Conservation agriculture and beyond: a view from the plant science industry

Conservation agriculture in Australia expanded rapidly from the early 1980s in parallel with the adoption of glyphosate and other herbicides. Poor knowledge of weed dynamics and herbicide use practices led to development of weed resistance. Societal and market pressures weakened research on new herbicide technologies in the years after the millennium. The early 2010s saw the adoption of a zero-tolerance approach to weed escapes, industry wide communication on resistance topics and re-investment in herbicide research. Plant science industry companies have supported industry efforts and undertaken parallel initiatives in their own right. Industry research has focused on better targeted and lower impact herbicides. As the focus of conservation agriculture turns from soil protection to climate adaptation and mitigation, the plant science industries are increasing efforts in boosting biological options and supporting a more regenerative agriculture.

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European farming in a foreign world

Recent years have seen new insights into the land management practices of First Nation Australian peoples, and the extent of the impact of European farming systems. Acknowledging that the relatively low population densities put limited pressure on environmental resources, historical records show that the condition of the country was admirable at the time of white settlement; "chain of ponds" systems were common in forested valley floors and plains were often so deep with organic matter and nardoo roots explorers reported difficulty in traversing them (Pascoe, 2018).

The advent of European farming practices had immediate and dramatic impacts. Intensive grazing destroyed relatively weak native grass fields and tree clearing damaged riverine environments. Traditional double or triple cultivation techniques reduced soil organic matter levels by over 50% in most intensively managed farming systems and resulted in severe soil erosion (Richardson et al., 2019). This reached crisis level in the 1930s and 1940s when several Australian states established government soil conservation services.

The author's first 'real' job was with the Soil Conservation Service (SCS) of New South Wales which for 50 years from 1948, repaired soil water erosion with a large fleet of bulldozers building thousands of kilometres of complex bank and waterway erosion mitigation systems.

Conservation agriculture – a new approach

Reduced tillage agriculture was first mooted in the 1940s as a response to United States (US) dust bowl events of the same period (Fischer & Hobbs, 2019). Widespread adoption only commenced in the 1970s with the development of a variety of effective chemical weed control options including glyphosate (Roundup®), paraquat (Gramoxone®) and atrazine (Gesaprim®). Supported by significant commercial marketing budgets and government extension services, adoption accelerated rapidly from 1983.

By 1995, around 90% of Australian farmers were using conservation agriculture techniques on at least some of their farms making it one of the fastest ever adopted agricultural technologies (Llewellyn & Ouzman, 2019). While initial adoption was mainly driven by soil erosion concerns, the simplicity of the technique enabled by the highly flexible and effective herbicide glyphosate cannot be understated as a contributing factor. It is no coincidence that the growth of the curve in Figure 1 (over page) started around 1980, when Roundup® received its first conservation tillage label.

Aside from soil conservation, many additional benefits soon became apparent including;

- The generally better soil tilth and aeration contributing to better soil health.
- Reduced rainfall run-off and rapid infiltration and adsorption which 'harvests' available water and 'banks' it for use during the growing season.

Chemical weed control challenges

While numerous challenges emerged to conservation agriculture, including fertility deficits, disease management, soil surface modifications and lack of suitable machinery, the availability of effective weed control options is of existential importance to the system. While there are many cultural and non-chemical weed control practices mooted, conservation tillage systems in Australia still depend heavily on effective herbicides. The system faces significant challenges in this respect.

Herbicide resistance development

The steady development of herbicide resistant weed populations has been catalogued by Ian Heap (2020) at weedscience.org. As of 16 February 2020, some 500 different weeds species globally have developed resistance to one or more herbicides. The most prominent cases have occurred in the acetolactate

