

Article

Opportunities for Improving Herbicide Resistance Management Strategies across New Zealand's Arable Sector

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Abstract: Herbicide resistance is increasingly recognised as a challenge for agricultural producers worldwide. International scholarship and practical experiences suggest that collective efforts by diverse agricultural stakeholders are crucial for effective resistance management. In New Zealand, such sector-wide initiatives and strategies remain fragmented, partly due to a lack of state coordination and national extension services. This article synthesises insights from three complementary social research methods involving actors across the country's arable-crop-growing sector (focus groups, semi-structured interviews, and an industry workshop) to identify pathways to foster collaboration and more strategic resistance management. The presented findings detail challenges, opportunities, and potential actions across four domains: strengths and weaknesses of New Zealand's farming context, better information and knowledge exchange, improved collaboration and coordination, and targeted education and training. Our analysis highlights that most opportunities described within these domains involve purposely strengthening existing, or forming new, social and institutional relationships as part of establishing resistance management as a shared sector responsibility. A portfolio of multipronged initiatives and programmes is then required for effective whole-industry strategies. We discuss potential next steps to collectively realise identified opportunities, from more immediately feasible steps to long-term activities. These insights conceptually contribute to the international scholarship on herbicide resistance by reinforcing the notion that industry leadership and meaningful farmer involvement are indispensable for more collaborative approaches aimed at strategically managing resistance.

Keywords: collective action; collaboration; coordination; social dimensions; shared responsibility; farm systems thinking; integrated weed management



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1. Introduction: Herbicide Resistance in New Zealand

Synthetic herbicides that inhibit a range of biological processes within target plants were first commercially released in the 1940s. Since then, they have been instrumental in enhancing agricultural productivity across farm systems worldwide by simplifying effective weed control. With the increasing use of herbicides, however, a growing number of instances have emerged where target plants are no longer susceptible to specific herbicides. The development of herbicide resistance (HR) in prominent weed species poses significant problems for agricultural producers, as it can lead to additional costs for alternative weed management, substantial yield loss, or reduction in revenue [1–3]. Detected instances of HR have risen sharply over the last decades, with cases now recorded in at least 267 weed species in 72 countries [4]. This makes HR a global challenge that national governments, industry bodies, and farmers seek to address with a growing sense of urgency.

First instances of HR were discovered in New Zealand in the late 1970s in *Chenopodium album* (fathen) populations in maize fields. Until the late 1990s, a small number of additional cases of resistant weed species were found in arable cropping and pastoral systems [5],

but HR was not regarded as a significant issue. This lack of concern could be attributed to the modest size of the country's arable sector, the availability of diverse crop and livestock rotation options helping growers manage resistance, and resistant weeds not causing major challenges in pastoral systems. Over the last two decades, however, the number of discovered cases has increased more rapidly and almost quadrupled. HR weed populations are now also found in vineyards, turf, and horticultural crops [1,4–7]. This suggests resistance is an emerging challenge for New Zealand's agricultural sector.

Despite resistance being detected in a variety of farm systems, HR poses the biggest problem for New Zealand's arable farmers who may face substantial yield reduction, revenue losses, and additional weed management costs [1–3]. This includes maize growers on the country's North Island and farmers in the main grain cropping region across the Canterbury plains on the South Island. Weed surveys in two maize growing areas indicate that 32–58 per cent of farms are likely to have HR in either *Chenopodium album* (fathen) and/or *Digitaria sanguinalis* (summer grass) [8]. In Canterbury, resistance has been detected in *Lolium perenne* (perennial ryegrass), *Avena fatua* (common wild oats), and *Lolium multiflorum* (Italian ryegrass) [5,9–11]. A randomised survey of 20 per cent of cropping farms in one Canterbury district identified HR ryegrass on roughly one-third of sampled paddocks, as well as resistance in several other weed species [7,12]. These surveys indicate that HR is already prevalent across New Zealand's agriculture, creating a growing need for effective management.

Core management recommendations usually involve three overarching themes: diversifying weed control methods, including non-chemical methods (e.g., cultivation); rotating and mixing herbicides with different modes of action; and routinely monitoring paddocks after herbicide applications, so that surviving weed populations can be detected and removed before they set seed. Despite these recommendations being relatively well established, weed scientists and rural professionals worldwide still frequently lament what is perceived as inadequate strategic HR management across the agricultural sector [13,14]. These concerns have led to calls for more collective approaches among growers and their support networks, the crop protection industry, and research, science, and innovation professionals. While attempts to mobilise such collective action have occurred sporadically in many countries and regions where HR is recognised as a sector challenge, collaboration efforts often remain fragmented and are yet to amount to broader industry strategies, including across New Zealand. This paper contributes to the growing international scholarship investigating how to foster more collaborative HR management by analysing opportunities and barriers for corresponding efforts in Canterbury, New Zealand.

2. Collaboration in Herbicide Resistance Management

With instances of HR continuing to increase across agricultural systems worldwide, similar challenges have been noted around the uptake of best practice herbicide use recommendations and corresponding extension efforts to support integrated weed management (IWM) practices among farmers in many countries [15,16]. This prompted targeted investigations into the human dimensions of weed and HR management [17,18]. Research findings demonstrate that herbicide decisions are influenced by a range of factors related to farmers' personal circumstances, their sociocultural context, as well as farm and agricultural system characteristics. These factors cover psychological, sociocultural, economic, technical, and biophysical aspects that affect herbicide practices and, in doing so, create interdependencies that can hinder the implementation of best practice guidelines [14,19–24].

Building on these insights, scholars suggest that shifting farmers' weed management practices requires a suite of behavioural preconditions, such as raising awareness and altering attitudes, building knowledge of management options, and encouraging long-term thinking. At the same time, lacking awareness or knowledge is often not the only or even primary barriers to changing on-farm practices. Factors that can prevent the translation of knowledge into action are, for instance, higher cost and time commitments associated with incorporating alternative weed management practices [13,15,17,22,25–27]. In addition

to situating farmers' HR-related decision-making within the complexities of their farm systems, scholars also stress the importance of attending to the sociocultural contexts that influence farm praxis and deep-seated beliefs about the 'right way' to farm [28]. Formal education shapes these beliefs and practices, but so too do interactions with other farmers in such settings as field days and farmer field schools. These settings may promote the development of social capital and communities of practice built on relationships with an extended network of trustworthy advisors [29,30].

These accounts demonstrate that solely focussing on individuals' behaviour can be both misleading and inadequate, particularly when effective management depends on access to off-farm support, education, supplies, and other resources. Instead, the ability to share and adopt applied understandings of new practices may require collective, coordinated, and collaborative efforts between a multitude of actors. This is recognised by a growing cohort of social scholars investigating HR management.

2.1. Collaborative Approaches to Herbicide Resistance Management

Suggestions to regard HR management as a collaborative effort are proposed for several reasons. Among those is the recognition that collectively held beliefs and norms associated with dominant weed management practices may hinder shifts towards alternative practices, such as overstated optimism in technological solutions, and thus need to be addressed [14,21,31,32]. As established norms shift, collaboration is needed across the wider agricultural system given the influence of other actors on farmers' HR management. In line with 'distributed' approaches that consider farmers' wider decision-making networks [33,34], some researchers thus advocate going beyond only considering the responsibilities of individual farmers. Coble and Schroeder [35], for instance, outline various actor groups and their roles in effective weed control, from those within the agricultural input supply network to government agencies. Other researchers have described the efforts required at local, regional, and national levels [15,17,22,36]. This distributed nature of weed management decision-making has prompted the notion of HR management as a 'shared responsibility' [13].

