Could herbicide resistance reduce the growth potential of our primary industries?

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KELLOGG RURAL LEADERSHIP PROGRAMME

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Lastly and certainly not least I wish to thank the Kellogg Programme Partners for their continued support and acknowledge the great team of people I was lucky to participate in the programme with; Cohorts 45 & 46.

3. Executive summary

Background: Thanks to our climate, location and innovate farming practices NZ primary producers have become very successful through being highly efficient at producing high quality and trusted foods.

Crop protection products have contributed to the success of New Zealand farmers and growers for many years. Whilst this is likely to continue for the foreseeable future, the rate that plants, insects and diseases are developing resistance to these tools is growing and likely to increasingly cost our industry and country into the future.

This report focuses on herbicide resistance and compares our situation in New Zealand to other OECD countries we often compare ourselves with. This report highlights current knowledge and/or awareness gaps, shares information we might use to influence decision making and propose ideas that we might adopt to tackle this issue.

This report answers two questions;

1, Could herbicide resistance reduce the growth potential of NZ's primary industries?

2, How might NZ mitigate the affects of herbicide resistance to our primary sectors?

Key Findings: Herbicide Resistance is a significant and growing threat to global food production (CropLife Australia). In NZ, the incidence of herbicide resistance has risen significantly over the last two decades (NZ Plant Protection Society). In one recent arable sector survey, completed in the canterbury region, it was reported that 48% of farms tested had some form of herbicide resistance (Buddenhagen 2021).

An overseas example from the UK shows one weed (Black Grass) is costing the UK economy nearly £400 million and 800,000 tonnes of lost harvest yield each year, with potential implications for national food security. The worst-case scenario – where all fields have a high proportion of resistant black-grass – could result in an annual cost of £1 billion, with a wheat yield loss of 3.4 million tonnes per year (Rothamsted 2019).

The majority of herbicide resistance cases have arisen during a time where only one new herbicide mode of action has been introduced, in the last 30 years (Blois 2022). When considering this trend, along with the industries need to replace "old chemistry" products and as certain ingredients become restricted, prohibited or ineffective (APHANZ 2021), it's clear we need to be doing more to manage this issue to be able to farm effectively into the future.

Recommendations: More detail is discussed in the recommendations section of this report. For this section I have kept this brief and grouped into six key areas;

1, Strategy – Whilst we support those currently managing herbicide resistance issues and those working in this area, we also should develop cohesive strategies. The plural is important, as in conjunction with a national strategy, this should be supported by regional and sector strategies to maximize results.

2, Awareness – To succeed, we will need to lift the level of importance of this issue, such that it receives more 'band width' and focus with in each of our farming sectors and on farm. Respected farming leaders could help champion this (similar to rural mental health).

3, Collaborate – We must act together in a structured way. For this to be most effective, we should consider how we can best engage national and regional government, science, sector bodies, rural professionals and applicators, but with farmers and their advisors in mind so that practices are practical.

4, Educate – Our sector is well resourced with experienced people in the following areas; science, extension and industry. With a staged and cohesive approach, we can improve knowledge levels on how to improve outcomes into the future. We are fortunate to have much science to refer to in this area.

5, Support – With the development of national, regional and sector plans, farmers will need support to help them implement these locally. Local groups should be developed and supported so that practices and strategies can be implemented. This will of course need national and local funding to succeed, this should be a mix of government (national and regional), sector and industry.

6, Act – With the benefit of clear, national, regional and sector plans we must implement change, utilizing new, existing and local best management practices to reduce the growth in future incidences of herbicide resistance to improve outcomes for our industry and farmers. This could start with reviewing the NZ Herbicide Resistance Task Force, which is a group of NZ Plant Protection Society members who are actively involved with researching herbicide resistance within New Zealand, to decide if this is fit for purpose and whether further support and investment is needed.

For more detail in any of these areas, please continue reading this report.

If you have any additional thoughts or questions, feel free to reach out to me via Rural Leaders team (LINK).

4. Introduction

New Zealand is blessed with a beautiful landscape, productive soils and innovative peoples who, over time, have collectively built a world class primary produce industry.

We are well known for our primary exports and have grown these into many high value markets internationally. A few examples of these are; the **Zespri** brand with its ability to generate premiums for its fruit globally (Zespri 2022), more recently, the increased focus from **Fonterra** on higher value markets – such as pediatrics, sports nutrition and medial ageing (New Zealand Milk Products), the packaging and free range 'Grass Fed' portfolio from **Silver Fern Farms** designed to stand out in the retail environment (SFF products for home), or the innovative and collaborative pipfruit industry approach who developed **Rockit** apples to forge a niche solution for busy mums and kids looking for a tasty apple (Stuff 2021) to name a few.

Unlike many countries NZ is regularly compared to within the OECD; Australia, United Kingdom and USA, NZ has a relatively high level (5.7%) of export earnings derived from our primary sector as a percentage of GDP (World Bank). In 2020, this equated to $48b; with dairy ($20.1b), meat and wool ($10.6b) and horticulture ($6.5b) rounding out the top three earners (MPI SOPI).

It is estimated NZ feeds 'more than 40 million global consumers each year' (NZ Trade & Enterprise)

For New Zealand to maintain its competitive advantage innovation will remain important, through utilizing a range of novel management practices to meet our farming goals and that of our global consumers.

With the world's growing population forecast to reach 10 billion by 2050 (UN data), we must remain productive whether this be at a local, regional or global perspectives.

It is well documented that our arable land is declining, whether measured globally (UN data) or locally. A recent NZ report showed the total area of land used for agriculture and horticulture has been decreasing since 2002 with an overall reduction of 1,878,409 hectares (14%) between 2002 and 2019 (Stats NZ 2021).

Many of our more affluent consumers expect or choose their produce by visual methods, meaning this produce needs to be free of many blemishes and visually appealing (Bilow 2014). Certainly, this is the case for fresh fruit and vegetables, where one only needs to spend time in some of our industries grading and packing sheds to confirm this.

This consumer approach supports the need to produce high quality foods, where New Zealand can create a point of difference and therefore continue to achieve premiums for our produce.

In a recent published report, designed to highlight the importance of the crop protection industry to the New Zealand economy, Agcarm, now Animal and Plant Health New Zealand (APHANZ) commissioned NZIER to produce a report, which showed some important statistics in relation to crop protection products (Nixon 2019);

1. Crop protection products contribution to NZ GDP was approximately $142.5 million in 2018.

2. The crop protection industry is less than 1% of GDP but the industries it services represent 10% of GDP.

3. Withdrawing crop protection products from the market would cost between $7.5 and $11.4 billion to the New Zealand economy.

This report also stated, "small increases in productivity can have major impacts". An example of this was how the kiwifruit industry responded to Psa-V, which illustrates how critical crop protection products can be in safeguarding horticultural productivity and managing the risk of a loss in productivity.

The report also highlighted how the cost of regulatory delays maybe affecting our economy and environment. In the last five years the time taken for EPA to approve applications has doubled. Over a ten-year period, this is estimated to cost New Zealand between $7 million and $70 million in contribution to GDP.

This report highlights the importance of crop protection solutions towards maintaining a high value and profitable primary industry for New Zealand.

Herbicide-resistant weeds are a serious threat to agricultural production in New Zealand. Since a review published in 1996, the number of different incidences of weed developing resistance to one or more herbicides in New Zealand has almost quadrupled (Ghanizadeh 2019). Most herbicide-resistant weed species reported in 1996 were found in the pasture and arable sectors. Since then, herbicide resistance has grown to a total of 25 cases, with resistance to nine herbicide sites of action, reported in different New Zealand agricultural and non-agricultural sectors. Whilst this figure may seem small it is the recent growth curve and number of findings recently that are concerning.

Developing an effective herbicide resistance management strategy requires a good understanding of both the extent of the problem, and also molecular and biochemical aspects of herbicide resistance, in order to develop innovative techniques to overcome herbicide resistance (Ghanizadeh 2019).

We must also look to how a range of cultural practices might improve the prospects for our future.

Figure 1 – CropLife Australia Fast Sheet Infographic

Source – https://www.croplife.org.au/wp-content/uploads/2017/12/RM_Herbicide_Infographic.pdf

Herbicides are likely to remain the key means of weed management and be the primary means for reducing soil tillage practices. Therefore, the conservation of herbicides is likely to continue to be important for the sustainability of contemporary agriculture. Herbicide molecules (and other pesticides) are scarce resources, upon which consumers largely rely on for food, feed, fiber, and energy security.

