resistant weed populations being found in non-agricultural land use is increasing.

In 2011–2012, research was conducted to determine current practices in the non-agricultural segment in relation to glyphosate use. The survey assessed issues include: knowledge of herbicide resistance risk; impacts on current or future adoption of alternative practices to glyphosate decision-making processes, policies and structure (including who makes decisions on weed management and what factors influence weed management decisions). This paper discusses the findings of this study and suggests appropriate awareness and extension programs for non-agricultural users of glyphosate.

Keywords Glyphosate, resistance, non-crop, lineal reserve, roadside, railway, channel, non-agricultural, weeds.

INTRODUCTION

Glyphosate is the most widely used and therefore the most important herbicide in world agriculture (Duke and Powles 2008). It is widely used because it kills a wide range of annual and perennial weed species, has low mammalian and environmental toxicity and little soil activity (Duke and Powles 2008). In addition to its use in crop and pasture systems, glyphosate is also used for weed control in other sectors including native vegetation areas, residential yards, parks and gardens, industrial premises, roadsides, rail lines and forestry.

The heavy reliance on glyphosate for weed control across such a wide range of situations leads to weed species shifts toward harder-to-kill species followed by the evolution of glyphosate resistant weed populations (Shaner 2000). This in turn leads to the development of hard-to-kill weed populations that ultimately increase weed management costs. Currently there are 23 species that have developed resistance to glyphosate in 14 countries (Heap 2012). In Australia six species have been confirmed resistant to glyphosate (Preston 2012).

While herbicide resistance has been studied and extension programs run in broadacre agriculture since the early to mid 1980s, little effort has been spent on raising awareness of the problems of glyphosate resistance in non-agricultural uses. The discovery of the first case of annual ryegrass to evolve resistance to glyphosate on a roadside was confirmed in 2010 with 85 cases now confirmed from NSW, South Australia and Western Australia. A second species, flax-leaf fleabane (*Conyza bonariensis* L. Cronquist), now has 27 confirmed populations from roadsides in NSW, Queensland and South Australia.

The evolution of glyphosate resistance in non-agricultural areas was the impetus for a project to survey areas for resistant populations, identify weed management practices used by non-agricultural land managers, evaluate existing knowledge of herbicide resistance and assess these practices to identify risks of glyphosate resistance and develop strategies to reduce the risks.

This paper discusses the findings of the market research component of the project, highlights current risks and suggests strategies to minimise the risks of developing glyphosate resistance in these areas.

METHODS

A questionnaire was developed to gather data on practices, weeds of concern, relative risk to developing herbicide resistance, understanding of herbicide resistance and its development, decision- making processes and where weed management information is sourced. Face-to-face interviews (n = 53) were preferred although telephone interviews (n = 23) were also

conducted. Interviewees were from NSW, Victoria, South Australia, Queensland and Western Australia covering a range of land managers from roadsides, rail, utilities, irrigation systems, specialist weeds contractors, local government, the NSW Roadside Environment Committee and the Department of Defence.

Interviews were of 30 to 120 minutes duration. Surveys were then allocated to organisational categories of aviation grounds, contractors, councils, irrigation, mining, rail, main roads, WA Department of Environment and Conservation (WA DEC) and utilities.

RESULTS AND DISCUSSION

Weed control using glyphosate For most areas including roadsides, roadside furniture, rail tracks, buildings and structures, mine conveyor belts, power delivery infrastructure, and firebreaks, where weeds are managed for the long term, there is no competitive vegetation.

Revegetation projects such as those following construction of roads, pipelines and mine site rehabilitation are deemed to have a lower risk of developing glyphosate resistance because the projects have a limited time-frame (2–3 years). Additionally, weed numbers are often low, and non-herbicide techniques such as scalping and replacement of topsoil are also practiced.

Road managers have weed control programs concentrating on total vegetation management for 1–3 m from the edge of the road seal. Some road managers only treat around guide posts and roadside furniture with glyphosate with or without residuals and then use slashing between the posts. Management of vegetation for the remainder of the road corridor varies between states. Although there is a trend to use these areas to conserve native vegetation, this can conflict with fire management objectives. Railways practice total vegetation control for the full width of the ballast, usually 4 to 6 m either side of the track centre.