In many cases, such collaborative efforts need to be coordinated on a larger scale to effectively manage weed populations that might move across regions or international borders. In emphasising the resulting "complex, multi-scale and collective nature of the weed problem", Bagavathiannan et al. [37] (p. 343) thus call for best practice recommendations to be complemented by "landscape-scale design principles that encourage cross-boundary coordination and cooperation". However, achieving lasting collective action frequently proves challenging for a suite of reasons, including a lack of concern about the migration of HR weeds [31,37,38]. Successful collaboration is then often, at least partly, preconditioned on perceived mobility of HR weed populations, either through biological (e.g., pollen) or anthropogenic (e.g., farm equipment) transfer [26,39]. As Schroeder et al. [40] (p. 478) found, in addition to getting conflicting and confusing information from various sources, farmers "saw the problem of HR as bigger than what they can address on their own and that HR is a threat related to the actions of others, including non-agricultural groups".

These insights highlight that actors across the wider agricultural system need to jointly tackle HR. Where such collaboration occurs, stakeholder interactions can take many forms. Doohan et al. [16], for example, note that facilitating two-way information exchanges between weed scientists and farmers can result in better outreach and adoption of IWM practices. This is echoed by Asmus and Schroeder [15], who stress that weed scientists should partner with agricultural producers and communities to translate general management recommendations into locally suitable on-farm changes. At national level, weed scientists can work together with industry and government agencies to develop coherent HR messages [15,41]. Effectively addressing HR as a collective challenge further requires the collaboration of weed scientists and researchers from other disciplines, including the social and applied sciences, in inter- and transdisciplinary programmes [15,42].

Such approaches have become more important with the decline in government-funded and -coordinated extension services in many countries. The corresponding decrease in public sector weed science capabilities creates not only new collaboration demands on researchers and practitioners but also the agricultural input supply network. Beckie [43] highlights the crucial role of the crop protection industry and notes growing collaboration among companies, as well as between companies and public sector partners and academia. These collaborative efforts are aimed at filling gaps in HR research, development, and extension activities (RD&E).

2.2. Collaboration in New Zealand's Agricultural Sector

The need for collaboration across the agricultural sector to better manage HR is particularly apparent in New Zealand. Following major agricultural policy reforms in the mid-1980s, public financial support mechanisms were discontinued with the aim of transitioning towards a market-driven primary sector. This means that farmers receive no government subsidies, unlike those in many other economically developed countries [44]. Furthermore, the country has no national extension services, resulting in agricultural advice being often provided by consultants, regional councils, and crop protection companies—although, some state-led initiatives aim to improve advice available to primary producers, such as the Ministry for Primary Industries' Primary Industry Advisory Services programme [45]. Observers note that the dearth of government-coordinated extension has led to disconnects between agricultural consultants and researchers, with negative implications for the effectiveness of RD&E activities. Therefore, improved interactions and collaboration among government agencies, industry, agricultural producers, and researchers are required to strengthen advisory services [46–48].

In the HR management space, such collaborative efforts have occurred sporadically in recent years, yet coordinated long-term strategies to facilitate sector-wide HR management collaboration are only emerging. Against a background of growing concerns over HR within New Zealand's arable sector and the outlined importance of collective action, this article advances existing social research [13,14] to describe opportunities and potential actions for the development of industry strategies that could, at least partly, address gaps concerning more collaborative HR management.

3. Materials and Methods

The presented findings are drawn from qualitative social research undertaken between 2018 and 2022 as part of a five-year, government-funded, integrated research programme that investigates the mechanisms, spread, and management of HR in New Zealand. The research activities focused on the country's main arable cropping area, the Canterbury region on the South Island (see Figure 1), with the aim of investigating opportunities for and barriers to more effective HR management. The insights outlined here are synthesised from three complementary research activities involving actors across the arable sector in this region (see Table 1). The study was approved by AgResearch's Human Ethics Committee (#08/2019), with informed consent recorded for all research engagements. First, two in-person focus groups were conducted in November 2019 and March 2020. The first group consisted of weed scientists and arable industry sector specialists, while the second group included rural professionals and weed management specialists (rural advisors, agrichemical company staff, and seed company representatives). The participants were in their early twenties to late sixties, with an approximately even gender distribution in the rural professional group and mainly males in the first group. Semi-structured discussions in each group prompted participants to reflect on three overarching aspects of HR management: knowledge and beliefs around HR, factors and stakeholders that influence decision-making processes around herbicide use, as well as barriers to and opportunities for more effective HR management.

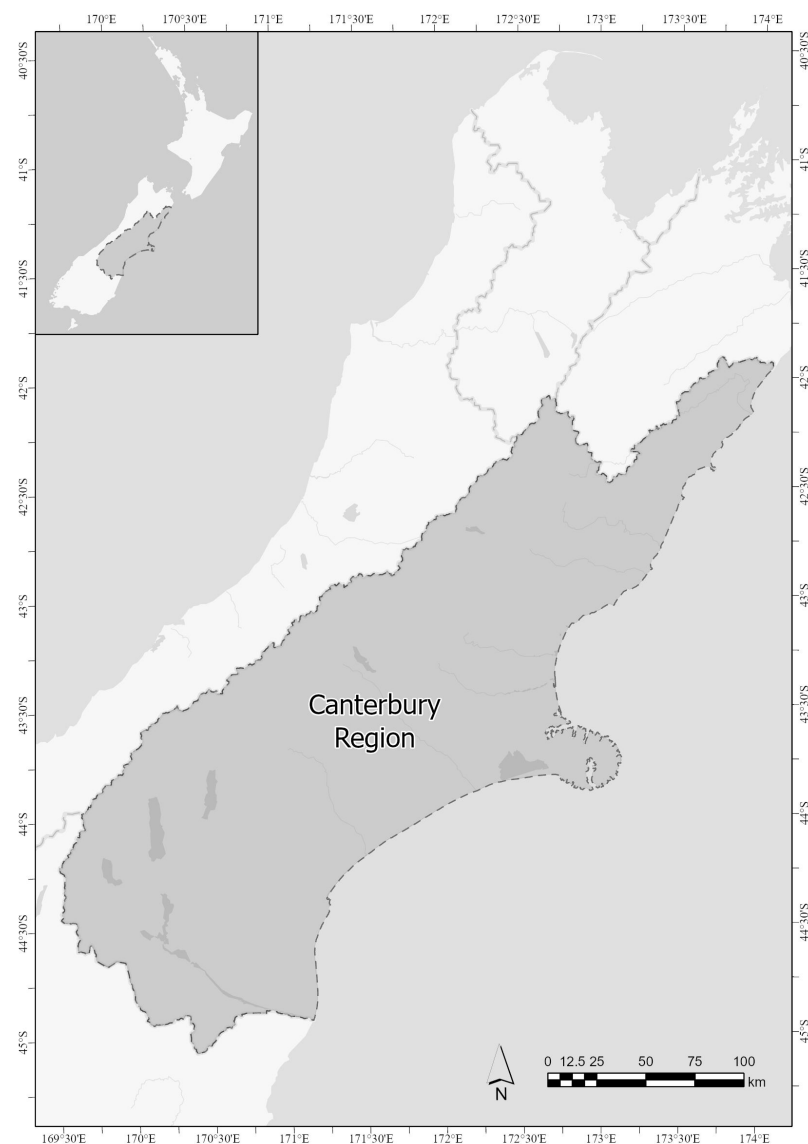


Figure 1. The Canterbury region of the South Island of New Zealand (source: created by Peter Pletnyakov based on Stats NZ's data [49]).

Table 1. Overview of research participants across the three research settings (NB: some participants were involved in two settings).

| | Farmers and Farm Managers | Rural Advisors and Field Agronomists | Crop Protection Industry Representatives | Industry-Good Bodies Representatives | Weed Scientist |
|-------------------------------|---------------------------|--------------------------------------|--|--------------------------------------|----------------|
| 1. Focus Groups | - | 5 | 4 | 2 | 6 |
| 2. Semi-Structured Interviews | 12 | 3 | - | - | 3 |
| 3. Arable Industry Workshop | 5 | - | 6 | 3 | 3 |

Second, eighteen semi-structured interviews were conducted with arable farmers and farm managers, as well as a small number of independent rural advisors and weed scientists who did not participate in either focus group. Interviews were mainly conducted online between November 2019 and June 2020. Participants were purposively recruited through existing professional networks based on their experiences with HR, with some interviewees recruited via snowball sampling following suggestions by other participants.

