Managing glyphosate resistance

K.C. Harrington[1], T.K. James[2] and M.D. Parker[3]
[1]Massey University, Private Bag 11-222, Palmerston North, New Zealand
[2]AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand
[3]Foundation for Arable Research, 85 Duncan Rd, RD3, Hamilton, New Zealand

August 2014

Background

Glyphosate is the most widely used herbicide in the world. It effectively kills a very wide range of broad-leaved and grass species, both annuals and perennials. Because glyphosate translocates down into underground structures, there is usually less regrowth than with most other herbicides. It is also strongly adsorbed onto soil particles thus losing activity on contact with the soil, making it suitable for use in preparing ground for sowing crops. Glyphosate also has a lower mammalian toxicity than many other herbicides. As a result, glyphosate is widely used for weed control throughout New Zealand in areas as diverse as along roadsides, urban areas, most cropping situations and pastoral systems for crop or pasture establishment, and selectively within orchard crops and vineyards.

As glyphosate is generally considered more effective and environmentally more benign than most other herbicide products, it could be considered to be over-used. There are many situations in New Zealand where glyphosate might be applied three or four times a year with no other form of weed control used, a recipe for herbicide resistance evolution. Glyphosate-resistant populations of weeds have recently developed in many parts of the world, especially USA and Australia (Heap 2014), due to repeated use of the herbicide causing selection pressure for individual plants with mutations that allow them to survive exposure to glyphosate. Continuing to apply only glyphosate allows these individuals to thrive without competition, multiply up and become the dominant vegetation in these sprayed areas (Preston 2014).

In 2013, the first cases of glyphosate resistance were reported in New Zealand, with perennial ryegrass and Italian ryegrass both developing resistant populations following many years of repeated glyphosate applications in Marlborough and Nelson vineyards (Ghanizadeh et al. 2013). This made us realise it was time to develop some glyphosate resistance management strategies for New Zealand before the problem became widespread.

General resistance management and prevention strategy

One of the main strategies to avoid resistance from occurring is to **occasionally use a herbicide with a different mode of action or use glyphosate in combination with a herbicide with another mode of action.**

Glyphosate is classed as being in Group G, as can be seen in the mode of action table, *http://resistance.nzpps.org/index.php?p=herbicides/mode_of_action* , so herbicides used in combination should be from another group. Glyphosate has a very large number of trade names in New Zealand, including various Roundup formulations, Glymax, Lion, Polaris, Samurai, Turbo, Zelam G360, Dryphosate, GForce Max, Deal, Touchdown, Weedmaster, *etc*. So alternating between these formulations will not reduce the selection pressure for glyphosate resistance. Looking for herbicides that are not Group G will help with selection of appropriate alternatives.

Following many sequential applications of glyphosate, some growers confuse the development of glyphosate-resistant populations within species that are normally susceptible to glyphosate (such as ryegrass) with the build-up of species that have never been controlled well by glyphosate, such as white clover, tall willow herb and mallows. However, similar strategies are required to solve both problems, so **if herbicide rotation and mixtures are used correctly, there should be no build-up of these tolerant species or individuals with genes for resistance**.

As part of a good herbicide programme, observations should be made of plants not controlled by glyphosate and be aware that this poor control might require changes in the way herbicides are being used rather than simply ignoring the situation. This strategy is called 'Looking for escapes' and these weeds which 'escape' control (not ones which emerge and grow after application) should be destroyed either by hand or by the use of another herbicide. **Herbicide rotations are only effective if the alternative products selected are able to control the weeds not affected by the glyphosate**.

Some suitable herbicide rotations will be suggested below for specific situations. Another overall strategy though is to not use just herbicides for weed control, but to **alternate with other weed control strategies such as cultivation, mowing, growing competitive ground covers or applying mulches**.

Specific situations where glyphosate is currently being over-used at times within New Zealand are listed below with suggestions on how to avoid herbicide resistance from developing:

- Vineyards and orchards
- Roadsides, railways, amenity areas and waste areas
- Fence-lines and headlands in arable crops and pastures

Vineyards and orchards

Although our first cases of glyphosate resistance have developed in vineyards, similar selection pressures are also being applied within pipfruit orchards, kiwifruit and other perennial fruit crops. Because glyphosate is more effective and less expensive than alternative herbicides, and also less likely to result in herbicide residues within fruit which

could cause market access problems like alternative herbicides, or contaminate ground-water, many growers have moved to using only glyphosate to control weeds. This has often led to a build-up of tolerant weed species such as mallows and tall willow herb.