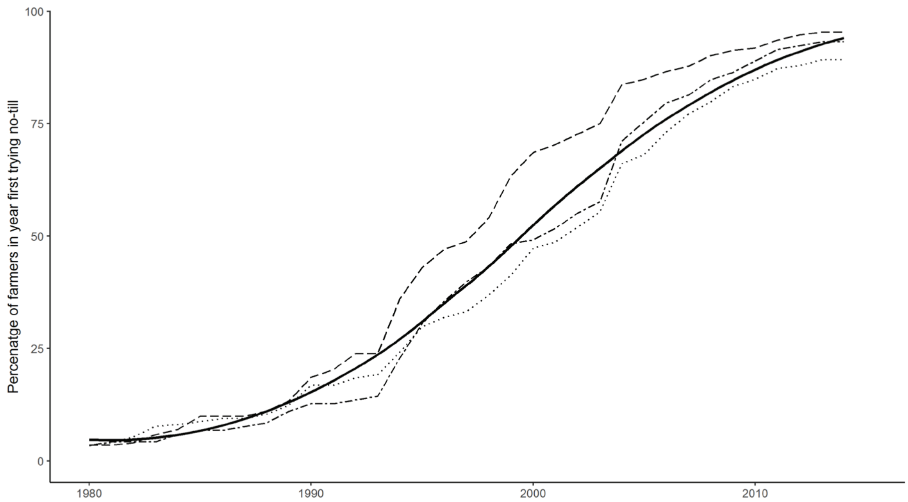

Figure 1: The cumulative proportion of Australian grain growers who had used some no-till (or zero-till) by year (solid line is national smoothed data, based on 2014 grower population, two dash line is northern, dotted is southern and long dashed is western).

Source: Llewellyn and Ouzman (2019).

synthase (ALS) and some photosystem II (PSII) inhibitors, however, since 1995, some 20 years after launch, there has been a growth in resistance to 5-enol-pyruvylshikimate-3-phosphate (EPSP) synthase inhibitors (e.g. glyphosate).

The first case of resistance in a weed in Australia was discovered in 1982 (Heap & Knight, 1982) and the number of cases has grown steadily during the subsequent three decades. There are some 19 weeds species showing resistance to glyphosate, including more than 500 known populations of annual ryegrass (rigid ryegrass, *Lolium rigidum*).

The realisation of the true nature of the weed resistance threat was only slowly recognised as:

1. There was poor understanding of weed population dynamics. Annual weeds seed generally only once per year meaning resistance builds up little noticed, over many years.
2. The predominant conceptual framework for weed management was the Economic Threshold Level (ETL) concept, which focused on annual, rather than long-term impacts on gross margin and accepted a certain number of weed escapes.
3. The frequent delivery of new herbicides during the 1990s led to the belief that resistance could be overcome by new products.

While farmers were encouraged to vary modes of action, several factors counteracted this:

1. The number of effective products available at any one time was usually limited so farmers were strongly inclined to re-use effective products.
2. Under economic pressure farmers, naturally tended to use the most cost-effective product.
3. Competing companies selling products with the same mode of action often raced to capture market share.
4. These factors accelerated after patent expiry when prices dropped and use expanded rapidly.

The release of a study by Llewellyn et al. in 2016 revealed for the first time the real cost of weeds to Australian broadacre farmers at some A$3.3 billion, or A$146 per hectare. The need for an effective and coordinated response to weed resistance is irrefutable.

Difficulty of finding new modes of action

The rate of discovery and launch of herbicides based on new modes of action fell significantly after the late 1990s (Beckie et al., 2019). A number of companies actually scaled down herbicide research and development due to:

- The dominance of glyphosate in the major herbicide tolerant crops of corn and soybeans, which removed these large potential markets and investment incentives.
- The steady increase in regulatory requirements and cost of herbicide development. The cost of developing a single successful pesticide was estimated at US$286 million in 2014 (Phillips McDougall, 2016). The same study indicated that on average, 159,754 molecules were screened to find a single successful candidate, a threefold increase from 1995. Average time to market increased from 8.3 to 11 years over the same period.

Growing societal pressures

Notwithstanding the greater regulatory oversight, and the fact that herbicides can be clearly shown to have strong benefits in terms of labour savings, environment and food security, societal acceptance of herbicide (and other pesticide) use in agriculture in general has continued to erode.

