The challenges of herbicide resistance in non-agricultural weed management systems

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Summary The development of weeds with resistance to glyphosate has paralleled the increasing reliance on this herbicide. Glyphosate is the world's most widely used herbicide with global use exceeding 850,000 tonnes in 2015. Western agricultural systems are increasingly reliant on glyphosate due to the expanding cultivation of glyphosate-resistant crops and the widespread use of glyphosate fallows for reduced or no-tillage farming systems. These systems have environmental benefits of reduced soil erosion and fuel consumption, with production benefits of lower labour and capital costs, and higher and more reliable crop yield through improved stored soil water.

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 also increasing.

The world's first case was found in 1996 in annual ryegrass (*Lolium rigidum* Gaudin.) in no-till small grains farming in Australia. Currently there are 38 species that have developed resistance to glyphosate, of which Australia has 17.

The increasing incidence of glyphosate resistance is concurrently increasing the use and pressure on other herbicides with different modes of action such as paraquat, glufosinate and grass selective herbicides.

Most Australian broadacre farmers have been exposed to the herbicide resistance management message for over 30 years. However, a 2011–2012 national study of glyphosate use practices in the non-agricultural sector found little awareness of the issues. Current evidence suggests little has changed in the last 6 years except for more cases of glyphosate resistance. Key targets for many weed management decision-makers are based on cost and aversion risk to staff and the public.

This paper discusses the current direction of the development of herbicide resistance and suggests appropriate awareness and extension programs for non-agricultural users of herbicides.

Keywords Glyphosate, herbicide-tolerant, paraquat, amitrole, glufosinate, non-crop, lineal reserve, roadside, railway, irrigation channel.

INTRODUCTION

Glyphosate is the world's most widely used herbicide with annual use estimated at over 826,000 tonnes in 2014 (Anon. 2018). A large proportion of this usage will be with the increase in herbicide-tolerant crops. It has been estimated that in 2016 there were 186 million hectares of genetically modified crops grown in the world (James 2017). Glyphosate is also widely used for weed control in other sectors including native vegetation rehabilitation, residential yards, parks and gardens, industrial premises, roadsides, rail lines and forestry. Its popularity is due to: low cost; the large number of species it controls; low odour; minimal soil activity; and low mammalian toxicity. The Australian Pesticides & Veterinary Medicines Authority (APVMA) has determined that glyphosate poses little risk to human health (Anon. 2017).

The wide usage of glyphosate in Australia is demonstrated by registration of 584 products containing glyphosate with nearly 40,000 registered uses (Infopest 2018).

Heavy reliance on any herbicide leads to the selection weed populations that can be both resistant or tolerant to that herbicide mode of action (Storrie 2014). Outside of agricultural uses, roadsides are one of the highest risk areas for selecting herbicide-resistant or tolerant weeds due to the repeated use of a herbicide with few non-herbicidal control strategies being used.

This paper updates the current world and Australian development of glyphosate-resistant weed populations and discusses alternatives to current use patterns with particular emphasis on roadsides. It also explores the possibility of applying an awareness strategy used in weed biosecurity on intractable roadside weeds.

CURRENT GLOBAL STATE OF GLYPHOSATE RESISTANCE

There are now 41 weed species confirmed to have resistant populations globally in 29 countries (Heap 2018). This has doubled since 2011.

The concerning and growing complication is that at least one quarter of these populations are also resistant to one or more other herbicide modes of action. Australia holds the multiple resistant record so

far with 5 modes of action in populations of annual ryegrass (*Lolium rigidum* Gaudin) and winter grass (*Poa annua* L.).

Resistance to multiple modes of action pose huge increases in weed control difficulty. This is called multiple resistance and it is a result of using a number of different herbicide modes of action without managing the seed set of spray survivors. Unfortunately, rotating herbicide modes of action continues to be one of the first recommendations in many herbicide-resistance management strategies.