Drivers for weed control In most sectors safety and infrastructure maintenance are the key drivers for weed control. Roadsides must have clear lines-of-site around and up to posts and signs and the allowable distance will vary with the allowed speed limit. Often there is a 30 cm intervention height for roadside vegetation. Topography and rainfall will determine whether the edge of the road 'seal' and shoulder are kept bare to prevent moisture lifting the tar. Railways also need to prevent vegetation growing in the ballast to reduce maintenance and maintain visibility.

Fire management is a significant reason for weed management in many land uses. Roads in Western Australia and southern NSW have been used in fire management for many years and there is increasing pressure on road managers to use road corridors as firebreaks, with fire authorities wanting to clear or burn corridor vegetation more often. Electricity and gas utilities as well as most land managers must reduce fire hazards so that infrastructure will be clear of vegetation prior to the commencement of the 'fire season'.

Current control practices Herbicides are the principle control strategy for most organisations. Glyphosate is the basis of nearly all herbicide applications which may or may not be applied with a tank-mix partner. Tank mixing another herbicide with glyphosate is common practice. This is usually done to broaden the weed spectrum rather than manage any potential threat from resistance. Some organisations see glyphosate as the only weed control strategy. This practice is considered 'high risk', as one of the major determinants of developing glyphosate resistance is its sole use, with few or no strategies in place to control survivors (Preston 2012).

The number of glyphosate applications in a year is usually determined by use situation and rainfall. Drier areas normally had 1–2 applications per year, whereas wetter areas ranged from 0.5 to 5 applications. In most environments spring was the key spray time, while summer spraying was dependent on summer rainfall. Fewer organisations used an autumn application unless there was early autumn rain or they wished to also apply a residual herbicide. Timing of control was also influenced by fire restrictions and when it was feasible to access the treatment area such as railways and busy public roads.

When asked what non-herbicide tactics were used, virtually all organisations used slashing (and whipper-snipping) as their main alternative management tool. Vegetation rehabilitation often used scalping or topsoil replacement and a range of selective herbicides. Weed numbers were usually low in these situations except where ex-farmland was being treated and weed number and diversity were always higher.

Significant weeds Weeds of concern that were recorded in the survey are those that glyphosate has never controlled well or have become resistant. Perennial grasses that were considered a problem include kikuyu (*Pennisetum clandestinum* Chiov.), couch (*Cynodon dactylon* L. Pers.), african lovegrass (*Eragrostis curvula* Shrad. Nees), chilean needle grass (*Nassella neesiana* (Trin & Rupr.) Barkworth) and paspalum (*P. dilatatum* Poir.). Annual grasses included annual ryegrass (*Lolium rigidum*), winter grass (*Poa annua* L.), annual veldt grass (*Ehrharta longiflora* Sm.) and

domestic cereals. It is interesting to note that feathertop Rhodes grass (*Chloris virgata* Sw.) was only mentioned in northern NSW however it is fast becoming a major roadside weed in many areas across eastern Australia. Annual broadleaf weeds in order of importance were fleabane (*Conyza* spp.), Paterson's curse (*Echium plantagineum* L.), khaki weed (*Alternanthera pungens* Kunth), capeweed (*Arctotheca calendula* L. Levyns), wild radish (*Raphanus raphanistrum* L.) and numerous others.

Level of herbicide resistance knowledge Most interviewees had low levels of understanding of the mechanisms that lead to herbicide resistance. This is to be expected as there has been little awareness and extension focus on non-agricultural herbicide use. Those with moderate to good understanding had either confronted resistance first hand, such as some rail and road managers, or had a connection with broadacre agriculture. Of concern was that many of those with a better understanding rated their risk of developing glyphosate resistance as low, despite not having any recognised resistant management strategies in place. This arose from their perception that their practice of using glyphosate once or twice a year was not selecting for resistance. This is contrary to scientific experience, as it is the number of years of use that has greatest influence, with glyphosate resistance commonly appearing after 12–15 years of use (Preston 2012).

On the other hand a number of interviewees indicated that they believed that their current herbicide practice was putting them at risk with some expecting they were at the early onset of resistance. This was also the case with respondents who had had no knowledge of glyphosate resistance before the interview. When it became clear to the interviewee there were few easy replacements for glyphosate, their level of concern increased dramatically.