The root cause appears to be growing "chemiphobia", an "irrational fear of chemicals", which James Kennedy (2019) contends is "spreading despite our world becoming cleaner and safer". Kennedy outlines that an instinctive evolutionary fear of contamination and stereotypes of man-made chemicals established during the early industrial age are taken advantage of by marketers, politicians and opponents to pursue their economic and political goals.

While regulations have continually been strengthened, community trust in government and their appointed regulatory agencies has steadily decreased:

> "The 2020 Edelman Trust Barometer reveals that despite a strong global economy and near full employment, none of the four societal institutions that the study measures – government, business, NGOs and media – is trusted." (Edelman, 2020)

Finally, the role of large international companies in the development of crop technologies is often linked by opponents with purported control of the global food supply chain by those companies.

The response has been a growing demand for a return to 'traditional approaches' and localised solutions believed by some to be more trustworthy. Regardless of the true ecological or economic impact of such approaches, some retailers have imposed non-scientific secondary standards. Most seriously, these concerns have stimulated politically motivated responses, particularly in Europe, that are not science based and which threaten the global market for commodities treated with crop protection products. Long term, this also impacts the incentive to develop such products.

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Industry responses

The decade starting 2010 saw a dramatic shift in attitudes across governments, farming communities and industry to the threat to facing conservation agriculture, especially in relation to weed control strategies.

The end of the age of "tolerance"

A key development was to move away from the short term ETL approach, to one of "zero tolerance" to weed survival and seed bank build up. The Global Herbicide Resistance Challenge conference in 2013 in Perth saw general agreement that any weed left in the field was a potential store of resistant seed. This transformed the discussion from one of economic management to a long-term fight for enterprise survival (Powles, 2014).

While in earlier decades, farmers seeking full weed control may have used more, or a greater range of herbicides, lack of effective options, cost and resistance risks now obviated this response.

A broader range of cultural practices were discussed, developed and trialled. Beckie et al. (2020), lists some 18 different strategies. There is also a better understanding that any repeated practice, chemical or otherwise, that places selection pressure on a weed population will inevitably lead to weed adaptation. A well known example is "crop mimicry" of barnyard grass *(Echinochloa crus-gali)* (Barrett, 1983), which evolved to resemble rice and thus avoid hand weeding.

The weed control community, including farmers, industry, advisors and researchers has recommitted to more integrated approaches where several strategies are combined to lower the selection pressure on any one strategy to create more sustainable systems.

Private-public partnering

Research focus on resistance

In 1998, the Grains Research and Development Corporation (GRDC) established AHRI (the Australian Herbicide Resistance Initiative) as one of the earliest global institutes dedicated to the study herbicides weed resistance. From the outset, the institute cultivated links with industry in the pursuit of practical on-farm solutions.

Global companies have also increased collaborative research and development (R&D). In 2000, Syngenta developed the herbicide resistance "Quick Test" in close collaboration with Australian researchers (Boutsalis, 2001). The Bayer Frankfurt Weed Resistance Competence Centre, established in 2014 with 12 staff, has undertaken collaborative research with AHRI and other Australian universities.

Weedsmart

The promotion of more complex integrated weed management systems made it important that all parties interacting with farmers communicated in a consistent way. In 2010, the GRDC, with the support of 21 industry partners, established Weedsmart (www.weedsmart.com.au, see Figure 2) to coordinate and harmonise extension programs and messaging. Weedsmart 'Big 6' is an example of simple messaging delivered via a wide range of messaging channels.