All farmers and rural advisors were located in the Canterbury region on New Zealand's South Island, which is the country's primary cropping area where a broad range of grains, certified seeds, and other crops (e.g., legumes and vegetable crops) are grown. Many Canterbury farm systems also include livestock components in their rotations, such as fattening lambs. Around half of the farmers knew of HR weed populations on their farms, which had been detected through random sampling in 2019 [6]. The interviewed farmers and rural advisors were all males in their earlier twenties to sixties. They mainly worked on family-operated farms with a diverse range of characteristics (e.g., farm size and crop rotations), but also larger-scale agricultural organisations. The interview questions focused on the same three thematic areas as those in the focus groups.

Third, an arable industry strategy workshop was held in March 2022 involving seventeen farmers, representatives from crop protection companies and industry-good bodies, and weed scientists. The workshop was organised to investigate the potential for dedicated efforts to foster more collaborative HR management in Canterbury and New Zealand. Participants were purposively recruited based on their sector-level expertise with HR management and their representativeness for key actor groups within the arable and related sectors. Most of the participants were male. Several participants had been involved in previous focus groups or interviews. The workshop was run online by three social researchers and involved facilitated discussions in three breakout groups, which centred around current challenges and opportunities faced for New Zealand's arable sector regarding more strategic and collaborative HR management, and which actions could be taken to realise opportunities. To better understand the current state of HR management strategies, the groups conducted a SWOT analysis (strengths, weaknesses, opportunities, and threats). The discussions in each group were video recorded and key points were captured on a shared PowerPoint canvas. Following the workshop, canvas notes were thematically clustered by the facilitators and combined on a single canvas for further analysis. A discussion summary was sent to participants shortly after the workshop.

Focus group and interview recordings were transcribed and thematically analysed, using the data analysis support software NVivo [50]. An inductive approach was applied to elicit themes related to the overarching questions of the integrated research programme, including insights into the drivers of farmers' herbicide use and potential solutions to managing HR [13,14]. Given the detailed notes taken by the three facilitators of the industry strategy workshop, it was deemed unnecessary to transcribe the recordings from each breakout group. Instead, the recordings were used to refine feedback captured on the shared canvases. The notes were thematically analysed according to the three focus areas of the workshop: current HR management challenges, opportunities, and potential actions. The thematic analysis was complemented by corresponding insights from focus groups and interviews. This triangulation of multiple methods and data sources ensured cross-validation between findings from each research activity and the robustness of the presented analysis. Potential limitations of this approach may, nonetheless, emerge from the study's geographic focus on the Canterbury region, the gender imbalance in farmer interviews, and specific engagement with the arable sector.

4. Results

This section describes a selection of current socioeconomic challenges related to strategic HR management in Canterbury and New Zealand's arable sector, identified opportunities going forward, and what actions sector stakeholders may undertake to realise those opportunities. We focus on four overarching thematic clusters: the New Zealand farming context, information and knowledge exchange, collaboration and coordination, as well as education and training (see Table 2). The selected challenges and opportunities are not intended to be exhaustive. However, they address key findings synthesised from across the various research settings regarding potential industry pathways towards more strategic weed and HR management.

Table 2. Selected challenges, opportunities, and corresponding actions to realise more strategic HR management across New Zealand’s arable sector.

| | Socioeconomic Challenge | Opportunity | Potential Action |
|---|--|---|--|
| New Zealand Farming Context | No subsidies, so farmers are under pressure to be profitable every step of the way. | Many farmers can run diverse crop rotations and are adaptable innovators. | Capitalise on farm system options, incl. livestock, and innovation readiness via collaborative research, development, and extension (RD&E) activities. |
| | No designated government agency to connect and coordinate fragmented, sometimes competing, sector actors on shared HR and weed management risks. | Engage with Ministry for Primary Industries (MPI) around the crucial role of herbicides for current and future farm systems. | Demonstrate the importance of herbicides to government agencies, e.g., for resilience and climate change strategies. Integrate MPI representatives into industry HR networks. |
| | Few independent advisors and many employed in the crop protection industry, with advice potentially biased or limited. | Promote the role of independent, skilled advisors in farm-system-level decision-making and strategic HR management. | Review the scope for the development of an independent advisory network. |
| Information and Knowledge Exchange | Diverse sources of recommendation, leading to inconsistent and fragmented advice that is not always timely. | Sector bodies, e.g., Foundation for Arable Research (FAR) and Animal and Plant Health NZ, consolidate inter-/national advice for implementation. | Industry bodies regularly circulate extension packages, with an emphasis on translating research into on-farm practice. |
| | Labels on herbicide packaging sometimes unclear regarding mode of action (MoA). | Maximise the utility of herbicide labels for best practice strategies, e.g., clear MOA. | Advocate for, and implement, improved labelling across the crop protection industry. |
| | No formal feedback mechanisms to communicate on-farm experiences and outcomes of farmers’ field trials. | Improve knowledge exchange between farmers, agronomists, crop protection companies, and researchers. | Establish dedicated mechanisms for the regular and timely exchange of HR-relevant developments and information. |
| Collaboration and Coordination | Limited sector cooperation on HR issues in agriculture and horticulture, including a network for integrated weed management using animals. | Better utilise existing industry networks, e.g., FAR and Animal and Plant Health NZ, and build new networks to improve sector cooperation. Expand the scope and duration of inter-/transdisciplinary RD&E programmes. | Establish a network of crop protection companies and peak organisations, industry-good bodies, and MPI. Co-develop voluntary industry codes of practice and charters. Co-design transdisciplinary RD&E programmes that integrate the natural, applied, and social sciences |
| Education and Training | Variable knowledge and confidence around HR and integrated weed management among practitioners. | Further utilise existing industry outreach and extension networks to facilitate widespread HR education, e.g., via FAR. Expand networks and forums to facilitate targeted HR education among all practitioners, not just farmers. | Expand forums for farmer learning, incl. farmer-to-farmer exchange. Implement industry programmes to regularly upskill rural advisors and field agronomists. Expand applied training courses for all practitioners, e.g., Massey University. |
| | Lacking training in whole-farm-system approaches and utilisation of the full weed management toolbox. | Improve existing training and education programmes. Use accreditation systems to build, and demonstrate, baseline integrated weed and HR management skills. | Incorporate farm systems thinking and integrated weed management in programmes (e.g., university degrees). Develop accreditation for rural advisors and agronomists, including farm-system training and HR management strategies. |

4.1. The New Zealand Farming Context

Without financial support from government subsidies, a key challenge for farmers is the need to remain profitable within an internationally competitive market. This has prompted many to focus on farm efficiency and adapt swiftly to changing operational contexts [13,14]. In relation to HR management, an industry-good body representative in a focus group noted accordingly that “there’s no subsidies here, so they [farmers] just do whatever they have to do to make money. And if that’s not using chemicals, I think they will adjust.” At the same time, many arable growers in New Zealand have access to a relatively high number of viable crop and livestock options in their farm systems, due to favourable climatic and environmental conditions. A farm manager in Canterbury with experience in the United Kingdom highlighted this during an interview:

New Zealand is quite unique, though, from an herbicide point of view, that we have a seriously large rotation. UK-wise, I’d only have maybe four crops, whereas here I’m looking after 15 maybe 18—makes a big difference.