Management practices that minimize the evolution of resistance have been identified and will be invaluable in preserving these vital resources. Resistance management begins with good agronomic practices, including the implementation of integrated weed management strategies that use a diverse range of tactics to reduce the frequency of herbicide applications and lessen the selection pressure they exert on weed populations.

5. Aims and objectives

The aim of this report is to help lift awareness of this growing issue, so that we might be able to implement a range of cross sector collaboration projects, to help farmers and their industry advisors rise to the challenge of increasing herbicide resistance incidences.

Whilst this project includes some technical information, it is not the authors intent to provide detailed technical information to educate our industry on the mechanisms of herbicide resistance. We are fortunate to have many technically experienced and capable people in this area, along with some very good technical reference papers for those wanting to dive deeper into this topic.

The objective of this report is to start a higher-level discussion about how we might collaborate to slow the prevalence of this issue and to highlight basic methods farmers might adopt to mitigate some of the potential effects of herbicide resistance. I aim to propose ways we might structure and resource this issue by sharing examples from some of our trading partners on what herbicide resistance is costing their primary industries and what some countries are doing to address this issue.

A key goal of this paper is that in a few years' time New Zealand has detailed; national, regional and sector strategies in place, with a support network who are implementing a range of plans and are leading the change I believe our industry needs to help us thrive into the future. So that farmers are able to start managing this issue well, not only for themselves, but as the great stewards of the land they are and that they have a range of plans, resources and practices in place to help protect the viability of our industry for future generations.

Typical multigenerational NZ farming business

Image Source Stuff NZ

6. Methodology

Literature Review

The primary investigative method used in this report was a literature review of herbicide resistance papers. This included both NZ and international research.

This literature review included a range of sources including; peer reviewed papers, websites, news articles, government and sector publications as well as industry information.

This helped identify emerging themes on the current state of herbicide resistance across New Zealand and other regions from around the globe. Including what some researchers have identified as critical success factors when developing herbicide resistance strategies.

Semi Structured Interviews

Following the literature review 14 semi-structured interviews were completed with a range of industry stakeholders who represented differing sectors across the primary industry. This included personnel from; Scientific/Research, Market Sector Bodies, Rural Professionals and End Users/Applicators.

During the literature review and interview's key themes emerged which I have explored further in the report.

7. Literature Review

Weeds are defined as 'unwanted plants' and are regarded as one of the impediments to world agricultural production. If left uncontrolled, weeds not only influence the quantity (i.e., yield) of desirable plants, but also affect the quality of crops. Effective weed management measures have always been crucial for successful agricultural production (Ghanizadeh 2019).

7.1 Significant Growth in Global Herbicide Incidences

Globally incidences of herbicide resistance have risen significantly over the last four decades. The global Weed Science website reports in the year 2021 there were 1,623 confirmed cases, compared to only 40 in 1980.

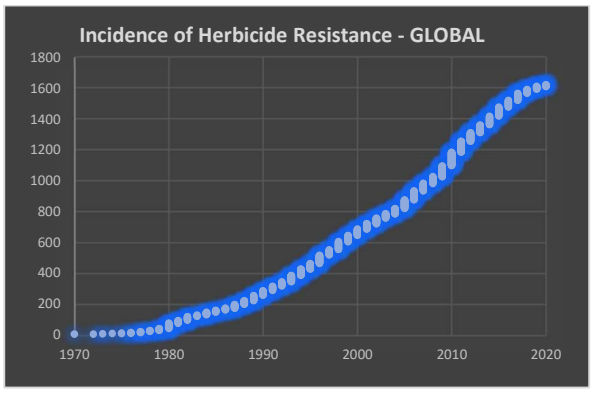


Figure 2 – INTERNATIONAL HERBICIDE-RESISTANT WEED DATABASE

Source – https://www.weedscience.org/Pages/GeoChart.aspx

Two large contributors to these figures, who NZ regularly compares ourselves to, are the United States of America and Australia. Since 1980 these two countries have increased from a relatively low base to 576 and 153 incidences respectively.

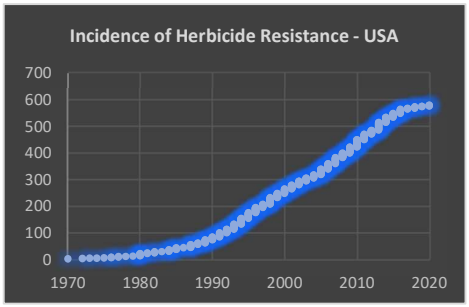


Figure 3 – USA HERBICIDE-RESISTANT WEED DATABASE

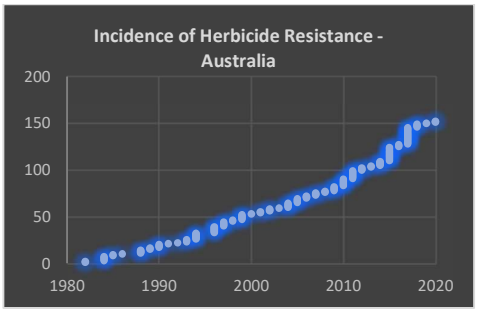


Figure 4 – AUSTRALIA HERBICIDE-RESISTANT WEED DATABASE

Source – https://www.weedscience.org/Pages/GeoChart.aspx

This equates to approximately one incidence per 572,000 people in the USA population and one incidence per 168,000 people in the Australian population.

In the USA many of the incidences are related to the growing of; cotton, corn, soyabeans and cereals.

In Australia many of the cases are related to the growing of; cereals and other arable crops such as canola and chickpeas. Also included in the higher reported incidences are; golf courses and fallow situations.

In two similar sized (by area) countries that have relatively similar climates and similar environmental regulatory systems, New Zealand and the UK have a similar number of herbicide resistance incidences.

In the 2020 year, NZ and the UK had 22 and 25 reported incidences respectively.

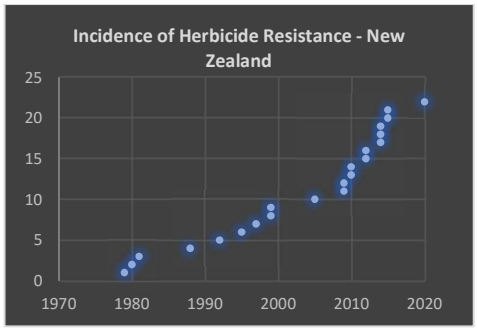


Figure 5 – NZ HERBICIDE-RESISTANT WEED DATABASE

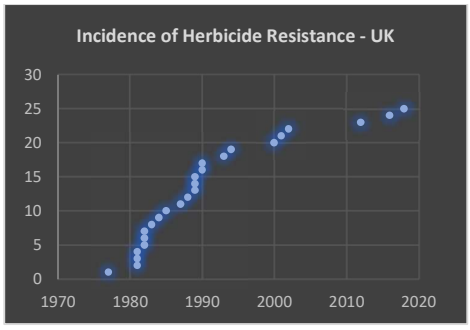


Figure 6 – UK HERBICIDE-RESISTANT WEED DATABASE

Source – https://www.weedscience.org/Pages/GeoChart.aspx

This data shows that in the last two decades, incidences in NZ have over doubled, compared to the UK which has only increased by a quarter.

Cereals are both situations where herbicide resistance is high for both countries, however it might be of interest to our pastoral industry that pasture equates to 27% of these situations for NZ.

This number of incidences equates to one per 227,000 people in NZ and one per 2,680,000 people in the UK.

Due to the population of the UK, perhaps using this metric isn't a great comparison, however due to the high amount of NZ's primary exports vs the relatively low amount of the UK's primary exports I did not consider this a great comparison either and welcome any thoughts and commentary in this area.

Moss (2017) proposes a good risk matrix, where three key grouped factors were reported. While the matrix has a European legislative focus, the approach and principles are relevant in NZ too;

A. the inherent risk of the herbicide
B. the inherent risk of the target weed
C. the agronomic management practices used in a given area, including the way the herbicide is used as well as alternative non-chemical methods of weed control.

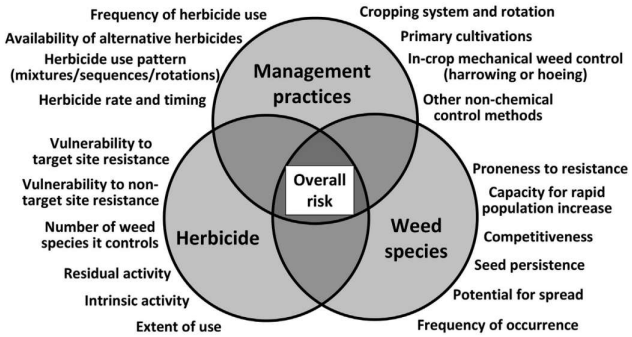


Fig. 1. Components of each of the three main resistance risk factors (Moss, 2017a).