Current resistance management Generally, little was being done to prevent herbicide resistance developing or to manage suspected resistant populations. Forty percent of organisations had low to very low ability to identify spray failures with no formal recording systems in place to monitor herbicide escapes except percent 'brown-out'. Any monitoring was usually *ad hoc*, and normally involved staff driving the roads for other reasons and reporting if they saw anything unusual. Managers of parks and gardens worked on a set management schedule and would be coming back to the same sites every 4 to 6 weeks so that winter weed escapes were less likely to set seed. Along roads and Council open spaces, follow-up was often in response to complaints from the public.

Rail managers tended to be the exceptions with regular patrols of the lines to spot weeds and other issues with the track. Only one other contractor had significant levels of monitoring as an integral part of their vegetation management practices.

Trends in weed management While half of the organisations had the same management regime in place for six or more years, some key trends were evident. Firstly, there was an increased reliance on contractors which usually meant a concurrent increased reliance on glyphosate to simplify management and minimise OH&S risks. Secondly, fewer residual herbicides are being used, largely to minimise risk of off-target damage and reduce costs. Many field staff felt that a change in practices was out of their control and the over-arching issue was cost containment.

When asked what would trigger a change in current weed control practices many indicated that they would use the presence of survivors as the trigger to start asking their sources of information about alternative herbicide products. There has been little thought to proactively seek an alternative product or strategy prior to the onset of survivors as this adds substantial complexity to their current operations, for no guaranteed future benefit. While there is concern over resistance, it does not appear to be overly worrying to most roadside managers as they know that they always have the option of mechanical control (slashing/whipper-snipper) if acceptable herbicides stopped working. Indeed for many, this will be the strategy of choice if glyphosate fails on key weeds, despite the increase in associated costs, and operator and traffic safety required with mechanical control. Slashing is not an available practice for rail managers so they are eager to learn about any new management strategies as they realise changing herbicide mode-of-action is a short-term option.

The potential for slashing to replace spraying maybe over-rated by some managers, as the interval required between slashing events to influence species change on roadsides is so frequent that it would be economically unviable (Storrie and Cook 1999). Slashing can also spread the seeds of those that have viable seed at the time they are slashed (Grech *et al.* 2010). There is likely to be reluctance to adopt more expensive tactics or IWM to prevent the development of glyphosate resistance in many sectors (Moss 2010), and tactics like slashing create their own problems.

Getting change and adoption For change to occur, both field staff and managers need to understand the problem they are facing.

Attitudes to herbicide resistance changed during the interview as interviewees became aware of the potential threats glyphosate resistance posed, such as increased control costs and potential need to use products and strategies that posed potential environmental and OH&S issues for their organisation. All interviewees wanted more information about glyphosate resistance management and there was general agreement that staff involved in vegetation management would benefit from training.

Awareness programs are required at all levels of the organisations involved in this study. To get behavioral change managers need to be informed that herbicide resistance is a potential OH&S, environmental or management issue that could affect future budgets.

It will therefore be important to work with employees who:

a. understand the key issues motivating the organisation,
b. are receptive to the concept of proactive weed management and not be locked into a reactive mindset, and
c. are in a position where they can influence decision making within the organisation.

Most interviewees felt a 2 hour session on how resistance develops, what species they need to monitor, and how relevant management strategies are, would meet a wide range of needs. Larger organisations felt that this could be integrated into existing staff training programs. There is also potential for half day workshops for certain sectors that require more in-depth information.

Training needs for managers will need a different emphasis to field staff and should focus on awareness and implications for use of non-glyphosate products, the necessity of scouting and monitoring, and non-herbicide options. This will be drawn together by emphasising implications for budgets and potential environmental and OH&S risks.

As contractors and sub-contractors are widely used in non-agricultural weed management, herbicide resistance training needs to be written into contracts. Additional duties such as monitoring and reporting herbicide escapes as well as the inclusion of alternate weed management tactic options could also be included in tender documents.

Relevant reference materials will also be needed in the form of easy-to-understand fact sheets and on-line resources that can be readily accessed and updated.

CONCLUSIONS

Australia has 612 000 km of roads and about 20 000 km of rail that can be considered moderate to high risk for weeds developing glyphosate resistance.

The solution to more complicated and expensive solutions in the future is to implement them now.

It is essential that a targeted awareness and extension program is developed to meet the needs of this sector before glyphosate resistance is widespread.

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