Where possible, growers should try to rotate and alternate herbicides during and between seasons. Amitrole (Group F3) is a broad-spectrum translocated herbicide generally not permitted while fruit are on vines or trees, but can be used in late winter to clean up weeds prior to the growing season, or after fruit harvest to deal with weeds that have built-up during the season, especially perennial weeds. Unfortunately a few (though not all) of the **glyphosate-resistant ryegrass populations found in Marlborough appear to be also resistant to amitrole**.

Glufosinate (Group H), sold as Buster, Bash, Fiestar, Nirvana, Agpro Glufosinate and in Vixen, is permitted in most fruit crops and, although it doesn't translocate into root systems, can be a useful product to rotate with glyphosate in summer, especially for annual weeds. Note however, that in some cases overseas **weeds have developed simultaneous resistance to glyphosate and glufosinate, even though glufosinate has never been used, and initial results suggest this is also the case with the glyphosate-resistant ryegrass in New Zealand.** Paraquat (Group D), sold as Gramoxone, Flash, Parable, PQ 200, Speedy and Uniquat, is now not permitted by some producer boards to be used in some fruit crops. However this is another herbicide that has been shown to be useful for rotating with glyphosate in fruit crops in Australia when glyphosate resistance has caused problems, although like glufosinate it to does not move into root systems. Experience in Australian vineyards unfortunately has shown that rotating with just glyphosate and paraquat can lead to resistance to both herbicides in rigid ryegrass (*Lolium rigidum*).

These are the main broad-spectrum post-emergence herbicides used in fruit crops. But there some herbicides used for specific weeds, especially Group A grass-killers such as fluazifop (Fusilade Forte) and clethodim (*eg* Centurion, Arrow, Cleo, Sequence, Vega) which can be used for grass weeds that have not died following application of these other herbicides. Fluazifop can give good control of glyphosate-resistant Italian ryegrass but is ineffective on perennial ryegrass which would need to be treated with clethodim.

Although currently frowned upon by many producer boards, residual herbicides can also be used to help prevent development of glyphosate resistance and thus allow more sustainable weed control. By having a herbicide such as terbuthylazine (Group C1, *eg* Gardoprim, Tyllanex, Terb 500, Terbo Flo, Nu-Terb 900) controlling weeds as they germinate for several months each year, this will reduce the number of weeds that need to be controlled by glyphosate. The full range of orchard residual herbicides and information on how to rotate these correctly can be found in our orchard triazine resistance strategy (Harrington 2014) *http://resistance.nzpps.org/index.php?p=herbicides/triazine_orchard* . Given the issues with amitrole, glufosinate and paraquat mentioned above, residual

herbicides probably need to become more commonly used again in fruit crops if sustainable levels of weed control are to be maintained in coming years.

Several products exist on the market for mixing with glyphosate to improve control of tolerant species such as mallows, and these include carfentrazone (Shark, Hammer, Affinity Force), oxyfluorfen (*eg* Goal, Browndown), fluroxypyr (Solstar, Tomahawk, Starane Xtra, Tandus) and saflufenacil (Sharpen). These are all herbicides with different modes of action so may help prevent glyphosate resistant biotypes from developing. With all of these alternatives though, check first that they are registered for use in the fruit crop being considered using the Novachem Manual (Agrimedia 2014) or on-line sample labels for New Zealand from the chemical's proprietor.

Once trees and vines are well-established, it should be possible to have the mown sward between the crop rows growing almost up to the base of the tree or vine without affecting crop yields. With off-set mowers that can mow under the branches, herbicide really only needs to be used for keeping vegetation away from the base of the tree or vine to facilitate the mowing process. By keeping the sprayed strip as narrow as possible, less weeds need to be sprayed, possibly reducing the chances of resistant individuals appearing, but also making it less costly per hectare of crop if more expensive alternative herbicides are used. If it is possible to direct mown clippings on to the narrow sprayed strip, this may form a thick enough mulch to reduce the germination of new weeds. Grazing of vineyards and orchards through winter may also reduce seed production for some weed species though won't have much effect on other species such as established ryegrasses. In some systems, use of flame-weeders or shallow cultivators might be an option for controlling weeds around the base of trees and vines.

Roadsides, railways, amenity areas and waste areas

Constant use of just glyphosate in situations such as roadsides, railways, urban areas and general waste areas provides a very strong selection pressure for development of glyphosate-resistant biotypes of weeds. A common strategy that has been used to avoid build-up of tolerant species is to add metsulfuron (*eg* Escort, Answer, Matrix, Eradicate, Zeal) to the glyphosate from time to time, or every time it is used. **Using metsulfuron too frequently increases the risk of resistance developing to this herbicide too, so it probably only needs adding once every three or four applications.** Another option is to add amitrole to the glyphosate occasionally, or to use amitrole by itself. Adding either metsulfuron or amitrole to the programme will also reduce the chance of glyphosate resistance from developing.