Figure 7 – Components of each of the three main resistance risk factors (Moss, 2017a);

Source – https://www.sciencedirect.com/science/article/pii/S0261219418302801

Table 1
Herbicide resistance risk based on HRAC Mode of Action (MoA) groups (Heap, 2018; *Information collated 31 August 2018*).

Resistance Risk	HRAC Herbicide MoA Groups		Example of active ingredient	Number of resistant species worldwide	% of total
High	B	ALS inhibitors	chlorsulfuron	160	32
	C1	PSII inhibitors (triazines)	atrazine	74	15
	A	ACCase inhibitors	cycloxydim	48	10
Medium	G	EPSP synthase inhibitors	glyphosate	42	8
	O	Synthetic auxins	MCPA	38	8
	D	PS I electron diverters	paraquat	32	6
	C2	PSII inhibitors (ureas & amides)	isoproturon	29	6
Low	E	PPO inhibitors	acifluorfen	13	3
	K1	Microtubule inhibitors	pendimethalin	12	2
	N	Lipid inhibitors	tri-allate	10	2
	F3	Carotinoid biosynthesis (unknown target)	amitrole	6	1
	K3	Long chain fatty acid inhibitors	flufenacet	5	1
	C3	PSII inhibitors (nitriles)	bromoxynil	4	1
	F1	Carotinoid biosynthesis inhibitors	diflufenican	4	1
	H	Glutamine synthase inhibitors	glufosinate	4	1
	L	Cellulose inhibitors	dichlobenil	3	1
	Z	Anti-microtubule mitotic disrupter	flamprop-methyl	3	1
Very low	–	Six other MOA	–	8 (1–2/MoA)	2

Figure 8 – Herbicide resistance risk based on HRAC Mode of Action (MoA) groups (Heap, 2018; Information collated 31 August 2018); Source – https://www.sciencedirect.com/science/article/pii/S0261219418302801

For herbicides, factors that affect how rapidly weed populations shift to predominantly resistant individuals include;

(1) the intensity of the selection (which is a function of herbicide dose, frequency, and timing of application),
(2) mutation rate and the initial frequency of resistant individuals in the population exposed to the herbicide,
(3) the genetic basis of the resistance (mode of inheritance, dominance),
(4) life-history characteristics of the weed species (such as annual vs. perennial life cycle, self 12mericanum12on vs. cross-pollination, fecundity, extent of seed dormancy), and
(5) the rate of reproduction and potential for recruitment of susceptible or resistant individuals from outside the population (e.g. from the soil seedbank or by immigration).

The following provides a good background for those interested in more detail about Herbicide Resistance issues and terminology, sourced from the **Global Herbicide Resistance Action Committee (HRAC)**.

This has been abbreviated to what I thought were the most important aspects, but for those interested in further detail I encourage further reading here (HRAC Herbicide Resistance).

7.2 A Background on Herbicide Resistance

Resistance of weeds to herbicides is a consequence of naturally occurring mutations and evolutionary processes. Individuals within a species that are best adapted and not susceptible to a particular practice, such as application of a specific herbicide, are selected for and will increase in the population. Mitigating or slowing the evolution of herbicide resistance relies on reducing selection pressure for resistance through the use of a diverse range of weed management practices.

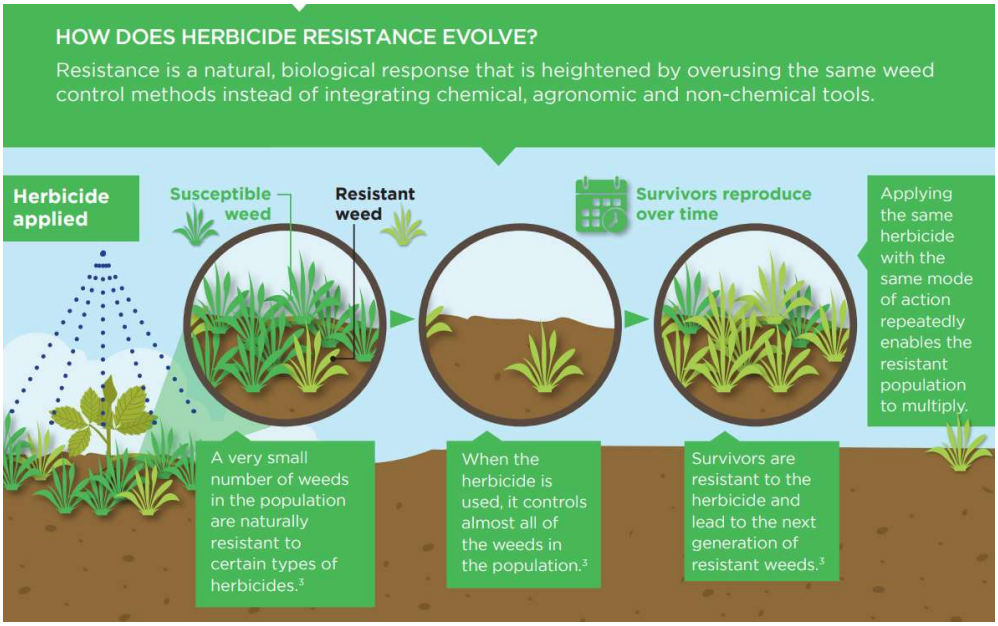


Figure 9 – CropLife Herbicide Resistance Infographic

Source – https://www.croplife.org.au/wp-content/uploads/2017/12/RM_Herbicide_Infographic.pdf

Resistance affects every sector of agricultural industries

The growing incidence of weed resistance to herbicides is a critically important issue for all stakeholders of agriculture sectors including farmers, crop production advisors, researchers and pesticide regulators, as well as the crop protection and seed industry members.

Herbicide resistance increases the complexity and often the cost of weed management programs. Herbicides provide effective, reliable and economical weed control for broad-acre agriculture. Therefore their use and longevity must be preserved. The fear that farmers may end up with few or no herbicides that control weeds resistant to multiple herbicide modes or sites of action is quickly becoming a reality.

Herbicide Resistance vs Herbicide Tolerance

Herbicide resistance is the ability of a weed to survive a herbicide application, where under normal circumstances that herbicide applied at the recommended rate would kill the weed.

In contrast, plant tolerance to a particular herbicide is the inherent ability of that plant species to survive and reproduce after treatment with that herbicide.

Cross Resistance and Multiple Resistance

Cross resistance occurs when a plant has one mechanism that enables plants to survive treatment with herbicides from different chemical classes or with differing modes or sites of action. Multiple resistance refers to plants that have more than one mechanism that enables them to survive treatment of herbicides with differing modes or sites of action. It is particularly challenging to control weeds that are resistant to multiple herbicide modes or sites of action. Controlling weeds with cross or multiple resistance is best accomplished with management practices that integrate a diversity of chemical and non-chemical measures.

Use of single herbicide mode (or site) of action accelerates herbicide resistance

Genes that enable weed species to resist herbicides are present in all weed populations. The frequency and occurrence of genes that impart resistance influences the rate at which resistance to herbicides in populations evolve. It is difficult to accurately predict the rate at which resistance will increase, until herbicides of a particular mode or site of action are exclusively applied over an extended period of time.

When individual weeds that resist a particular mode or site of action are able to mature and set seed, plants arising from those seeds the following growing season will have a higher frequency of resistance to that herbicide mode or site of action. Resistance to that herbicide site of action will be selected for and will accelerate with long-term repeated application of the same herbicide or other herbicide with the same site of action. After several seasons of selection, resistant weed biotypes will come to dominate the weed population. Strength of resistance selection pressure depends on several variables including herbicide efficacy and site of action, weed biology and ecology, longevity of the weed seed in the soil and weed management practices used.

Herbicide resistance best management practices

Increasing the diversity of chemical and non-chemical weed management practices used in crop management programs, including use of multiple herbicide modes and sites of action applied together, each cropping season, will slow herbicide resistance development and reduce the adverse impacts of herbicide resistance on crop production systems. Further information on Best Management Practices (BMP) are covered further on in the report.