In the last 7 years some countries have had large increases in the number resistant species while other countries have had no or little change (Table 1). Australia's more than tripling of glyphosate-resistant species largely comes from the widespread adoption of no-till crops with a concurrent decline in cultivation for weed control. This is compounded by the extensive use of fallow that is kept weed-free by the repeated use of glyphosate (Storrie 2014). The Americas have had the next largest increase (excepting Chile) largely due to the widespread adoption of glyphosate-resistant crops. European countries do not grow significant areas of herbicide-tolerant crops.

Other knockdowns There is a problem with the increasing resistance to other knockdown (non-selective) herbicides such as paraquat (Group L), glufosinate (Group N) and amitrole (Group Q). To date Australia has 10 species with Group L resistance. Globally three species have glufosinate resistant populations and all but one have multiple resistance to 2, 3 or 4 modes of action. Six species have resistance to amitrole, including annual ryegrass in Australia. Three of these species are also resistant to 2 or 3 modes of action.

Table 1. The number of species with populations resistant to glyphosate in 2011 and 2018 for a range of countries. (Heap 2018).

Country	Number of species	
	2011	2018
Australia	5	17
USA	11	17
Canada	1	6
Brazil	5	8
Argentina	3	11
Chile	1	1
Spain	5	5
France	2	2
China	2	2
Israel	2	2
South Africa	3	3

Glufosinate has been widely used in fruit trees and vines following registration in 1995. Glufosinate is now also being used in broadacre cropping as a fallow herbicide and as a post-emergent in glufosinate-resistant LibertyLink™ crops including cotton, maize, soybeans, sugar beet and canola. There are over 24 million hectares of LibertyLink™ crops being grown globally (James 2017).

GLYPHOSATE RESISTANCE IN AUSTRALIA

There are currently 17 species with populations confirmed resistant to glyphosate including 10 grass species and 7 broadleaf species of which 6 are winter-growing weed species and 11 are either non-seasonal or summer-growing species (Preston 2018). A detailed list can be found elsewhere (AGSWG 2018).

Many of these populations have been selected in broadacre cropping or related areas such as around buildings and along irrigation channels. Annual ryegrass, flaxleaf fleabane (*Conyza bonariensis* (L.) Cronquist), tall fleabane (*Conyza sumatrensis* (Retz.) E. Walker), windmill grass (*Chloris truncata* R.Br.) and feathertop Rhodes grass (*Chloris virgata* Sw.) are however now significant roadside weeds.

THE PROBLEM WITH ROADSIDES

Australia has nearly 800,000 km of roads (Anon. 1987) that are at risk of developing weeds with resistance to glyphosate. Road 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 maximum height for roadside vegetation. Road edges or shoulders are also managed to keep them clear of vegetation to minimise movement of water under the 'seal' or into the road-base to minimise pot-holing and increased maintenance costs (Storrie *et al.* 2012). The two main methods of vegetation management are slashing and spraying.

Slashing is relatively slow and often requires several staff to alert motorists to the tractor-slasher ahead. In wet years and higher rainfall areas such as the coast it can be difficult to keep vegetation at the allowable height. The design of many slashers also makes it impossible to prevent weed seed spread without significant down-time for cleaning. Also, most slashers are not able to get close to roadside furniture. Some managers deal with this by spraying around posts and roadside furniture.

Spraying the road shoulder is now the major form of vegetation management outside town boundaries.

The width of the sprayed area varies from 1–5 m (Storrie *et al*. 2012). Glyphosate is the main herbicide used. Tank-mixing with other herbicide modes of action is often used to broaden the range of weeds controlled. The use of tank-mix partners, if any, will vary greatly depending on the management authority and state legislation.

The number of glyphosate applications in a year is usually determined by use situation and rainfall. Drier areas normally have 1–2 glyphosate applications per year, whereas wetter areas range from 1–5 applications. In most environments spring is the key spray time, while summer spraying is dependent on summer rainfall (Storrie *et al.* 2012).