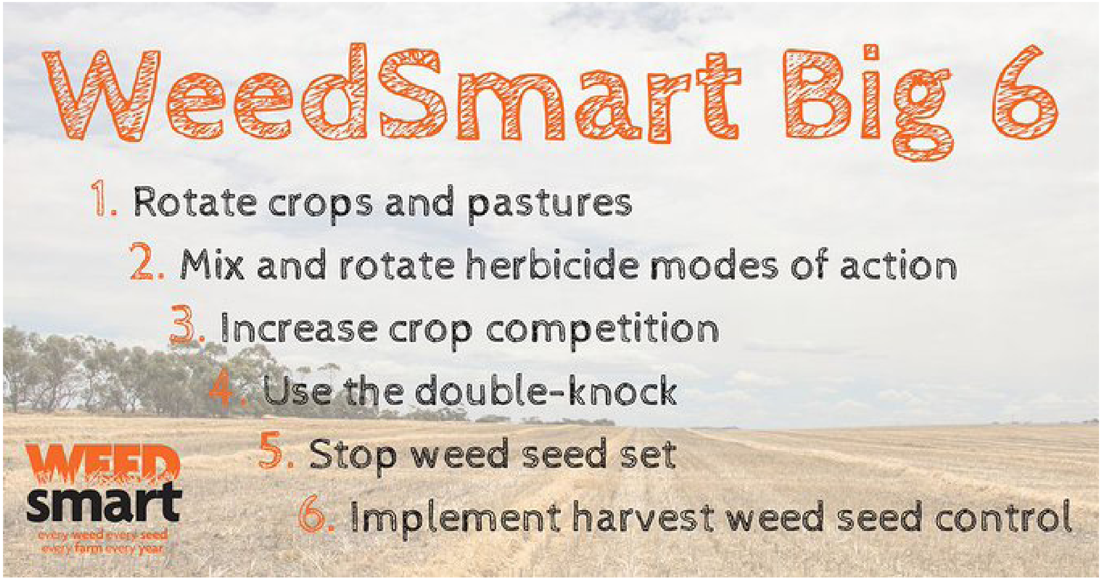

Figure 2: Example of integrated broad-based messaging supported by 21 industry partners.

Source: weedsmart.org.au

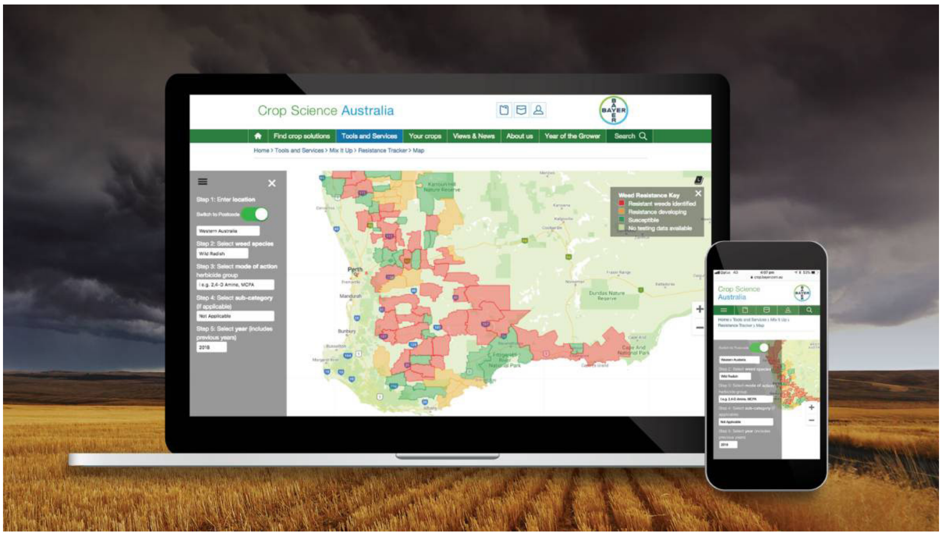

Figure 3: Resistance Tracker Tool assembled by Bayer from de-identified resistance test results is an example of industry provided tools adding to grower understanding of resistance.

Source: www.mix-it-up.com.au

Industry communication

In addition to Weedsmart, many companies have promoted weed resistance messaging. Bayer Crop Science offers a suite of services under the 'Mix-it-up' banner.

A 'Resistance Tracker' (see Figure 3), combines de-identified test results at regional (postcode) level from a number of sources to allow farmers to track the herbicide resistant weed populations to various herbicide mode of action groups over time. The Mode of Action (MOA) tool allows farmers to select the most effective combination of products, as well as providing access to global best practice approaches on resistance issues. Finally, farmers can apply for subsidised 'Quick Test' (for plants) and 'Seed Test' resistance services, provided in partnership with the University of Adelaide and Charles Sturt University.