7.3 Herbicide resistant weeds in New Zealand – Current state of knowledge (Ghanizadeh 2019)

New Zealand has one of highest levels of invasion by introduced plant and animal pest species in the world (Williams & Timmins, 2011), including approximately 500 introduced plant species that impose costs on both productive and conservation lands.

Herbicide-resistant weeds are serious threats to agricultural production. Since a review published in 1996, the number of different examples of weed biotypes developing resistance to one or more herbicides in New Zealand has almost quadrupled. By 1996, six weed species had been shown to have developed resistant biotypes, mostly to either triazine or auxinic herbicides (Ghanizadeh 2019).

Although there is a considerable body of research into the ecology and control of weeds on productive land in New Zealand, and significant expenditure each year on weed control by both the public and private sectors, there is a lack of information on the total costs of weeds. These costs may include the costs of weed control and the reductions in productivity, both of which can affect the sustainability of productive land use (Saunders 2017).

Understanding those costs is essential for developing cost-effective weed management strategies and the effective allocation of funds for weed research and management.

When a range of studies were recently reviewed, a key finding found these 'had little in common methodologically, often contained guesswork, or were outdated'. Their aggregation resulted in a conservative estimate of the cost of weeds to New Zealand's agricultural economy of $1,658 million (2014 NZD) (Saunders 2017).

Although alternative non-chemical weed management strategies are available (Harrington and Ghanizadeh 2016), herbicides are an effective way to control weeds, with alternatives generally not providing adequate levels of control by themselves.

PASTURE (NZ): In New Zealand, pastoral farming is the major land use (almost 55% - Statistics New Zealand 2013). Most pastures in New Zealand consist of a mixture of grasses and clovers. (Kemp et al. 2000). Weeds are a threat to pastoral production as they reduce the quantity and quality of fodder for livestock (Ghanizadeh and Harrington 2019c). Phenoxy herbicides such as MCPA and 2,4-D have been applied to some of these pastures since the 1940s (Pilbrow 1952). As a result, the evolution of resistance to phenoxy herbicides was detected in the 1980s in populations of Nodding thistle (Carduus nutans) in Hawke's Bay (Harrington and Popay 1987; Harrington 1989) and later in other parts of the North Island (Rahman 1990).

There are currently 245 plant species from 40 plant families that are considered to be troublesome weeds in New Zealand pastures (Ghanizadeh 2019).

Non-chemical agronomic approaches such as grazing management and using competitive pasture species often play a more important role than herbicides for weed management in many New Zealand pastures. Thus, integrated weed management using a combination of herbicides and good pasture management strategies leads to the most cost-effective and efficient control of pasture weeds in New Zealand (Ghanizadeh 2019).

In pastures, weeds can reduce pasture persistence, utilization and production. 15mericanu these weeds can cost farmers millions of dollars per annum. Pasture weeds in New Zealand need to be managed appropriately to reduce their economic impacts (Ghanizadeh and Harrington 2019).

One example of a problem weed in pastures Californian thistle (Cirsium arvense), was estimated to cost farmers $685 million per year ($446 million dairy, $233 million sheep/beef, and $6 million deer). Total annual costs were based on price assumptions used in the 2011-12, (Saunders 2017).

ARABLE (NZ): Harrington and Ghanizadeh (2016) stated that herbicide resistance is an increasing threat for the arable industry in New Zealand.

Prior to a recent survey completed in 2021 by Buddenhagen et al, it was believed there was a low prevalence of herbicide resistance in wheat and barley farms. For example, in the authors funding proposal it was estimated that 5–10% of farms might contain resistant weeds. However, this work found weeds survived herbicide applications on 42 of the 87 (48%) of the randomly surveyed farms from across the canterbury region.

Arable cropping in New Zealand generally differs from that in many other parts of the world. Crop rotation is practiced more widely in this country, with different crops being grown each year. Pasture is also often grown for several years as part of the arable crop rotation. These practices help prevent the buildup of pest and weed populations and result in different agrichemicals being used each year for each paddock.

HORTICULTURE (NZ): The NZ horticultural industry has been steadily growing its export contributions to our economy. In New Zealand this includes perennial fruit crops (e.g. apples,

grapes and kiwifruit) as well as annual vegetable crops (e.g. kumara, potatoes) (Fresh Facts 2021).

The first case of herbicide resistance in this industry was found in a Kumara crop, where paraquat-resistant Black nightshade (Solanum nigrum) were common (Lewthwaite 2009).

In 2013, the first cases of glyphosate resistance ryegrasses (L. perenne and L. multiflorum) were reported from vineyards in Marlborough and Nelson. More recently it has been proven that ryegrass resistance to glyphosate and amitrole is becoming common in New Zealand vineyards (Buddenhagen 2022).

TURF (NZ): Weeds in turf or lawns are often controlled with herbicides in NZ (FineLawn). Onehunga-weed (Soliva sessilis) is a widespread and troublesome prickly weed in turf throughout New Zealand. Clopyralid, often in rotation with a mixture of triclopyr and picloram, has been used routinely in many turf situations to control S. sessilis (Harrington and Ghanizadeh 2016). In the late 1990s, pyridine-resistant S. sessilis was found at the Helensville Golf Course near Auckland (Harrington et al. 2001). The biotype was cross-resistant to clopyralid, triclopyr and picloram.

Roadsides and other areas: This is one area where there is little or no information for herbicide resistance, due to the repeated use of the same actives each year, it is one area I believe we should be monitoring more.

7.4 Herbicide Resistance in Australia

Herbicide Resistance in Australia started developing in the 1980s and emerged as a major influence on Australian crop systems (Howat, 1987; Powles & Holtum, 1990). For more than 20 years, Australia stood out as having by far the most serious case of herbicide resistance in the world. Now, in major cropping areas, close to 100% of field samples of ryegrass plants are found to have resistance to selective herbicides and most are resistant to multiple herbicide modes of action (Owen, Martinez, & Powles, 2014a).

In the first decade of the 21st century, Australia led the world in the number of Herbicide Resistance cases, with high frequencies of multi-resistant populations evolving on a grand scale throughout all cropping regions. Conservation agriculture dramatically increased the productivity and sustainability of Australian cropping (Busi 2021).

Weed control and production losses due to residual weeds in Australia has been calculated for; low, average and high weed impact scenarios. An average production loss cost of $4,823 million is estimated for winter and summer broad acre cropping, rice, cotton, horticulture and livestock industries, using the 'economic surplus' approach (McLeod, R. (2018)).

7.5 Herbicide Resistance in Europe (and UK)

Countries where herbicide resistance has been widely reported are the UK, France, Germany and Belgium in central Europe; Spain and Italy in southern Europe; and Poland, Czech Republic and Hungary in eastern Europe.

Some simulations have indicated that, if left unchecked, resistant Black Grass (Alopecurus myosuroides), may eliminate profitability for some European farmers. The same study indicates that a proactive approach that utilizes a greater diversity of crops, tillage and herbicides may reduce net profitability by 4–24% compared with an intensive cropping system without resistance, but in the long term will be more profitable compared with resistance development.

Studies in the UK have demonstrated that a weed management system based on only herbicides is not sustainable, and resistance can increase costs up to €240 ha.

In those areas of the UK where Herbicide Resistance is not manageable with alternative herbicides, implementation of the following has been observed (Peterson 2017):
(1) innovative planting and cultivation tools, such as redesigned drilling equipment that causes minimal soil disturbance.
(2) delayed drilling combined with stale seedbeds to reduce early-germinating weeds cohorts.
(3) diversity in crop rotation/cultivation, such as the inclusion of summer crops to disrupt winter grasses.
(4) adoption of cover crops to improve soil structure and drainage to allow flexible drilling dates on heavy land, as well as giving spring crops a head start over weeds.
(5) increasing crop competitiveness by choosing more competitive varieties, helping to reduce grass weed tillering, heading and seed production; and
(6) enhancing herbicide performance in various ways (i.e. improved application methods, proper growing stage and avoiding applications under adverse conditions).

Key lessons from the UK are that it is all about managing the weed population density and soil seed bank, irrespective of resistance status. Thus, an aggressive and proactive anti-resistance management strategy needs to be implemented in such rotations (Peterson 2017).

Efforts to convey common and effective messages promoting the introduction of diversity into cropping systems through the adoption of integrated weed management (IWM) are being made by EU universities and agricultural research centers, as well as the industry. Education is critical, and its importance cannot be underestimated (Peterson 2017).

Chemical weed control is becoming highly reliant on one single class of herbicide (sulfonylureas), which have progressively replaced all other families of herbicides.