Market research has found most non-agricultural land managers are ill prepared to deal with glyphosate resistance and found that many councils would only use glyphosate for simplicity, safety and cost (Storrie *et al.* 2012). Field staff and contractors wanted training, but this was not mirrored by management.

A review of weed management plans by authorities involved with roadside management shows no mention of the threat of herbicide resistance. Roadside weed management focuses on managing remnant vegetation, and declared and Weeds of National Significance.

A 2011–2012 project on non-agricultural glyphosate use in Australia included a physical survey that targeted four weeds – annual ryegrass, fleabanes, windmill grass, and awnless barnyard grass (*Echinochloa colona* (L.) Link) (Malone *et al.* 2012). Testing showed that half the annual ryegrass and fleabane samples were resistant to glyphosate as were a smaller number of windmill grass populations. The majority of resistant samples came from roadsides.

Glyphosate-tolerant weeds are also becoming an increasing roadside problem. Glyphosate-tolerant weeds include *Hyparrhenia* species, African lovegrass (*Eragrostis curvula* (Schrad.) Nees), windmill grass, feathertop Rhodes grass, flaxleaf and tall fleabanes, crownbeard (*Verbesina encelioides* (Cav.) A.Gray subsp. *encelioides*), stinkwort (*Dittrichia graveolens* (L.) Greuter) and dove weed (*Croton setiger* Hook.).

Failure to manage for glyphosate resistance on roadsides is well demonstrated in South Australia (SA). In the early 2000s the SA government decided that only glyphosate would be used on roadsides for environmental work, and for health and safety reasons. In 2011 the Department of Planning, Transport & Infrastructure were alerted to widespread infestations of glyphosate-resistant annual ryegrass on many SA roads. This was raised by irate farmer organisations concerned about the spread of glyphosate-resistant weeds from roadsides into their paddocks. The SA government then had to quickly develop a state-wide management plan to arrest the problem. Resistant infestations on roadsides are now mapped and receive additional control tactics as well including a tank-mix of paraquat plus amitrole following glyphosate.

How to manage roadsides There are two basic options to manage difficult roadside weeds. First is the reactionary approach where the decision makers are forced into playing 'catch-up', often implementing systems that are expensive and less than ideal from a cost and worker safety perspective. The second and preferable option is proactive implementation of relatively simple monitoring and management systems to identify and deal with hard-to-control weeds.

As discussed there is ample evidence across the nation of increasing incidence of both glyphosate-resistant and glyphosate-tolerant weeds on roadsides, however despite this, little proactive management takes place, due to either decision makers for remaining unaware of the problem, or they consider it a low priority (Congreve *et al.* 2012).

For change to occur contractors, field staff and managers must understand the threats and cascading effects resulting from hard-to-control weeds. Many authorities have already started mapping 'significant' roadside vegetation so it is only a small step to map glyphosate-resistant and tolerant weeds as they are the ones still growing after treatment.

Resistance management costs will need to be included in contract costs with the contractor not bearing the additional cost.

To initiate change, messages need to be framed in positive terms to which managers can relate. Messaging to get managers 'on-board' might include:

cheaper overall weed management – monitoring and mapping of problem weeds allows site-specific programs to be used, rather that treat all roadsides with more expensive strategies;

better relationships with ratepayers / Councillors. Spread of glyphosate resistant or tolerant weeds into farmers' paddocks creates unnecessary conflict; and

well trained and involved staff will be happier and work more effectively.

A great start to the management of these weeds would be a modification of the 'Red guide post program' (Bosse 2017). This program aimed to increase awareness of declared weeds on roadsides and was supported by a well planned extension campaign that included a wide range of pathways targeting all road users and managers.

Using a similar strategy for resistant and tolerant roadside weeds could easily improve adoption of better management, reduce the risk of increasing roadside

vegetation management costs and reduce the spread of these weeds.

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