Herbicide research strengthened

The continued critical importance of herbicides as an 'anchor' technology in Australian farming systems was highlighted in a recent paper by Beckie et al. (2020), which compared the use of glyphosate with 17 non-herbicidal weed control strategies across 13 attributes. Only systems utilising glyphosate scored highly on all 13 attributes. The significant launches of the new pre-emergence herbicides Sakura® (pyroxasulfone, Bayer) and Boxer Gold® (S-metolachlor and prosulfocarb, Syngenta) have not diminished the importance of glyphosate.

The pressing need to find new herbicide options led Bayer and the GRDC to enter into a multi-year collaboration known as the Herbicide Innovation Partnership (Figure 4, over page). Established initially for five years, the partnership's primary objective finding and providing new herbicides and safener compounds for broadacre markets in Australia and beyond with a particular focus on resistance-breaking solutions for cereals. In this project, Australia receives specific focus as a priority 1 country via the inclusion of weed and crop species of relevance to Australian agriculture in screening and profiling platforms as well as early-stage testing within Australia. An additional benefit is capacity-building via the training of more than 30 Australian and New Zealand post-doctoral chemists and biochemists in advanced industrial research. This partnership has increased throughput of herbicide and safener discovery at Bayer and the chance of a successful outcome with an Australian fit.

Figure 4: GRDC Bayer HIP partnership: Australian and New Zealand Post Doc chemists are instrumental in discovering new herbicide compounds, which are tested under Australian conditions.

Herbicide tolerance traits

The potential of herbicide tolerance (HT) traits for agriculture is clearly demonstrated by the success of glyphosate tolerance in soybean, maize/corn, cotton and to a lesser extent canola. HT developments introduce new herbicide modes of action in crops for which they would not normally be used and offers farmers greater flexibility. In Australia, some 99% of cotton and 10% of canola is tolerant to glyphosate. Triazine and imidazoline tolerance have been useful in canola, with some limitation due to yield penalties and spectrum.

Given the challenge of discovering new herbicide modes of action, it is important that HT is fully developed. The possible future roll-out of phenoxy and glufosinate tolerant trait in Australian cotton will further broaden options for farmers. Given advances in breeding technology, such as CRISPR, there is hope that developments in this area will accelerate in the future.

Digital agriculture

The advent of global navigation satellite systems in the 1990s and reliable yield monitors heralded the beginnings of precision agriculture (PA). Initially the focus was on improving management approaches based on historical yield and soil mapping.

From 2010 there has been an explosion of interest in digital agriculture (DA). Driven by much better satellites, drones, machine-based sensors and computers, DA seeks to use models and algorithms to provide decision support at a hyper-local level (e.g. several metres square or individual trees). This promises better targeting of inputs and planning of farm operations for better economic and environmental outcomes.

The role of DA in weed control strategies can include:

a) better targeting of stand-alone weed control programs
b) deployment of integrated weed management approaches.

Targeting of herbicides might be improved by:

a) Patch spraying weed dense locations based on previous remote mapping or predictive algorithms.
b) 'Green on Brown' spot spraying based on normalised difference vegetation index (NDVI) driven identification.
c) 'Green on Green' spot spraying of weeds in inter-rows, or by machine learnt weed identification.
d) In line mixing of herbicides, 'on the run' to choose the best mix to control individual weeds.

Delivery platforms might include tractor pulled and auto propelled sprayers, wheeled robot sprayers,[1] spray drones[2] and possibly larger unmanned aerial vehicles (UAVs).

The use of such DA approaches need not only apply to chemical weed control. An interesting development is the 'active cultivation' systems that rapidly deploy to destroy individual weeds or patches of weeds. Microwave destruction,[3] flaming, electrical and laser destruction are all being developed and could be applied via the same digital technology.

Many of the above technologies will require safety and regulatory review, but offer real options for new approaches to weed control.