This has in part come about due to registration restrictions (see following data).

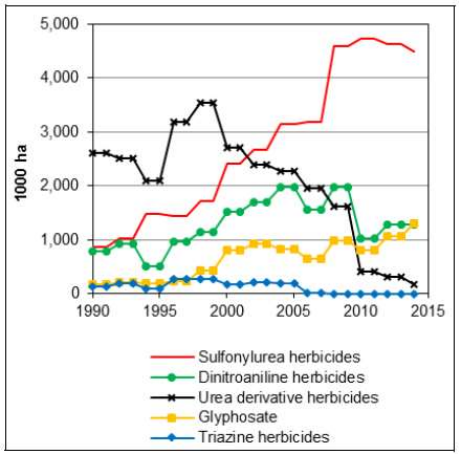


Figure 10 – Total area treated for weed control in cereals by class of herbicide in Great Britain, 1990-2014.

Source – Pesticide Usage Surveys (Food and Environment Research Agency [FERA], 2015).

As new actives or mode of action groups are adopted these too have shown incidences of herbicide resistance. Trends have also been noted that new reports of cases resistant to older herbicides stop or reduce. This is believed to be due to the lack of testing and reporting for these older actives.

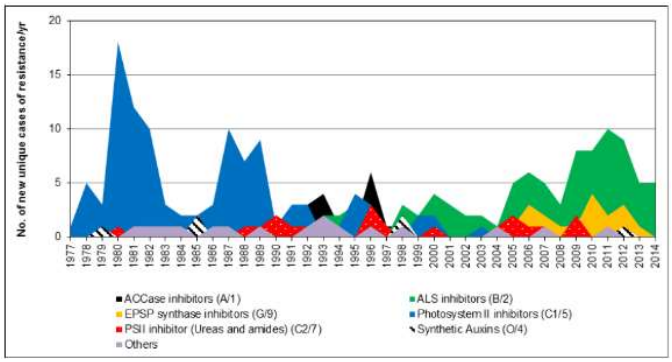


Figure 11 – New unique cases of weed resistance in the EU Member States, 1977-2014.

Source: Heap (2015)

7.6 Herbicide Resistance in North America

North America (including Canada, Mexico and the USA) produces a significant portion of the world's grains and oilseeds. This includes 8% of all wheat, 34% of all soybean, and 36% of all maize (corn). Production areas for these crops are largely in the USA and Canada, the vast majority of North American herbicide resistance cases are reported in these two countries.

The first case of herbicide resistance reported in North America was Wild carrot (Daucus carota) in 1957. However, very few additional reports occurred until the first case of triazine resistance was recorded in 1970. Triazine resistance dominated reports over the next 17 years until 1987, when the first instances of ALS-resistant species started to appear. Reports of resistance to ACCase herbicides began about the same time. By the mid to late 1990s, cases of ALS resistance were beginning to dominate the survey and instances of multiple resistant populations were appearing. The first case of resistance to glyphosate was noted in California in 1998 (annual ryegrass) and within 2 years in Delaware was the first reported glyphosate resistant broadleaf species. Since 2005, the number of glyphosate resistant broadleaf weeds has increased significantly.

It has been found the costs of resistant weeds can be especially large, especially in the first year they infest a field because by the time that growers realize glyphosate applications have been ineffective, weeds have grown too large to be controlled by other post-emergence herbicides (Weirich et al. 2011). In severe cases, growers may abandon fields altogether (Culpepper, Whitaker, MacRae, & York, 2008).

There are also concerns that herbicide resistant weeds could discourage the continuation of conservation tillage in many areas (Culpepper et al. 2012; Price et al. 2011; Steckel & Culpepper. 2006). The soil disturbance from tillage generally causes higher erosion with sediment, nutrient and pesticide-laden runoff, and more carbon dioxide emissions from oxidizing soil particles. The private and environmental costs of herbicide resistant weeds imply large potential gains from preventing (or at least delaying) resistance.

Alternatives to herbicides are important in an overall weed management plan. These may include tillage, both pre-plant and in-season. Narrow row spacings, increased crop density, cover crops and other cultural practices can enhance crop competitiveness with weeds and put less selection pressure on herbicides.

In agriculture, large-scale cost estimates are lacking but anecdotal evidence combined with crop areas suggests that, in the US, increased chemical costs due to glyphosate resistance may exceed $10bn annually. Costs due to yield loss would further increase this figure.

7.7 Herbicide Resistance Action Groups recommendations.

During my literature review, two excellent papers stood out that provided a review of 'Design principles and lessons' from 'Community-based approaches' and 'Rationale and recommendations' for 'Best Management Practices' in relation to herbicide resistance.

These two papers were as follows;

Pannell, D. J., Tillie, P., Rodríguez-Cerezo, E., Ervin, D., & Frisvold, G. B. (2016). Herbicide resistance: Economic and environmental challenges.

Norsworthy, J., Ward, S., Shaw, D., Llewellyn, R., Nichols, R., Webster, T., . . . Barrett, M. (2012). Reducing the Risks of Herbicide Resistance: Best Management Practices and Recommendations.

These could be of high value as we form plans and strategies into the future. They summarize as follows.

Lessons from past community-based programs were discussed, (Ervin and Frisvold, 2015), were they evaluated several different agricultural programs to consider what useful lessons they may provide.

First, local or private land managers were actively involved in defining the design and geographical scope of these programs, in addition to monitoring and implementing the program. *Second*, local entities did not just participate in these programs, but had key leadership roles in program implementation and evaluation. *Third*, successful implementation of these programs relied on local social networks. *Fourth*, while these programs had (to varying degrees) mandatory requirements and regulatory authority, local farmers and political jurisdictions agreed upon these mandates and regulations beforehand.

Several lessons emerged from studying these programs. *First*, successful programs have a solid theoretical understanding of biological mechanisms as well as an understanding of how strategies might succeed (or fail) in different agronomic settings. A strong scientific underpinning is needed to receive financial and technical assistance from federal agencies and acceptance by growers. Scientific principles must also be communicated effectively. This requires strong linkages between university research and extension programs. *Second*, social scientists are actively involved from the outset of programs. Understanding socio-economic dimensions are important for understanding the social context of current practices, barriers to adopting new practices, and group dynamics. Economic analysis can estimate potential gains of program implementation prior and economic benefits of successful programs post.

These papers emphasized the importance of having a strong local leader or coordinator to maintain program focus. In some cases, full-time coordinators were hired. This acknowledges the fact that efforts can be an overwhelming time commitment for most farmers. Coordinating regional or sector activities may need to be a full-time responsibility.

Detailed monitoring, data collection, reporting, and evaluation need to be ongoing. This is important for establishing baselines and monitoring program progress. In some cases, grower groups may already be in place with monitoring and practice requirements.

The authors also stressed the need to clearly establish geographic boundaries. This is critical to prevent immigration of resistant weeds from outside a management area. Different groups may have different incentives and capacities to manage resistance. Attaining group cooperation may require additional transaction costs and transfer of support mechanisms to encourage adoption.

Groups outside agriculture may also need to participate. Weed management along roads, rights of way, and ditch banks requires actions off farmland and by non-agricultural land managers. Agencies with authority over public lands, such as conservation areas, can affect herbicide resistance by their management of weeds and waterways.

Results also suggest challenges that programs may face. Some programs emphasized the importance of simplicity of practices in encouraging adoption. Recent trends have been toward (over) simplification of weed management systems and reduced diversity of tactics. Yet, studies have found that demand for participation in programs is relatively low among farmers not currently facing a problem. Resources developed to assist in the establishment of Weed Prevention Areas (e.g., Christensen, Ransom, Sheley, Smith, & Whitesides, 2011; Ransome & Whiteside, 2012) may assist in developing herbicide resistance prevention programs.

Ostrom (1990) proposed eight design principles for stable local action groups that can improve their chance of success.

1. Establish clearly defined boundaries.
2. Develop congruence between the appropriation and provision rules for the common resources that are adapted to local conditions.
3. Implement collective-choice arrangements that allow most resource appropriators to participate in the decision-making process.
4. Conduct monitoring by monitors who are part of or accountable to the resource appropriators.
5. Institute a scale of graduated sanctions for resource appropriators who violate community rules.
6. Create mechanisms of conflict resolution that are cheap and easily accessible.
7. Higher-level authorities recognize self-determination of the community.
8. For larger common-pool resources, organization in the form of multiple layers of nested (polycentric) enterprises may be required.