These rotation options offer arable farmers opportunities to diversify their herbicide use, for example by enabling them to apply herbicides with varying modes of action across different target crops while removing weed populations that have developed resistance to one mode. Participants in the industry workshops emphasised that there remains scope for better capitalising on these rotation options to manage HR. However, growing and integrating larger numbers of crops into a farm system requires relevant knowledge and practical know-how. To support the required capability building and ensure that available information can be readily implemented, arable sector stakeholders should collaborate to co-design suitable research, development, and extension (RD&E) activities.

An obstacle within the agricultural system mentioned in all research settings is a perceived lack of government agencies connecting the fragmented, and sometimes competing, agricultural sector actors and coordinating their activities around shared HR and weed management risks. A weed scientist participating in one of the focus groups elaborated on this matter:

MPI [Ministry for Primary Industries] should have realised a decade ago that this was going to be building up into an ongoing problem. . . . The government really should have been taking the lead . . . and saying, ‘This has to be addressed and nipped in the bud’, and it’s been completely missing in action.

Given growing government interest in transitioning the agricultural sector towards improved environmental performance, food security, and climate resilience, the workshop participants saw an opportunity to further engage with the sector’s key government department, the Ministry for Primary Industries, on the crucial role of herbicides in the future of New Zealand’s agri-food sector. This would involve demonstrating the need for herbicides in many farm systems that align with envisioned national strategies. One example of this is no or low till cultivation and direct drilling techniques, which are adopted to improve carbon sequestration and lower agricultural greenhouse gas emissions. This illustrates how MPI representatives should be integrated into collaborative industry networks focused on developing shared HR management strategies, coordination efforts, and streamlined communication.

A third challenge is a shortage of independent agronomy advisors in New Zealand. While industry-good bodies, such as the Foundation for Arable Research (FAR), provide valued general advice, many growers rely to some degree on recommendations from staff employed within the crop protection industry or by crop contract companies, of which only some may have formal agronomy training while others are primarily sales representatives. Such advice can be short-term focused on individual crops and weeds, with several participants cautioning against potential limitations or biases towards specific agrichemicals. Growers often also receive recommendations from multiple agronomists at once, while, in some cases, contractual agreements specify agrichemical treatment plans for contracted crops. This can lead to ad hoc and piecemeal decision-making, at the

expense of strategic weed management as part of holistic farm-system planning. Many participants thus saw opportunities for supporting more independent advisory services. Despite acknowledging the potential value of these services for more farm-system-based decision-making, scepticism about the viability of such services was frequently mentioned. One independent advisor cautioned:

[B]ut I'll say though it is quite hard. I should make the point that chargeable agronomy, it's a slow growth ... because if we employed a new agronomist tomorrow and I said, 'Go out and find ... 30 chargeable agronomy clients', then you wouldn't be able to get anybody.

There are thus opportunities to support the growth of independent advisory services, but the lack of demand and willingness to pay may pose, at least initially, considerable practical obstacles. This opportunity might, therefore, require more substantial long-term changes across the agricultural system and established growers' decision-making networks.

4.2. Information and Knowledge Exchange

One implication partly associated with the lack of independent agronomists is that most growers rely on diverse sources of information. Many participants described how this can lead to fragmented, disconnected, and at times inconsistent HR management recommendations. As one grower noted, "there's so many different people and there's lots of different information coming from different sides." Furthermore, the required information may not always be available when management decisions are made, such as specific recommendations for herbicide usage following unusual weather events (e.g., drought periods). Participants in the industry strategy workshop thus saw opportunities for sector bodies to consolidate up-to-date national and international information into timely practical advice that enables the implementation of alternative on-farm management practices. FAR or Animal and Plant Health New Zealand, the association of the crop and animal protection industry, were regarded as key organisations, due to their already well-established domestic and international networks. A seed company agronomist alluded to this opportunity in a focus group when she commented that "what's interesting about that is, we're going to chemical companies to find out that information, not to the likes of FAR to find that information." Integrating advice from different sources and circulating regular weed management extension packages could be one activity industry-good bodies undertake to address HR challenges across the arable sector. Given those bodies' existing social networks and extension capabilities, participants in the industry strategy workshop felt that this opportunity was among the more or less immediately feasible activities that would support more strategic HR management.

Similar information challenges were noted in relation to product labels on herbicides, particularly regarding the clear visibility of the modes of action of their active ingredients. The following exchange between participants in the rural professional focus group demonstrates this challenge:

Person 1: That's where I'm trying to focus my growers more on active ingredient rather than brand names. ... I personally think the labels need to be changed, ... active ingredient should be in bigger letters for people to see easily. Currently, I need big glasses sometimes to read some of the active ingredient names. ...

Person 2: Especially all the generics.

Person 3: Well, that's the problem, you go into chemical sheds and ... they [herbicides] are all the same. [Yet, the farmer says,] 'Oh, but they've got different names'.

With the regular rotation of herbicides working through different modes of action being one core recommendation for managing HR, growers and those within their support networks should routinely record applied modes of action and refer to this information in their long-term planning. Stating relevant information concisely and in an easily visible

format on product labels may, thus, contribute to more strategic decision-making. To realise this opportunity, industry-good and peak farmer organisations could advocate for improved labelling, while the crop protection industry and regulatory bodies need to implement the relevant changes. A farmer further suggested that labels could be used to state crucial information about HR directly, as a constant reminder to consider relevant management implications.

A third key opportunity to address knowledge-related challenges discussed across several research settings, particularly the industry strategy workshop, is to improve the multi-directional information flows between the stakeholder groups involved in weed and HR management. Participants noted, for instance, that currently no formal mechanisms exist for farmers to communicate adverse or beneficial outcomes from trialling new practices, or avenues to report potential cases of HR to weed scientists. Crop protection or contract companies often have relevant in-house chains of communication for field representatives, while the staff of industry-good bodies, such as FAR, may receive feedback from growers or agronomists through informal communication. However, this knowledge exchange is still insufficient, as noted by a workshop participant:

I also think the information flow from farmers, industry and researchers can be improved. Seed companies are doing a huge amount of work and we get information on some of it. It would be great to have some more knowledge exchange happening, so research isn't doubled up or farmers are already doing things on farm that works. This is probably something [an industry peak body] can work on more.

This sentiment was echoed by farmers during interviews. While one grower felt that “knowledge sharing is becoming huge right across the board”, another emphasised the need to share information more effectively within farmers’ decision-making networks:

Well, doesn't it come down to information transfer? If we go back to the dairy industry, . . . how successful it has been over the last 20, 30 years simply through information transfer. That's what I think the arable industry is missing. You can't do any more than FAR, FAR are fantastic. The information they provide is actually fantastic, but I'm talking about on-the-ground information transfer, from your reps, from your chemical reps to your field reps. That information has got to be even more available than it is already.

More formalised exchange processes could be established to improve multidirectional information flows, particularly from farmers and field staff to other stakeholder groups. The workshop participants discussed the possibility that FAR might be in a position to collect and further distribute relevant information. As outlined in the next section, however, this may also be facilitated by a wider network of collaborating organisations.

4.3. Collaboration and Coordination

Throughout the various research settings, participants described how effective collaboration can support improvements in on-farm weed and HR management. On one level, this concerns farmers’ ability to draw on strong social networks in their decision-making, including other farmers, representatives from crop protection companies and industry-good bodies, and agricultural scientists. As a farmer acknowledged when discussing his farm management:

I'm very lucky in the fact that I've surrounded myself by good people that I go to all these things with—[biophysical scientist] and all her colleagues. I'm exposed to all this stuff, so I'm thinking about it day in day out, but I'm sure there are plenty of people that don't.

In other instances, farmers collaborate in farmer-to-farmer learning and knowledge exchange programmes organised by industry-good bodies, or in social networking activities,

such as young farmer groups. Collaboration thus occurs regularly in a range of more or less formalised settings, but in most cases, it does not amount to coordinated strategic efforts.