Ideally, a residual herbicide should also be added to the mixture. This reduces the chance of glyphosate resistance developing both by reducing the regularity with which glyphosate needs to be applied plus by adding a herbicide with another mode of action to the control programme. Although residual herbicides are used less often now due to risks of

contamination of water-ways, in some situations this risk may not exist, and also a few residual herbicides such as oxyfluorfen are less likely to leach into waterways than others. In gravely areas such as roadsides and railways, however, residual herbicides are often less effective, providing little added benefit to glyphosate alone, so are only useful for their knockdown value.

Many residual herbicides are available on the market that might be used in waste areas, including simazine, terbuthylazine, oxyfluorfen, oxadiazon, diuron, bromacil, terbacil and imazapyr (Agrimedia 2014). Some of these are available as mixtures, such as Terminator GTA (glyphosate + terbuthylazine + amitrole) and TAG G2 (the same mixture with oxyfluorfen also added).

In some waste areas, it may be possible to make a few small changes to the site to make it more suited to being mowed, removing the need for herbicides and providing a better surface for reducing nutrient and hydrocarbon flow into drains than bare gravel. Or perhaps areas can be covered in concrete or bitumen to make weed growth less likely. Some areas might be suitable for converting into gardens with bark mulch and perennial shrubs to remove the need for herbicides.

Fence-lines and headlands with crops and pastures

Some pastoral farmers apply glyphosate frequently along the bottom of electric fence-lines to stop vegetation growing up into the fence and shorting it out. The comments above about adding in products such as metsulfuron, amitrole and a residual herbicide apply here as well. However, the best strategy may be simply to not have the bottom wire electrified or raise the bottom wire as livestock frequently graze pasture very hard under fence-lines due to less dung and urine being deposited here. Removing electrified wires at the base so that grazing is not discouraged may provide perfect vegetation control, without needing to rely on non-selective herbicides which create bare ground and thus encourage weeds to establish.

Around the edges of arable crops there is usually an area of bare ground known as a headland where no crop is grown so that harvesters, other machinery and crop plants do not get too close to fence-lines, especially where machinery is turning at the end of rows. As this soil is left bare, weeds generally grow, and some farmers control these weeds year after year in frequently cropped paddocks using glyphosate to prevent weed seed production, contamination of the crop (*eg* by weeds such as yellow bristle grass) and to keep paddocks tidy. If done too often, this could lead to glyphosate resistance developing. Although some of the herbicides mentioned above could be added to the glyphosate to reduce this risk, residues from these herbicides may affect future use of this land.

One possibility is to cultivate or mow the headland on occasions to keep weeds controlled. Or if the paddock was previously in pasture, the pasture could be left unsprayed and

uncultivated in this zone. Recent trials by the Foundation for Arable Research (FAR) have found establishment of weed suppressing swards of species such as clovers (red or white), lucerne, prairie grass or other pasture grasses in this zone can decrease weed growth without relying on glyphosate. In addition they provide a buffer zone for nutrient runoff, and in the case of the legumes provide additional nitrogen to the outside crop margin. These suppressive species can also be sprayed with selective herbicides to control troublesome species such as yellow bristle grass. On dairy farms in particular, these headland species can also provide extra feed when the crop stubble is grazed.

Applying glyphosate across a paddock prior to direct drilling shouldn't result in resistance developing, even if done every year, because selective herbicides used within the crop should deal with any resistant individuals that survive. However, if patches of a weed survive the glyphosate spraying which would have been expected to die, it might pay to cultivate the paddock prior to sowing just to make sure they are controlled. Large patches of surviving weeds may not be controlled by the normal herbicides used in the crop. As the glyphosate resistance trait in ryegrasses is known to be carried in pollen, it is possible that it might spread into pastures from nearby areas where glyphosate has been overused.

Acknowledgements

The assistance of colleagues within the Herbicide Resistance Task Force and also the SFF/FAR Glyphosate Resistance project in providing constructive comments on this strategy was appreciated. Funding from the Sustainable Farming Fund and collaborating funding bodies helped bring some of the information used in this strategy together, and Hossein Ghanizadeh shed new light on some aspects of the glyphosate-resistant ryegrass problem with his PhD work at Massey University.

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