Norsworthy et al (2012) suggested programmes for herbicide-resistance management must consider use of all cultural, mechanical and herbicidal options available for effective weed control in each situation and employ the following best management practices (BMPs);

1. Understand the biology of the weeds present.
2. Use a diversified approach toward weed management focused on preventing weed seed production and reducing the number of weed seed in the soil seedbank.
3. Plant into weed-free fields and then keep fields as weed free as possible.
4. Plant weed-free crop seed.
5. Scout fields routinely.
6. Use multiple herbicide mechanisms of action (MOAs) that are effective against the most troublesome weeds or those most prone to herbicide resistance.
7. Apply the labeled herbicide rate at recommended weed sizes.
8. Emphasize cultural practices that suppress weeds by using crop competitiveness.
9. Use mechanical and biological management practices where appropriate.
10. Prevent field-to-field and within-field movement of weed seed or vegetative propagules.
11. Manage weed seed at harvest and after harvest to prevent a buildup of the weed seedbank.
12. Prevent an influx of weeds into the field by managing field borders.

Widespread adoption of these BMPs must overcome several real barriers. In particular, growers focus on immediate economic returns must be overcome as well as their beliefs that the evolution of herbicide resistance in weeds is unavoidable and that continued availability of novel herbicide technologies will solve the problem.

Two key recommendations must be more widely implemented: diversifying weed management practices and using multiple herbicide MOAs. Growers need to be educated about MOAs and be made aware that discovery of new herbicide chemistries is rare, that the existing herbicide resources are exhaustible, and that indiscriminate herbicide use leading to rapid evolution of herbicide resistant weeds may result in the loss of herbicide options for all.

To address the increasingly urgent problem of herbicide resistance, they made the following recommendations:

1. Reduce the weed seedbank through diversified programs that minimize weed seed production.
2. Implement a herbicide MOA labeling system for all herbicide products and conduct an awareness campaign.
3. Communicate that discovery of new, effective herbicide MOAs is rare and that the existing herbicide resources are exhaustible.
4. Demonstrate the benefits and costs of proactive, diversified weed-management systems for the mitigation of HR weeds.
5. Foster the development of incentives by government agencies and industry that conserve critical herbicide MOAs as a means to encourage adoption of best practices.
6. Promote the application of full-labeled rates at the appropriate weed and crop growth stage. When tank mixtures are employed to control the range of weeds present in a field, each product should be used at the specified label rate appropriate for the weeds present.
7. Identify and promote individual BMPs that fit specific farming segments with the greatest potential impact.
8. Engage the public and private sectors in the promotion of BMPs, including those concerning appropriate herbicide use.
9. Direct federal, state, and industry funding to research addressing the substantial knowledge gaps in BMPs for herbicide resistance and to support cooperative extension services as vital agents in education for resistance management.

In some instances, short-term costs may not favor implementation of BMPs that provide insufficient immediate economic benefit, even though their adoption will delay the evolution of herbicide resistant weed populations over time. In such cases, consideration should be given to providing incentives and expert advice for growers to develop and implement risk reducing weed management plans, following the precedent set by similar incentives for the conservation of soil and water resources in agriculture.

Repeating the same control tactics at a given timing, whether a herbicide application or a nonchemical control methods, may also result in the evolution of avoidance mechanisms in a weed population by selecting for biotypes that have not emerged, or are outside the optimal growth stage, when control is implemented (Reddy and Norsworthy 2010).

Herbicide resistance-management strategies have been typically implemented reactively when a resistant weed population has grown to problematic levels and must be controlled. Far less often are proactive management strategies implemented to mitigate the evolution of herbicide resistance. Introduction of new HR crop cultivars can provide options for managing weed populations resistant to other herbicide MOAs, but good resistance-management practices must be employed to avoid evolving resistance to the new herbicide as well.

Weeds in unmanaged habitats, including field margins, roadsides, ditch banks, railroads, and riparian zones can serve as a corridor for the introduction and movement of new weed species (Boutin and Jobin 1998), including HR weeds.

Our current knowledge of best practices for managing herbicide resistance is incomplete.

8. Findings and Discussion

Key stakeholders who are highly knowledgeable in herbicide resistance are currently working to ascertain the size of this issue in New Zealand. This is being supported by MBIE funding; [2018 Endeavour grant C10X1806] "Improved weed control and vegetation management to minimize future herbicide resistance."

A few examples of a media search show concern over the growing issue of herbicide resistance;

- Herbicide resistance greater than expected, growing concern. (AgResearch 2021)
- Spray resistance a big problem. (Rural News 2021)
- Herbicide-resistant weeds pose risk to NZ wheat and barley crops – research. (NZ Herald 2020)
- Herbicide resistance found on 48% of Canterbury cereal farms. (Stuff 2021)
- Glyphosate Resistance Confirmed in New Zealand. (FAR 2012)

Many of those interviewed were aware of Herbicide Resistance

Whilst all those interviewed were aware of herbicide resistance as an issue for NZ agriculture and horticulture, almost all agreed we need to be doing more in this area as they saw this as a growing issue that needed further focus. Most felt that (generally speaking) NZ farmers were not as aware of this as they could be, and we could be doing more to support them with best practice adoption.

Those with a higher level of experience in this area felt the issue is most likely underreported with one suggesting the number of herbicide resistance incidences could be as high at ten times the level currently reported.

Some highlighted the challenge of maintaining sufficient 'band-width' at farmer level, due to the unprecedented level of compliance and 'red tape' that has been forced onto farmers in recent times.

Different farming sectors see Herbicide Resistance differently

PASTURE: Those interviewed in the pastoral industry saw this as a significant threat to their productivity, due to a lack of awareness at farmer level. A couple interviewed highlighted the latent knowledge that exists in this sector due to a strong focus on anthelmintic resistance historically. However, the theme from this sector was there existed many opportunities to lift awareness and communication to bring this into focus further.

Whilst this sector has many actives or mode of actions available to them, certainly for those who can utilize a range of break/forage or cash crops into their systems, the pasture phase within these systems (or extensive breeding systems) is highly reliant on too few herbicides. These herbicides primarily belonging to Group 2 (ALS inhibitors) and Group 4 (auxin mimics) that have been in use for many years now.

A few of the comments from those interviewed in the Sheep/Beef/Dairy sectors were; "*this is so far off farmers radar*", "*they are too bogged down in other red tape at present*", "*many opportunities to improve awareness and communications on this topic*" and "*I'm not sure the pasture industry realizes the potential impacts on them*".

Those more involved in this sector saw the good work their peers have been doing in the Arable and Horticultural markets as opportunities for pastoral farmers.

ARABLE: This sector is seen by many to be leading on this issue in NZ. Their ability to use crop rotations is high, which affords the ability to rotate crops or use a range of different herbicides from a range of different groups. However, the previous study cited on page 11 suggested there is still much work to do in this area.

With much of the New Zealand arable industry reliant on the wider canterbury area for cereal and small seed production, this poses a significant threat, and one wonders if we need to diversify back into other regions.

Certainly, the Foundation for Arable Research is starting to address this, having been heavily involved in much of this recent research. As one example of how this group is educating and providing solutions for farmers the following LINK offers some management practices and information to help maize growers.

A few commonly themed comments from those interviewed in this sector were; "*extension and adoption – it can be a challenge to get key messages/practices out more broadly*", "*it seems to be the same people going to key field days – how do we get to those who aren't coming*", "*product use is often based more on price (Ha) and less on the quality*", "*with machinery and contractors moving from farm to farm a lot, what practical biosecurity measures could farmers adopt to protect themselves*".

HORTICULTURE: Those more involved in this sector felt they needed more support to develop longer term programmes to help minimize the likely effects of growing herbicide resistance.

Due to the broad range of different crops grown in this industry and the representation of subgroups such as; Pipfruit NZ, Vegetables NZ, Zespri and New Zealand Winegrowers etc. some felt that whilst a national horticulture strategy for herbicide resistance would be a great start, a sub sector approach would yield the best results.

A few of the comments from those interviewed in this sector were; "*Fruit producers are too reliant on too few herbicides*", "*vegetable producers have crop rotation options – but could up-skill further*", "*thanks to the recent glyphosate issues, awareness is starting to grow.*" And "*these are often more programme based, but I have concerns on the appropriate time horizons (are these long enough)*".

Key themes emerged on what is needed from different parts of our industry.

During each interview we discussed what key parts of our farming markets might need to help improve our current state. This was for the following areas; Researchers, Market Sector Bodies, Rural Professionals and Farmers/Applicators.