The SWOT analysis conducted by each group in the industry workshop highlighted this lack of coordinated collaboration as a current weakness in the arable sector. Participants noted that the absence of a central industry or government body not only often leads to information challenges but also an overall lack of sector-wide coordination on shared risks, such as agrichemical resistance. This challenge is compounded by the fact that such coordination is required across several agricultural sub-sectors, with many Canterbury farmers, for example, including livestock in their farm systems. Furthermore, HR-resistant weed populations are also found in vineyards and horticultural crops, from where they might migrate through biological or anthropogenic transfer.

Improving inter- and cross-sector connections could help to both facilitate the multi-directional information flows discussed above and establish avenues for more strategic coordination of shared HR risks. Several workshop participants thought that a designated network of industry-good bodies (e.g., FAR and Animal and Plant Health New Zealand), rural supply companies (e.g., Ravensdown), crop contract companies (e.g., PGG Wrightson or Midlands), and the Ministry for Primary Industries could facilitate such coordination. Key public interest and research groups should also be included, such as the New Zealand Plant Protection Society. Together, this cross-industry network could further leverage existing inter-/national connections for timely knowledge transfer on developments in HR management, for example to the Australian's Grains Research and Development Corporation. The workshop participants discussed a range of activities that a cross-industry network could support, including voluntary industry codes of practice, or charters focused on promoting good HR management or establishing standards for testing traded seed lines for HR to reduce their mobility.

A second opportunity for better sector-wide collaboration and coordination was discussed during reflections on the benefits of previous and ongoing transdisciplinary RD&E programmes. Participants reflected on the benefits of initiatives such as 'A Lighter Touch: Agroecological crop protection to meet future consumer demands', a collaboration of New Zealand's plant-based food sector (horticulture, arable cropping, and wine production), or the government-funded integrated HR management programme through which the workshop was conducted. Building on the transdisciplinary capabilities and insights developed in such initiatives, a cross-industry network could coordinate concerted efforts to co-design ongoing RD&E programmes focused on developing and implementing management strategies for evolving HR challenges. This should include the integration of multiple scientific disciplines and meaningful participation of non-researchers, particularly farmers as the primary on-farm decision-makers.

4.4. Education and Training

Knowledge and skills associated with a diverse range of weed control methods are well-understood prerequisites for effective HR management [13,14]. As one interviewed farmer remarked, "If we know we can do something. If we don't know, we're just going to do what we did." Yet, research participants acknowledged that levels of knowledge and skill vary markedly among those involved in on-farm decision-making. Given the distributed nature of these processes, however, relevant knowledge and skills development needs to occur not just among farmers but across the sector as a whole. A seed company agronomist stressed this in a focus group:

That's the biggest thing, ... education for all of us in the industry. From the farmer to seed suppliers to us as agronomists and farm advisors ... that's the thing that's lacking the most.

When interviewed farmers were asked what would support them in terms of weed and HR management, many voiced similar sentiments. For instance, one farmer noted, "More knowledge—not just for me but the entire industry."

Participants in the industry strategy workshop reiterated this challenge and discussed how further utilising existing outreach and extension networks, for instance those of industry-good bodies, could help build foundational knowledge of HR management across the entire sector. To include those stakeholders still outside these networks, new avenues for information sharing and educational efforts need to be explored. The industry networks described above could coordinate their outreach and extension activities to expand the forums for formal and informal farmer learning, including opportunities for farmer-to-farmer learning. Given the evolving nature of weed and HR management challenges, the workshop participants also considered the implementation of a cross-industry programme to regularly upskill rural advisors and field agronomists, since they are often integral to farmers' decision-making. Expanding applied training courses for weed and HR management already offered by Massey University, one of New Zealand's main agricultural tertiary education institutions, was mentioned as another potential avenue. However, their scalability across the sector was a concern, due to the limited number of weed science educators and cost involved in training a large number of staff across the industry.

Several research participants further stressed that, while weed and HR management education will be beneficial, it is also crucial to foster holistic thinking and farm-system-level planning. As noted above, many farmers currently navigate a significant number of crop- and weed-specific recommendations, often against a background of competitive annual crop contracts. This can complicate rotation planning across multiple seasons and hinder longer-term strategic decision-making. A seed company agronomist critically reflected on this situation in a focus group:

I think that's where the problem kind of starts, . . . a farmer would do business with a lot of agronomy services. So, [one company] would grow some ryegrass there, [another company] would grow beet crop there, we would grow whatever there. So, everybody is just chasing their crop and there's no holistic planning going on, long-term planning.

An agrichemical company representative in the same focus group lamented that HR management in this context is frequently short-term-oriented and reactive. As they noted, "We're talking about it, but it's not until you've actually got the problem that you start talking about it." Following a similar line of thought, some participants in the industry workshop saw an opportunity for improving existing education and training programmes to support whole-farm-system approaches that include the proactive integration of the diverse weed management options available to many arable farmers. One suggested avenue to realise this opportunity was to incorporate more modules on farm systems thinking and integrated weed management into relevant university degrees.

Another topic of discussion in the workshop centred around the fact that in New Zealand no accreditation is required to provide commercial agronomy advice. This was also mentioned during interviews with rural advisors, with one of them comparing this to their previous experience as an agronomy service provider in the United Kingdom:

I think that's what New Zealand lacks, it lacks a body to actually keep people up to date in terms of agronomy. . . . If you go back to the UK model, you've actually got to be BASIS * qualified to be able to write out a recommendation, so the farmer actually has to employ an agronomist or else he has to become BASIS qualified himself.

(* an independent standard-setting and auditing organisation for land management and food production, including the pesticide and fertiliser sectors.)

Some workshop participants thought that using an accreditation system for agronomy advisors to build, and demonstrate, baseline integrated weed management skills and farm system training could support more long-term-oriented HR strategies. However, such a system would have to be established specifically for the New Zealand context and in accordance with national legislation, environmental regulation, and reporting

requirements. The rural advisor with previous experience in the UK acknowledged this and noted, “a lot of things that we’re doing in New Zealand, they’re unique to New Zealand. So, any qualification has got to be unique to us.” This reinforces the finding that the involvement of state agencies and national-level industry bodies is likely required for effective HR management, in this instance to regulate and oversee compliance with relevant accreditation systems.

5. Discussion: Towards Improving Sector Collaboration

In returning to the themes raised in the international literature about moving from a focus on individual farmers’ roles in HR management to cross-sector collaborative approaches, our results highlight some key opportunities and challenges. Many of these challenges emerge, at least partly, due to insufficient connection and coordination across the arable sector, which are, in turn, to no insignificant degree a result of the absence of public extension services overseen by government departments [44–48]. As such, most opportunities described here involve purposely strengthening existing, or forming new, social and institutional relationships among the stakeholder groups involved in HR management, including state actors. This requires recognising the sociocultural facets and distributed nature of farmer decision-making, which points towards the corresponding need for targeted collaborative efforts aimed at developing effective whole-industry strategies. Our research highlights that making such strategies effective involves a portfolio of multipronged activities that address various barriers to implementing HR management recommendations.

It is not novel within wider international scholarship to argue that achieving lasting behaviour changes among farmers and rural communities requires a range of complementary approaches. Decades of extension research and practice show this in an array of environmental management areas. Blackstock et al. [51] (p. 5637), for instance, note in relation to agricultural pollution that “no single approach or strategy for influencing farmers’ behaviour to manage diffuse pollution in the context of climate change is likely to be sufficient”. Similar arguments have been made about extension programmes in general, often with reference to multiple communication avenues and practice change components needed to improve programme efficacy [33,34,52,53]. As outlined above, researchers have already refined some of these insights in relation to weed and HR management. This body of literature outlines key aspects that in conjunction can make extension efforts more effective, such as diversifying the media through which novel information is communicated, exploring combinations of incentives and regulatory mechanisms, and attending to the roles of non-farmers [17,33,34,41,43,54,55].