DA may also allow the integration of several weed control methods at highly localised scale driven by a decision support algorithms. As expressed in Beckie et al. (2020):

> "A weed map from the past growing season that is used to predict the following season weed threat would allow farmers to 'stack' a number of targeted control measures, both chemical and non-chemical, thereby ensuring weed control diversity. For example, identified weed patches could have higher rates and/or more diverse mixtures of PRE herbicides, very high crop seeding rates (even broadcast in the patches), inter-row tillage and targeted POST herbicide applications and reduced harvest height to ensure weed seed interception for harvest weed seed control (HWSC). As part of this patch intensive management, more expensive herbicides may be justified because of the reduced area being treated."

Beyond conservation agriculture – from weed management to regeneration

Much of this paper has focused on the critical issue of herbicide resistant weed management as this poses a major threat to conservation agriculture. At the same time, the future climate will challenge Australia's agriculture in new ways.

1 e.g. Swarmfarm.com

2 e.g. xagaustralia.com.au

3 e.g. https://www.growave.ag/

a) Rainfall in the southern grain belt is expected to be lower, more summer dominant and fall more heavily. Temperatures and evapotranspiration will rise. The importance of soil carbon and coverage is will thus be more important than ever.

b) The pending Glasgow COP26 climate conference is expected to see the number of countries committing to zero emissions by 2050 grow. Soil carbon sequestration is likely to move from an agronomic desire to an obligation for agriculture. While a potential burden to farmers, this may spur new research and additional funding via new carbon markets.

c) More broadly, many leading farmers and commentators are proposing that agriculture goes beyond conservation, or carbon sequestration toward a paradigm of continual improvement of farm landscapes, often loosely termed as regenerative agriculture.

The plant science industry has a clear role to play in each area and is already starting the process of research and technology development.

While conservation agriculture appears to have halted the decline in soil carbon at a new equilibrium, sustainable increases in carbon have been difficult, especially where rainfall is less than 500 mm. Recent developments however have given some hope that a path forward may be found. These include:

– There is a growing interest in soil health driven by greater understanding of soil biology. Horticulture Innovation Australia, with industry support, has trained farmers via the multi-year Soil Wealth project[4] including composting, minimum tillage, controlled traffic, multispecies cover cropping and targeted soil amelioration with biological additives.

– Rapid uptake of multispecies cover cropping in higher rainfall areas has shown a wide range of benefits, including improved soil organic matter, improved soil

4 https://www.soilwealth.com.au/

structure, nitrogen fixation and improved soil drainage (Kaye & Quemada, 2017). The practice has been adopted by leading large horticulturalists in Australia (e.g. Robert Hinrichsen's Kalfresh; HIA, 2017) with impressive results including rapidly increasing soil organic matter.

- Several companies have launched commercial biological products in support of this trend. Bayer has launched Serenade® Prime, based on the beneficial soil bacteria *Bacillus subtilis* (*B. amyloliquefaciens*) strain QST713 which has seen significant adoption in horticultural systems.

- The use of cover cropping to build organic matter in lower rainfall areas remains challenging. In his 2017 Nuffield Report, Alex Nixon (2019) underlined the potential benefits, and set out a tentative pathway for adoption including establishing a multi-year plan, reflecting the longer-term benefits of such a system, and seeking alternative funding sources. Emerging government and voluntary carbon markets may eventually provide such funding incentives.

- Bayer has launched TagTeam® a multi-action inoculant that addresses both nitrogen and phosphate fertility in broadacre areas. By combining nitrogen fixing rhizobia with the naturally occurring soil fungus *Penicillium bilaii* this product may help address the 'stochiometric challenge' of building organic matter and humus, which necessitates high level of fertiliser addition (Richardson et al., 2019).

Finally, at a landscape scale, there are more discussions on how to repair and rehydrate whole landscapes. The Mulloon Institute (Wilson, 2019), east of Canberra, promotes activities that could improve overall soil moisture availability across large areas, this being the critical driver of all soil health and carbon improvements.

Conclusions

Conservation agriculture was a concept that had incubated for 40 years before seeing rapid adoption from the early 1980s with launch of effective knockdown herbicides. This transition was supported by researchers, industry, farmers and advisors who nonetheless mainly operated individually. It was however built on a narrow technology base and an incomplete understanding of the long-term impacts of such a system. Weed resistance arose as a key threat to the sustainability of the system.