RESEARCHERS – Many commented on the need for a lift in sustained funding to address this issue with strong science. One commented that with the current MBIE grant this is ok at present but would like to see something longer term so that the current work can evolve and continue. Some sector personnel thought targeted research programmes to support key areas of concern from each sector would be a great way to engage those farming in these areas. Again, sector personnel felt we have some excellent researchers, however they would like to see further 'bench strength' developed in this area to continue building capability and resources for industry. A few of those interviewed wondered if our experienced researchers are able to spend enough time in the field and how we might provide stronger 'feedback loops' from industry back into science personnel.

MARKET SECTOR BODIES – Many felt there was a big opportunity from each of our sector bodies to help lift awareness of this issue. With a lift in awareness and an understanding of the potential impacts on each of our sectors, many felt the opportunity to proactively collaborate would maximize the impact at both national and regional levels. This included supporting the

development of a national strategy, developing differing sector strategies, utilizing their relationships with farmers/growers to help make these practical and to help with identifying a few farming champions to lead this in a way farmers are likely to respond to.

RURAL PROFESSIONALS – Many felt this group needed support to lift the awareness of this issue and to grow their knowledge and skills to better support farmers into the future. Broadly speaking, many acknowledged a gap in education and tools/resources to support this group. Whilst some have been through university or completed the 'Understanding Herbicides' short course at Massey University (LINK), many where thirsty for more information on how they may support this further. Some industry personnel felt we could improve our focus away from the immediate and least costly product, into products or programmes that deliver the best mid to long term results. Two asked whether the 'cheap' or 'house brand' approach provided the best formulated solutions and results on farm.

END USERS (Farmers/Applicators) – All interview felt we could be doing more to support farmers. In addition to lifting awareness, most felt there is a large need for quality information and resources to help with decision making on farm. Many felt those who are aware of this issue and trying to manage this on farm had the benefit of good networks, either with sector bodies or experienced advisors. In addition to good advisors/rural professionals, many felt a range of sector decision support tools and resources would help improve practices, were these to be readily available. A few interviewed thought that with education we could change some of the stigma around this from 'this is my fault' or 'I've stuffed up' to one that acknowledges 'these genes have always been in plants and the tools/practices we've used can be changed to continue farming sustainably'.

With some of the industries heavy reliance on rural/spraying contractors, some saw this group as an opportunity to help with this issue, specifically in the pastoral sector. With many interviewed seeing farmers as being quiet 'time poor', some saw an opportunity for product recording and advice to come from their rural contractors. With this group being supported by the Rural Contractors association (RCNZ) (LINK) they could be a great resource for applicators (along with industry) on this issue.

A range of ideas on how to manage herbicide resistance and support farmers

Some of the group of interviewees felt the biosecurity side was an important opportunity, not only at a national level to reduce the level of incursions, but also at a regional and farm level. A few highlighted the opportunity to learn from M-bovis and how we could apply these learnings to reduce the physical spread of weeds and their seeds.

All saw a major opportunity to lift; awareness, collaboration and communication, to not only support farmers, but also their advisors who help in this area. Many saw an opportunity to more closely link researchers with market sector bodies and rural professionals, rural contractors and of course farmers.

Many discussed the need for the free flow of information, at a range of levels and from multiple sources. As well as the need for the flow of this information to be clear, concise, and consistent within farming types. Several commented on the need for a detailed regional 'stock take' or regional map to help farmers and their advisors make the best decisions.

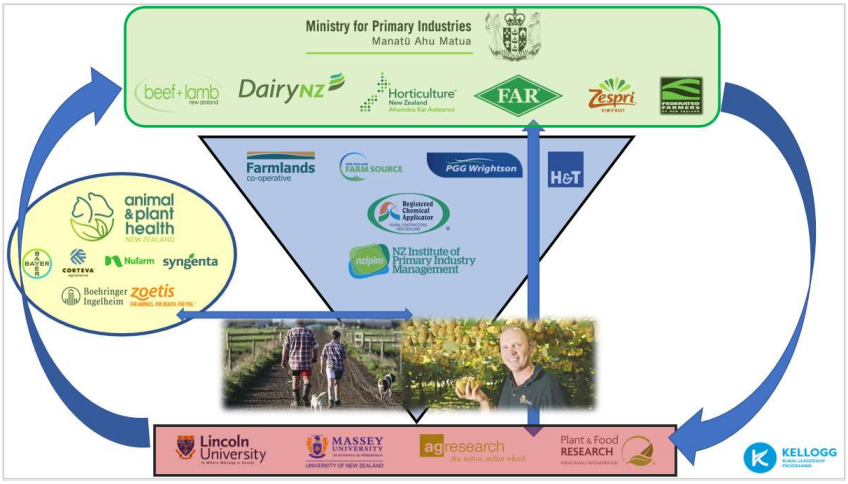
Some acknowledged we have very good information on this subject, however felt much of this was in 'too few hands' and asked how we can effectively capture this knowledge and share this is an effective way so that it is relevant for different farmers and advisors supporting different parts of our industry.

Similar themes arose around what can we learn and how can we use the information the pastoral industry has developed on anthelmintic resistance or the arable or horticultural industries knowledge on fungicide and insecticide resistance.

With many highlighting the time challenge on farm, several thought that our larger farming enterprises/corporates offered the ability to dedicate some resource into this area and share their results and findings with smaller owner operators.

All agreed a quick and cost-effective testing service would be essential to help with ongoing management into the future. The development of this must be an immediate priority.

From themes highlighted during the literature review and interviews I developed a basic structure on how we might resource the development of a national strategy and implement this by sector and regionally;



Note – not all key stakeholders are captured and is an example of a concept.

Figure 13 – Industry Structure Mindmap

Source: Author Kellogg Phase 3 Presentation

Strong Change Management Required

A google search on the topic of change management yields many examples on the need for change management in many of situations. Several of those interviewed highlighted the need for a social science aspect for strategy implementation. John P Kotter's book 'Leading Change' succinctly highlights eight strategies that help with implementing change and creating success in this area;

1, Establish a sense of urgency
2, Create a guiding coalition
3, Develop a vision and strategy
4, Empower people to take action
5, Remove any barriers to action
6, Generate short-term wins
7, Consolidate gains and produce more change
8, Anchor change in the culture

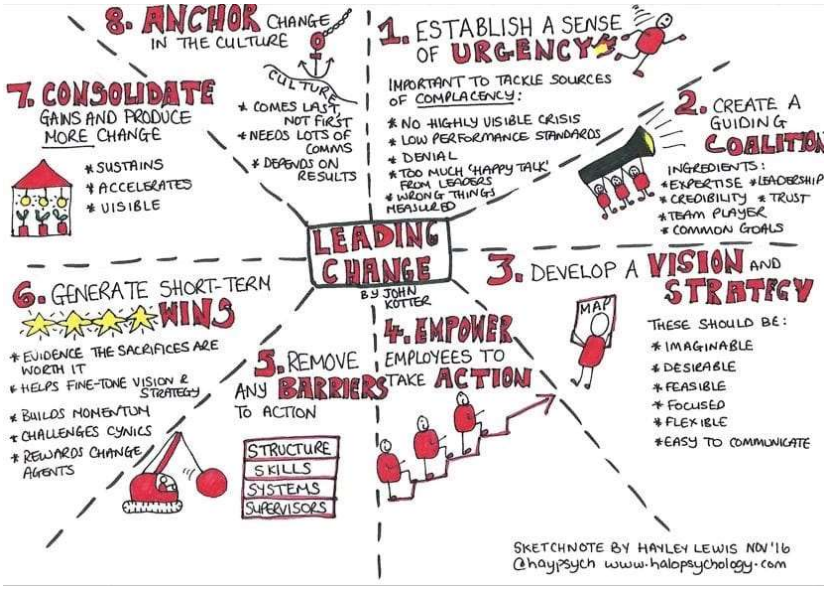


Figure 14 – Leading Change Mindmap

Source: Hayley Lewis www.halopsychology.com

Results of rating questions in semi-structured interviews;

"How bad do you perceive herbicide resistance in NZ?"
- This average score was **3.15** with a range from 2 to 4.
"How much more do you believe NZ could be doing in the area of herbicide resistance?"
- This average score was **4.27** with a range from 3 to 5.
"How bad do you perceive herbicide resistance globally?"
- This average score was **3.93** with a range from 3 to 4.8.
"How much more do you believe we should be doing globally?"
- This average score was **3.27** with a range from 3 to 4.5
"How would you rank your knowledge on herbicide resistance?"
- This average score was **3.5** with a range from 2 to 4.5.