Our findings do make two noteworthy contributions to this literature. First, they detail opportunities for action among various stakeholder groups across one agricultural sector. The corresponding activities to realise these opportunities provide tangible steps for multipronged approaches to support on-farm management changes, which are generally applicable across agricultural systems in other countries. In doing so, our analysis empirically substantiates the outlined conceptual arguments within international scholarship for why better sector-wide collaboration and coordination are required to enhance HR management. Second, the presented insights start to fill a specific gap in HR research and practice in New Zealand that acknowledges the challenges of establishing collaborative efforts where strategic support is sporadic and uncertain, as may be common in similar contexts where state coordination and investment are intermittent. A key point is thus to highlight that effective collaboration should involve (re)establishing relationships between the public and private sectors, which may have to some degree been compromised by decades of limited state oversight. This finding supports comparable conceptual insights that highlight how effective HR management requires ‘distributed’ efforts by various actor groups across local, regional, and national levels [15,17,22,33–36,40]. The contribution of our analysis is to demonstrate that, in the absence of coordinated state-led support, purposely initiating sector-wide discussions around HR management strategies is crucial for strengthening such collaborative relationships, while

not suggesting that these can fulfil what may be regarded as state functions and, thereby, absolve state agencies of their responsibilities.

Establishing HR management as a ‘shared responsibility’ [13] and considering strategic options is but an initial step, though. Having identified several strategic opportunities, the next phase in the collaborative endeavours of New Zealand’s arable sector needs to explore the feasibility of potential activities and clarify which groups are able, and willing, to assume responsibility for actioning them. Here, we briefly discuss this component of the research to stimulate further efforts among arable sector stakeholders to collaboratively explore feasible strategy implementation pathways for Canterbury and New Zealand. This discussion also offers broader insights useful for other agricultural sectors and countries in a similar stage of developing HR management strategies. Moreover, these insights can inform future collaborative RD&E agendas related to weed management in New Zealand and corresponding international calls for more transdisciplinary weed research [15,42].

The first, and in the short-term likely most achievable, activities centre around improving information and knowledge exchange, as well as initial steps towards more formalised industry collaboration and coordination. The potential of such activities is well-documented in the social scientific literature, for instance in Doohan et al.’s [16] discussion of how two-way information exchanges between weed scientists and farmers can result in better outreach and adoption outcomes. To realise this opportunity for New Zealand’s arable sector, already established and well-connected industry-good bodies, such as FAR and Animal and Plant Health New Zealand, could regularly consolidate domestic and international developments around HR management and circulate up-to-date extension packages focused on translating this information into suitable on-farm practices. Public interest groups with weed science expertise, for instance the New Zealand Plant Protection Society, might be able to support this information exchange. Furthermore, the same organisations could lead an arable industry network involving crop protection bodies, industry-good organisations, and relevant government departments. The terms of reference should specifically note an intention to foster better two-way exchange between practitioners on the ground, industry bodies, and regulators, with the aim of swiftly responding to new HR developments. This network may include weed scientists, or at least communication avenues with them, to promptly discuss RD&E priorities.

Second, education and training opportunities may be enhanced in the medium term by building on existing learning forums. This can help build agricultural stakeholders’ knowledge and skills related to effective weed control, which have been highlighted as crucial preconditions for more strategic HR management [13,14]. Corresponding learning activities can also strengthen informal social networks, such as farmer-to-farmer learning groups or local natural resource management groups. These types of interactions already occur within many of New Zealand’s agricultural communities, and other farmers are often a key source of information for farmers learning new knowledge and skills. The efficacy of peer-to-peer learning is well-documented in other countries [33,34,56], with such settings also offering opportunities to promote the development of social capital and communities of practice [29,30]. Likewise, rural advisors in most New Zealand crop contract or crop protection companies liaise regularly with colleagues and other advisors in their network to resolve specific weed management problems. Some of these companies also have in-house staff training and upskilling programmes. In other instances, training can be more formalised, such as a short course on understanding herbicides offered by Massey University, one of New Zealand’s leading agricultural tertiary institutes. However, a key challenge in expanding these informal and formal learning opportunities is their scalability. Given that training and routine upskilling are required for various stakeholder groups across the entire arable sector, particularly those within farmers’ immediate decision support networks, viable avenues for regular HR-related learning would need to be established for a significant number of people. This requires concerted efforts to build a long-term-oriented portfolio of education and training opportunities. Incorporating integrated weed and HR

management as a compulsory component in agricultural degrees could be one way to mitigate challenges with scalability.

Third, more fundamental structural changes to New Zealand's agricultural system would require significant sector efforts, including strategies to achieve required regulatory changes. Our findings show that establishing an independent advisory network can be highly beneficial in terms of prompting more integrated weed and HR management practices. However, building such an advisory network likely requires a separate accreditation system to ensure sufficient skills among independent advisors, clarify liabilities for management recommendations, and build confidence among farmers. As noted by other researchers investigating HR management, fostering such systemic changes likely requires a suite of top-down regulation, voluntary industry initiatives, and creative incentive mechanisms [17,41,54,55]. Voluntary collaboration within the crop protection industry and with public sector partners and academia is also crucial for filling any gaps in required RD&E activities [43], particularly in contexts marked by a dearth of government-coordinated extension. At the same time, the presented findings from Canterbury's arable sector highlight that cultural changes among farmers would be needed so that the value of independent agronomy advice is recognised. The required systemic and cultural changes involved in establishing and sustaining an independent advisory network as well as ongoing RD&E activities make this a more difficult action that will require long-term efforts on multiple levels. Nonetheless, commencing these efforts can be part of a multipronged sector strategy that includes a portfolio of short- to long-term activities.

This brief discussion of steps that may be taken by arable sector stakeholders in Canterbury and New Zealand to realise the identified opportunities demonstrates that the next phase in the sector's collaborative efforts should include detailed evaluations of the feasibility of implementing corresponding actions. Among the identified opportunities, especially those requiring more substantial systemic changes may face considerable implementation barriers. Overcoming these barriers will require a long-term vision and sustained sector efforts guided by collaboratively developed strategies. With HR increasingly recognised as a growing challenge worldwide, the insights offered through the presented results and discussion can inform similar efforts in other sectors and national settings where strategic HR management efforts are emerging, particularly in contexts of limited government-funded and -coordinated oversight.

6. Conclusions

Our research highlights that effective management of HR is not the sole responsibility of individual farmers. Instead, the presented results outline the diverse ways in which HR is a large-scale challenge beyond the ability of any one farmer to manage, which emphasises the need to take a more collective approach centred around strategic collaboration and coordination. An important point flowing from this is to recognise that 'good farming' praxis is a sociocultural endeavour rather than an individual choice, with diverse roles and responsibilities across decision-making processes. Thus, the first implication of our research is to acknowledge these sociocultural dimensions, which should be accompanied by developing a better understanding of the complex and extended web that constrains and enables farm practices. This may be true not just of managing herbicide resistance, but of efforts to address pesticide and antibiotic resistance as well.

Within this extended web, agricultural sector organisations and state agencies are key to the strategic coordination and support of multipronged efforts given their responsibilities across crucial management aspects, such as formal and informal education, border biosecurity, funding for R&D and its dissemination, or regulation and compliance regarding agrichemical use. Yet, our research recognises that such coordinated support can be sporadic and intermittent, particularly in contexts that, similar to New Zealand, are characterised by a dearth of dedicated state extension services and coordination. We, therefore, conclude that while governments should not be absolved of their involvement in, and support for, HR management initiatives, enabling sector-led strategic approaches may

be necessary. Given the ever-evolving nature of HR weeds and absence of silver bullet solutions, sector leadership will also be indispensable for the early detection of new HR problems and their ongoing resolution through agile R&D and timely management efforts.