The years since 2010 have seen the realisation of the magnitude of the threat of resistant weeds. Public-private collaboration is now much stronger in promoting integrated approaches to tackling weed resistance. The global plant science industry, in partnership with Australian farmers, researchers and government agencies, has increased R&D efforts into such integrated systems, as well as into new herbicides.

The key learning from the past is that conservation agriculture must be based on a broadly based integrated system. While technologies provided by the plant science industry may still be critical, there is a willingness to promote integrated systems as they will ultimately ensure long-term sustainability.

The future holds new challenges and opportunities as the focus moves from conservation agriculture to carbon sequestration and regenerative agriculture. The plant science industry, which provided critical technology for the conservation agriculture revolution is ready to support, then make, such a new system a reality.

References

Barrett, SCH (1983), Crop mimicry in weeds, *Economic Botany,* vol. 37, no. 3, pp. 255–82.

Beckie, HJ, Ashworth, MB & Flower, KC (2019), Herbicide resistance management: recent developments and trends, *Plants,* 8, p. 161.

Beckie, HJ, Flower, KC & Ashworth, MB (2020), Farming without glyphosate? *Plants,* 9, p. 96, doi:10.3390/plants9010096.

Boutsalis, P (2001), Syngenta Quick-Test: a rapid whole-plant test for herbicide resistance, *Weed Technology,* vol. 15, issue 2, June, pp. 257–63.

Edelman (2020), Edelmen trust barometer 2020, https://www.edelman.com/trustbarometer

Fischer, T & Hobbs, P (2019), Tillage: global update and prospects, in *Australian agriculture in 2020 – from conservation to automation,* edited by Jim Pratley and John Kirkeguard, Agronomy Australia.

Heap, I (2020), The International Survey of Herbicide Resistant Weeds, online, 15 February 2020.

Heap, JW, Knight, R (1982), A population of ryegrass tolerant to the herbicide diclofop-methyl*, Journal of the Australian Institute of Agricultural Science,* 48, pp. 156–7.

Horticulture Innovation Australia (HIA) (2017), Three vital practice changes at Rob Hinrichsen's Kalfresh: a case study, 30 November, available at: https://www.soilwealth.com.au/imagesDB/news/SW-ICP_CaseStudy_KalbarQLDDemoSite_v3.pdf

Kaye, JP & Quemada, M (2017), Using cover crops to mitigate and adapt to climate change. A review, *Agronomy for Sustainable Development,* vol. 37, article number: 4.

Kennedy, J (2019), *Fighting chemophobia,* ISBN 9781691751808.

Llewellyn, R & Ouzman, J (2019), Conservation agriculture in Australia: 30 years on, in *Australian agriculture in 2020 – from conservation to automation,* edited by Jim Pratley and John Kirkeguard, Agronomy Australia.

Llewellyn, RS, Ronning, D, Ouzman, J, Walker, S, Mayfield, A & Clarke, M (2016), *Impact of weeds on Australian grain production: the cost of weeds to Australian grain growers and the adoption of weed management and tillage practices,* Report for GRDC, CSIRO, Australia.

Nixon, A (2019), Farming for the future: optimising soil health for a sustainable future in Australian broadacre cropping, Nuffield Australia Project No. 1709.

Pascoe, B (2018), *Dark Emu: Aboriginal Australia and the birth of agriculture,* ISBN: 9781921248016.

Phillips McDougall (2016), The cost of new agrochemical product discovery, development and registration in 1995, 2000, 2005–08 and 2010–14.

Powles, S (2014), Global herbicide resistance challenge, Ahri.uwa.edu.au

Richardson, A, Coonan, E, Kirkby, C & Orgill, S (2019), Soil organic matter and carbon sequestration, *Australian agriculture in 2020 – from conservation to automation,* edited by Jim Pratley and John Kirkeguard, Agronomy Australia.

Wilson, C (2019), Dehydration and rehydration of the Australian landscape, *Geography Bulletin,* vol. 51, issue 1.

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