With no statistical analysis, my view of these results is that the group saw herbicide resistance as a significant threat globally and one we could be doing much more in New Zealand to manage. This of course could be colored due to the interview questions and discussions, however I believe this is likely to be representative of those in our industry who are aware of this issue.

9. Conclusions

The wider New Zealand primary industry would benefit greatly from a programme to lift awareness on Herbicide Resistance.

There is strong science to support communication and strategies either globally, nationally or regionally in NZ.

Many structures and networks are currently in place to support farmers and growers, however providing some support to these networks is vital to ensure more positive outcomes.

We must answer the question of what is meant by "resistance management" as a country. Does it mean adapting to herbicide resistant weeds once they emerge? Does it mean managing weeds to delay resistance (i.e., prevention)?

Farmers, industry bodies and supporting companies would benefit from a national strategy, industry sectors should be supported to help create sector strategies, which they could own and drive forward.

Farmers engage well with issues when farmers are fronting/leading them. A great example is rural mental health where key stakeholders have stepped up to support their peers, we must mind those willing to do this for herbicide resistance.

Pastoral farmers are less aware of the herbicide resistance issue compared to arable and horticultural growers. They have fewer herbicides and fewer rotation options. However, they are well placed to adopt best practice programmes as most management practices are already understood through the animal health industry – Drench Rotation, combining actives and or stock class rotation are mostly well understood – see WormWise (LINK).

Funding – Farming sector bodies and commercial companies need funding to get this off the ground. Initially government funding may help with action/strategies, followed by industry funding to support key initiatives and ongoing management.

An affordable 'quick test' is needed to help manage this issue at both national and local levels.

There will never be a silver-bullet solution to herbicide resistance. Crop protection products are a finite resource and must be used wisely to protect their ongoing use. Effective ongoing weed control will always require a mixture of weed control methods used in combination.

Strategically we can learn from other countries regulator examples, where some of their decisions can be directly related to herbicide resistant outcomes – we must acknowledge and include this in our regulator decision making processes.

We must support influencers/advisors/decision makers with good science and practical decision support tools to help farmers.

10. Recommendations

1 Develop Strategies – The development of national, regional and sector strategies should be an early priority. Having a clear plan forward that addresses the following recommendations will help with supporting a more positive outcome into the future for our industry. Several times during the literature review or interviews, the benefits of incorporating social science skills into a strategy and programme were highlighted. Wherever possible a broad collaborative approach should be adopted here.

2 Lift Awareness – There is currently a lack of awareness across much of our industry, we need a dedicated campaign that will help with lifting awareness. One that profiles the current impacts and the potential implications of herbicide resistance on our industry and how we might address this, along with some success stories.

3 Find Advocates – Farmers appreciate hearing from their peers on how they have practically solved topical issues. In addition to specialists/experts on this topic we should find farmers who have been addressing this and are willing to help their peers and lift engagement in this area.

4 Increase Education – Our industry is filled with innovative, knowledgeable and practical people, if we can share this knowledge and skills in a practical way, we can create a more positive future for our industry. This should be provided in a staged process, such that key people are not overwhelmed. Having a national resource center that might then be broken out into sector centers is likely to help with uptake, such that information is relevant to the recipient.

5 Collaborate – For a strategy and programme to be successful, our industry and sectors need to work together. Government/Ministry, sector groups, crop protection companies, farm advisors, rural retailers, contractors and most importantly farmers together can solve this. There are very good papers and examples discussed earlier that we can utilise the learnings from. These should form key parts of our national, regional and sector strategies on how we best implement management programmes.

6 Develop Tools/Resources – Sector based resources that help farmers and advisors adopt best practice management practices into farm systems are critical. Sector bodies who support these and are part of this development process are likely to benefit from a more engage group of farmers and growers on this topic. These will support the future productivity and profitability of our industry.

7 Increase Funding – To start with, a 'Kick Start' fund to assist with strategy development and then for industry to tap into to get national projects off the ground will be critical. This could come from our Ministry for primary industries, Sector bodies and other commercial entities that see the need for this.

Ongoing industry funding – farmers currently pay a range of levies, some of these should be directed towards this issue to assist with the ongoing need to resource agreed strategies.

Crop protection company and rural retailer funding – it's in this industries best interests to support good practices for the longer term, this way we are more likely to have the tools we need to address this issue further into the future. Currently many companies support AgRecovery (LINK), who provide funding for the recycling of much of our packaging. This could be paralleled to allow resourcing for the ongoing support of best practice adoption and education.

8 Investigate Certification – Certification may not be required immediately, but is something our industry should consider periodically. Whilst there may be some strong benefits of having a 'Certified Crop Protection Advisor', similar to what the fertiliser industry encourages (Certificate

in Advanced Sustainable Nutrient Management – LINK), there are also some trade offs in doing so. I do however strongly encourage anyone involved with recommending herbicides to complete the 'Understanding Herbicides' short course with Massey University (LINK).

9 Consider NZ Weed Resistance Action Group – NZ should consider if a broader approach to the current New Zealand Herbicide Resistance Task Force (NZHRTF) is needed. This group has some excellent capabilities, however, based on some of what I have highlighted earlier, it is worth considering how we might strengthen this group and provide further support to maximize their impact.

Key aims and objectives from this group could include;

1. To provide a forum for information exchange from a broad range of stakeholders involved in herbicide resistance
    a. Include; Government, Councils, Research, Sector, Rural Retail, Applicator and Farmer representation

2. To discuss/develop strategies to avoid resistance and to manage herbicide resistance

3. To define and agree priorities for important research needs

4. To lead a nationally developed strategy and to support sector and regional activities

5. To develop statements for national media, and support regional responses as required

6. To maintain communication with similar groups that have been established successfully in other countries.

10 Incorporate strong change management principles – For these strategies, groups, and practices to 'germinate and grow' strong change management principles need to be applied. This supports the need to incorporate social science into many aspects.

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12. Appendices

The list of interview questions were as follows;

Are you aware there is herbicide resistance in NZ?
What is your current perception of this issue?
In your view what are the different NZ farming sectors doing well/differently.?
Who do you believe is doing a good job of managing/mitigating resistance?
What do you feel is required to manage this better for NZ.?
What might help farmers with this issue in the future?
What do you believe would help improve herbicide resistance issues for;

- Researchers –
- Market sector bodies –
- Rural Professionals –
- End users Farmers/Applicators –

Do you or many of your network use the Plant Protection Society website/information on herbicide resistance.?
What more would you like to know about herbicide resistance?
Any additional comments or thoughts?

Rating Questions:
On a 1-5 rating – How bad do you perceive this issue in NZ?
On a 1-5 rating – How much more do you believe NZ could be doing?
On a 1-5 rating – How bad do you perceive this issue globally
On a 1-5 rating – How much more do you believe we could be doing globally?
On a 1-5 rating – How would you rank your knowledge on this issue?

HRAC Mode of Action Classification;
An essential tool for those; selling, using, recommending herbicides.
https://hracglobal.com/tools/hrac-mode-of-action-classification-2022-map

NZPPS Herbicide Resistance website
Records current reported cases in NZ.
https://resistance.nzpps.org/index.php?p=herbicides/introduction

Herbicide Mode of Action Groups
Old & New MoA Groups and actives used in NZ,
https://resistance.nzpps.org/index.php?p=herbicides/mode_of_action

Also available via Novachem Manual;
https://www.novachem.co.nz/

13. Final Thoughts

Imagine a time, in the not-too-distant future, where New Zealand farmers have a significant agronomic advantage to their peers internationally. Where they've adopted a range of practices to help keep them competitive on the global stage. They understand that a mix of short-term practices and longer-term thinking is leading them to more flexibility in their management practices and reduced long term costs.

Their wider industry support networks have seen this opportunity and partnered with them to help create this situation. Together with the support of government, they've invested in a national and regional support network and built a great success story. Where knowledge is shared widely, and decision support resources are freely available to help make tough decisions and provide practical solutions.

Regulatory authorities have been part of this success and have helped ensure a broad range of solutions are available to farmers. Their partnership with industry means we have a range of actives that aren't often used elsewhere due to their ineffectiveness in other markets.

Combined, these efforts have not only helped NZ farmers remain competitive, but also mean our next generation have more options to farm more sustainably into the future.

This future is just over the horizon. All we need are willing partners who want to help create this. Are you willing to help create a better tomorrow?