For such sector-led approaches to be effective, they will have to be multipronged, comprising a suite of programmes and initiatives. As our research demonstrates, determining the roles and responsibilities for implementing the components of such multipronged approaches should be an explicit discussion topic among the diverse groups of actors involved in HR management and occur early in the strategic planning process. Perhaps most importantly, this will involve evaluating the practical feasibility and realistic implementation pathways for corresponding activities with those engaged in on-farm management. Thus, the final conclusion of our research—and one that connects firmly back to the initial point about collective and collaborative approaches—is that farmers and those directly involved in on-farm management are central to more collaborative approaches aimed at strategically managing herbicide resistance.

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References

1. Ngow, Z.; Chynoweth, R.J.; Gunnarsson, M.; Rolston, P.; Buddenhagen, C.E. A herbicide resistance risk assessment for weeds in wheat and barley crops in New Zealand. *PLoS ONE* **2020**, *15*, e0234771. [CrossRef] [PubMed]
2. Pannell, D.J.; Tillie, P.; Rodríguez-Cerezo, E.; Ervin, D.; Frisvold, G.B. Herbicide resistance: Economic and environmental challenges. *AgBioForum* **2016**, *19*, 136–155.
3. Saunders, J.; Greer, G.; Bourdôt, G.; Saunders, C.; James, T.; Rolando, C.; Monge, J.; Watt, M.S. The economic costs of weeds on productive land in New Zealand. *Int. J. Agric. Sustain.* **2017**, *15*, 380–392. [CrossRef]
4. Heap, I. The International Herbicide-Resistant Weed Database. 2023. Available online: <http://www.weedscience.org> (accessed on 4 February 2023).
5. Ghanizadeh, H.; Harrington, K.C. Herbicide resistant weeds in New Zealand: State of knowledge. *N. Z. J. Agric. Res.* **2021**, *64*, 471–482. [CrossRef]
6. Buddenhagen, C.E.; James, T.K.; Ngow, Z.; Hackell, D.L.; Rolston, M.P.; Chynoweth, R.J.; Gunnarsson, M.; Fengshuo, L.; Harrington, K.C.; Ghanizadeh, H. Resistance to post-emergent herbicides is becoming common for grass weeds on New Zealand wheat and barley farms. *PLoS ONE* **2021**, *16*, e0258685. [CrossRef]
7. Buddenhagen, C.E.; Harvey, B.; Wynne-Jones, B.; Hackel, D.L.; Ghanizadeh, H.; Ando, Y.; Ngow, Z.; James, T.K. Ryegrass resistance to glyphosate and amitrole is becoming common in New Zealand vineyards. *N. Z. Plant Prot.* **2022**, *75*, 57–63. [CrossRef]
8. Ngow, Z. Herbicide Resistant Weeds in Maize in New Zealand: A Survey for Herbicide Resistant Weeds in the Bay of Plenty and Waikato. Master’s Thesis, The University of Waikato, Hamilton, New Zealand, 2022.

9. Ghanizadeh, H.; Harrington, K.C.; Mesarich, C.H. The target site mutation Ile-2041-Asn is associated with resistance to ACCase-inhibiting herbicides in *Lolium multiflorum*. *N. Z. J. Agric. Res.* **2020**, *63*, 416–429. [\[CrossRef\]](#)
10. Gunnarsson, M.; James, T.K.; Chynoweth, R.J.; Rolston, M.P. An evaluation of the resistance of annual and perennial ryegrass to herbicides. *N. Z. Plant Prot.* **2017**, *70*, 165–170. [\[CrossRef\]](#)
11. Harrington, K.C.; Chynoweth, R.J. Have wild oats in Canterbury become resistant to herbicides. *N. Z. Plant Prot.* **2014**, *67*, 331. [\[CrossRef\]](#)
12. Buddenhagen, C.E.; Gunnarsson, M.; Rolston, M.P.; Chynoweth, R.J.; Bourdot, G.; James, T.K. Costs and risks associated with surveying the extent of herbicide resistance in New Zealand. *N. Z. J. Agric. Res.* **2020**, *63*, 430–448. [\[CrossRef\]](#)
13. Espig, M.; Henwood, R.J.T. The social foundations for re-solving herbicide resistance in Canterbury, New Zealand. *PLoS ONE* **2023**, *18*, e0286515. [\[CrossRef\]](#) [\[PubMed\]](#)
14. Espig, M.; Dynes, R.A.; Henwood, R.J.T.; James, T.K. The Drivers of Herbicide Use among Arable Farmers in Canterbury, New Zealand: Toward an Integrated Approach. *Soc. Nat. Resour.* **2022**, *35*, 281–300. [\[CrossRef\]](#)
15. Asmus, A.; Schroeder, J. Rethinking outreach: Collaboration is key for herbicide-resistance management. *Weed Sci.* **2016**, *64* (Suppl. S1), 655–660. [\[CrossRef\]](#)
16. Doohan, D.; Wilson, R.; Canales, E.; Parker, J. Investigating the human dimension of weed management: New tools of the trade. *Weed Sci.* **2010**, *58*, 503–510. [\[CrossRef\]](#)
17. Moss, S. Integrated weed management (IWM): Why are farmers reluctant to adopt non-chemical alternatives to herbicides? *Pest Manag. Sci.* **2019**, *75*, 1205–1211. [\[CrossRef\]](#)
18. Ward, S. Human dimensions of herbicide resistance. *Weed Sci.* **2016**, *64* (Suppl. S1), 551. [\[CrossRef\]](#)
19. Barrett, M.; Ervin, D.E.; Frisvold, G.B.; Jussaume, R.A.; Shaw, D.R.; Ward, S.M. A wicked view. *Weed Sci.* **2017**, *65*, 441–443.
20. Dentzman, K. “I would say that might be all it is, is hope”: The framing of herbicide resistance and how farmers explain their faith in herbicides. *J. Rural Stud.* **2018**, *57*, 118–127. [\[CrossRef\]](#)
21. Dentzman, K.; Gunderson, R.; Jussaume, R. Techno-optimism as a barrier to overcoming herbicide resistance: Comparing farmer perceptions of the future potential of herbicides. *J. Rural Stud.* **2016**, *48*, 22–32. [\[CrossRef\]](#)
22. Hurley, T.M.; Frisvold, G. Economic barriers to herbicide-resistance management. *Weed Sci.* **2016**, *64* (Suppl. S1), 585–594. [\[CrossRef\]](#)
23. Jussaume, R.A., Jr.; Ervin, D. Understanding weed resistance as a wicked problem to improve weed management decisions. *Weed Sci.* **2016**, *64* (Suppl. 1), 559–569. [\[CrossRef\]](#)
24. Shaw, D.R. The “wicked” nature of the herbicide resistance problem. *Weed Sci.* **2016**, *64* (Suppl. S1), 528–552. [\[CrossRef\]](#)
25. Dentzman, K. Governance of emerging pests and pathogens in production landscapes: Pesticide resistance and collaborative governance. *Curr. Opin. Environ. Sustain.* **2022**, *58*, 101220. [\[CrossRef\]](#)
26. Ervin, D.E.; Breshears, E.H.; Frisvold, G.B.; Hurley, T.; Dentzman, K.E.; Gunsolus, J.L.; Jussaume, R.A.; Owen, M.D.; Norsworthy, J.K.; Al Mamun, M.M.; et al. Farmer attitudes toward cooperative approaches to herbicide resistance management: A common pool ecosystem service challenge. *Ecol. Econ.* **2019**, *157*, 237–245. [\[CrossRef\]](#)
27. Owen, M.D.K. Diverse Approaches to Herbicide-Resistant Weed Management. *Weed Sci.* **2016**, *64* (Suppl. S1), 570–584. [\[CrossRef\]](#)
28. Parks, M.M.; Anderson Brekken, C. Cosmovisions and Farming Praxis: An Investigation of Conventional and Alternative Farmers along the Willamette River. *Cult. Agric. Food Environ.* **2018**, *41*, 34–44. [\[CrossRef\]](#)
29. Charatsari, C.; Lioutas, E.; Koutsouris, A. Farmer field schools and the co-creation of knowledge and innovation: The mediating role of social capital. *Agric. Hum. Values* **2020**, *37*, 1139–1154. [\[CrossRef\]](#)
30. Gosnell, H. Regenerating soil, regenerating soul: An integral approach to understanding agricultural transformation. *Sustain. Sci.* **2022**, *17*, 603–620. [\[CrossRef\]](#)
31. Height, K.; Graham, S.; Campbell, R.; Hawkes, G.; Schrader, S.; Blessington, L.; McKinnon, S. Opportunities to Manage Herbicide Resistance through Area-Wide Management: Lessons from Australian Cropping Regions. *Sustainability* **2022**, *14*, 1793. [\[CrossRef\]](#)
32. Norsworthy, J.K.; Ward, S.M.; Shaw, D.R.; Llewellyn, R.S.; Nichols, R.L.; Webster, T.M.; Bradley, K.W.; Frisvold, G.; Powles, S.B.; Burgos, N.R.; et al. Reducing the risks of herbicide resistance: Best management practices and recommendations. *Weed Sci.* **2012**, *60* (Suppl. S1), 31–62. [\[CrossRef\]](#)
33. Rose, D.; Keating, C.; Morris, C. Understanding How to Influence Farmers’ Decision-Making Behaviour: A Social Science Literature Review. Report to the AHDB. 2018. Available online: https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Docs/FarmersDecisionMaking_2018_09_18.pdf (accessed on 13 December 2022).
34. Rose, D.; Keating, C.; Vrain, E.; Morris, C. Beyond individuals: Toward a ‘distributed’ approach to farmer decision-making behaviour. *Food Energy Secur.* **2018**, *7*, e00155. [\[CrossRef\]](#)
35. Coble, H.D.; Schroeder, J. Call to action on herbicide resistance management. *Weed Sci.* **2016**, *64* (Suppl. S1), 661–666. [\[CrossRef\]](#)
36. Gould, F.; Brown, Z.S.; Kuzma, J. Wicked evolution: Can we address the sociobiological dilemma of pesticide resistance? *Science* **2018**, *360*, 728–732. [\[CrossRef\]](#) [\[PubMed\]](#)
37. Bagavathiannan, M.V.; Graham, S.; Ma, Z.; Barney, J.N.; Coutts, S.R.; Caicedo, A.L.; De Clerck-Floate, R.; West, N.M.; Blank, L.; Metcalf, A.L.; et al. Considering weed management as a social dilemma bridges individual and collective interests. *Nat. Plants* **2019**, *5*, 343. [\[CrossRef\]](#) [\[PubMed\]](#)
38. Graham, S.; Roger, S. How local landholder groups collectively manage weeds in south-eastern Australia. *Environ. Manag.* **2017**, *60*, 396–408. [\[CrossRef\]](#) [\[PubMed\]](#)

39. Ervin, D.E.; Frisvold, G.B. Community-based approaches to herbicide-resistant weed management: Lessons from science and practice. *Weed Sci.* **2016**, *64* (Suppl. S1), 609–626. [\[CrossRef\]](#)
40. Schroeder, J.; Barrett, M.; Shaw, D.R.; Asmus, A.B.; Coble, H.; Ervin, D.; Jussaume, R.A.; Owen, M.D.K.; Burke, I.; Creech, C.F.; et al. Managing Wicked Herbicide-Resistance: Lessons from the Field. *Weed Technol.* **2018**, *32*, 475–488. [\[CrossRef\]](#)
41. Shaw, D.R.; Barrett, M.; Schroeder, J.; Asmus, A.B.; Ervin, D.; Jussaume, R.A.; Coble, H. Critical Next Steps in Combating Herbicide Resistance: Our View. *Weed Sci.* **2018**, *66*, 559–561. [\[CrossRef\]](#)
42. Jordan, N.; Schut, M.; Graham, S.; Barney, J.N.; Childs, D.Z.; Christensen, S.; Cousens, R.D.; Davis, A.S.; Eizenberg, H.; Ervin, D.E.; et al. Transdisciplinary weed research: New leverage on challenging weed problems? *Weed Res.* **2016**, *56*, 345–358. [\[CrossRef\]](#)
43. Beckie, H.J. Herbicide resistance: The increasingly important role of the crop protection industry. *Pest Manag. Sci.* **2021**, *77*, 1557–1558. [\[CrossRef\]](#)
44. Ministry for Primary Industries. New Zealand Agriculture: A Policy Perspective. 2017. Available online: <https://www.mpi.govt.nz/dmsdocument/27282-New-Zealand-Agriculture#:~:text=New%20Zealand%20farmers%20receive%20the,no%20subsidies%20or%20other%20payments> (accessed on 13 December 2022).
45. Duncan, R.; Kirk, N.; Booth, P.; Robson-Williams, M. Primary Producers' Perspectives on New Zealand's Primary Industries Advisory Services System. MPI Technical Paper No: 2021/01. 2021. Available online: <https://www.mpi.govt.nz/dmsdocument/48931-Primary-producers-perspectives-on-New-Zealand's-primary-industries-advisory-services-system> (accessed on 13 December 2022).
46. Botha, N.; Coutts, J.; Roth, H. The Role of Agricultural Consultants in New Zealand in Environmental Extension. *J. Agric. Educ. Ext.* **2008**, *14*, 125–138. [\[CrossRef\]](#)
47. Turner, J.A.; Rijswijk, K.; Williams, T.; Barnard, T.; Klerkx, L. Challenges to effective interaction in the New Zealand agricultural research and extension system: An innovation systems analysis. *J. Agric. Ext.* **2013**, *9*, 89–98.
48. Turner, J.A.; Landini, F.; Percy, H.; Gregolin, M.R.P. Advisor understanding of their roles in the advisory system: A comparison of governance structures in Argentina, Australia, Brazil, and New Zealand. *J. Agric. Educ. Ext.* **2023**, *29*, 3–28. [\[CrossRef\]](#)
49. Stats NZ. Annual Boundaries; Regional Council 2020 Clipped. (Generalised). 2020. Available online: <https://datafinder.stats.govt.nz/layer/104253-regionalcouncil-2020-clipped-generalised/> (accessed on 9 May 2023).
50. Braun, V.; Clarke, V. *Successful Qualitative Research: A Practical Guide for Beginners*, 1st ed.; Sage: London, UK, 2013.
51. Blackstock, K.L.; Ingram, J.; Burton, R.; Brown, K.M.; Slee, B. Understanding and influencing behaviour change by farmers to improve water quality. *Sci. Total Environ.* **2010**, *408*, 5637–5638. [\[CrossRef\]](#) [\[PubMed\]](#)
52. Payne, T.A.; Turner, J.A.; Rijswijk, K.; Mcdermott, A.K.; Wakelin, R.D.N. Informing extension project design: The right tool for the job. *NZGA Res. Pract. Ser.* **2016**, *16*, 33–38. [\[CrossRef\]](#)
53. Rhodes, A.P.; Casey, M.J.; Payne, T.A.; Brown, M. Over the fence: Understanding what people do and how they might change. *NZGA Res. Pract. Ser.* **2016**, *16*, 39–45. [\[CrossRef\]](#)
54. Barrett, M.; Soteres, J.; Shaw, D. Carrots and sticks: Incentives and regulations for herbicide resistance management and changing behavior. *Weed Sci.* **2016**, *64* (Suppl. S1), 627–640. [\[CrossRef\]](#)
55. Powles, S.B.; Gaines, T.A. Exploring the potential for a regulatory change to encourage diversity in herbicide use. *Weed Sci.* **2016**, *64* (Suppl. S1), 649–654. [\[CrossRef\]](#)
56. Goeb, J.; Lupi, F. Showing pesticides' true colors: The effects of a farmer-to-farmer training program on pesticide knowledge. *J. Environ. Manag.* **2021**, *279*, 111821. [\[CrossRef\]](#)

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