Alternative Weed Control Measures

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Executive Summary

Australian farmers are among the world's best at managing limited resources, but our techniques are not without compromises. Weeds are costing producers an average of $113 per ha in both chemical and non-chemical control measures with yield losses from crop competition costing producers $33 per ha. Herbicide resistance is costing an extra $187 million to industry in extra herbicide treatments (GRDC, 2016).

This report aims to highlight some weed control measures that can be implemented into Integrated Weed Management (IWM) plans, reducing or preventing the frequency and cost of herbicide resistance. Australian agriculture is one of the least subsidized industries in the world, which increases the importance of developing systems which both increase the efficiency of weed control programs and reduce the risk of developing resistance to any herbicide.

What if we could lower our reliance on herbicides? This could have a beneficial effect on both the profitability of crops and on the health of the environment. A reduction in herbicide use should have a beneficial effect on the public perception of farming, thus adding to the probability of maintaining a positive social license in the general community, which is a good thing for all stakeholders. Agricultural grains production contributes $13 billion in farm gate value, 20% of the total agricultural value. In a highly variable environment, there's a lot to be proud about in Australian grains sector.

Keywords:

Herbicide, Resistance, Production, Profitability, Efficacy

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Foreword

I have a family farming background, with a primary focus on broadacre crop production to which I was exposed to at a young age. This led to an interest in all things concerning agriculture and food production. Upon finishing my primary school education, I was due to head away to boarding school, however our family decided to take a break from the day -to-day farming operations and relocated to Brisbane, exposing me to a different urban way of life. I was removed from agriculture for seven years except during holidays. This gave given me the opportunity to look at things from both sides.

It also stopped me from being molded into the carbon copy of the older generation on the farm and instilled a different way of looking at things from an alternate perspective, away from the thought patterns that were being used on the family farm. Personally, I believe that for any business and industry we need people and producers to be out questioning the why and what-if's to drive innovation and change breaking the current mold, in order to shape our future.

"The best way to predict the future is to create it" (Williamson, 1986). As an industry we need to be the ones shaping our future. because we as producers are the main stakeholders in this sector. Best practice now may not be the best practice in 5-10 years' time, driven by the rapid progression of agriculture technologies (Agtech).

Once we returned to the day -to-day farming operations in 2009 we were focused initially on broad-acre grain and sheep production in the Wimmera Mallee region in Victoria. This region is a medium rainfall environment and historically a mixed farming region. Having returned to farming and being in a different area our production system was modelled by those around us through the advice they provided. Over time our business evolved via analysis and influence from leading producers in the region: we pivoted from our initial cereal grain fallow and sheep enterprise into a continuous cropping business. To facilitate this change in systems the sheep and cultivation were removed from the operation, which in turn forced a major reliance on herbicide to control our weeds, even though the shift in business model was more profitable and sustainable in the sense of soil structure and moisture retention.

With stubble retention and better weed management we increased our water use efficiency (WUE). However, the system wasn't all positives and over time herbicide resistance began appearing in small areas, which slowly grew over time and as we expanded the farm and imported resistant weeds from these paddocks we added.

This development forced me to ask, "what else can we do?". We reintroduced hay into our system again after an earlier trial had a negative experience. We also installed seed mills on the headers. This enabled us to move away from windrow-burning our legume stubble, resulting in greater plant matter retention as well as eliminating another operation post-harvest. Seed mills enabled us to expand our harvest weed seed control (HWSC) to our cereal program allowing us to implement HWSC every year as opposed to every three to four years. We recently added a sprayer with cameras sensitive to both green-on-brown and green-on-green modes, which resulted in a reduction in herbicide use and an increase in flexibility. It allowed us to use higher rates or more expensive mixes to control problem weeds whilst reducing our total herbicide use and costs, especially in our summer fallow period. Hay and seed mills were utilized, out of recognition that failure to do anything at all could be the undoing of a profitable business and justified the short-term pain and adjustment of new practices.

This led me to my study topic and purpose of this report: Alternative weed control measures. We as producers need to prioritize weed control as it is a major contributor to profitability. We cannot let the weeds dictate our rotation or take control of our farming system as overall profitability will be significantly reduced, due either to poor weed control, reduced flexibility or increased costs

When assessing a new technology, I try to reduce it to basic issues by comparing the new system with the system we are currently using, under the following headings:

1. What is the problem costing?

2. What is the probable level of control?

3. What is the likely return on investment?

For instance, consider fleabane control in summer fallow on the eastern seaboard cropping zone. The widespread use of the “double knock” process (two adjacent sprays of knockdown chemical) usually gives a control rate of anywhere from 50% – 90% depending on a few factors. This is costed out at two spray applications at $13 ha plus a spray brew in the vicinity of $12-$16 per ha, followed by another brew of $7 leads to an application cost of $45-$49 per ha which, in most cases, results in an unsatisfactory and costly level of fleabane control.

Outline of Scholarship

Table 1. Individual Travel itinerary

Travel date	Location	Visits/contacts	Host	Purpose
July 27-Aug 2nd, 2023	Texas Kansas	Texas A&M Greenfield Robots	Muthukumar Bagavathiannan Clint Brauer	Cover Cropping Greenfield Bots
August3 – 8, 2023	Virginia	Anthony Beery Paul Davis Robert Wharton		Cover Cropping
August 8-15, 2023	Maryland Virginia Ohio	Grow (USDA) Maryland University Michael Flessner Global Neighbour	Steven Mirsky Kurt Vollmer Jon Jackson	Camera Technology Flaming Cover Cropping Blue Light Technology
August 16-23, 2023	California Iowa Minesota	Blue River Technology Fehr Farming Pat Kruger	William Padzholt Thomas Fehr	Camera Technology Laser Weeding. Hand weeding Weed Zapping

Acknowledgments

I would like to thank Nuffield Australia and the selection boards for not only providing me with the opportunity to enable me to embark on this journey but also for the personal and professional development that has occurred through their confidence and belief in me. GRDC also deserves thanks for sponsoring my scholarship and in turn also enabling me to have this unique opportunity.

I also must thank my very understanding and supportive wife Sheree for the push I needed to apply and complete the scholarship, especially considering this wasn't the standard timeline for a scholarship with the global challenges caused by the pandemic, not to mention handling all the personal challenges at home with a young family. Ash Fraser also deserves credit for the motivational pep talk which pushed me to submit my application when I was unsure of time requirements and suitability. And finally, I would like to acknowledge those within Nuffield who have been so generous with their time and ideas, both here and abroad.

My scholarship would not have been possible if not for the efforts and support of my family within the farming business. They have held the fort whilst I have been coming and going over the last couple of years. Due to their unselfish efforts I have been able to step sideways in the business and know that there is capacity to cover the other bases effectively.

A big thank you to those people that opened their doors and their contacts to enable me to further study my topic, including Michael Walsh of UWA for not only opening his door and showing me his research, but also putting me in touch with the leading weed scientists and researchers in the USA at Texas A&M, Michael Flessner from Virginia Tech and Kurt Vollmer from Maryland University.

Also a big thank you to those from industry, including Jon Jackson from Global Neighbour, Pat Kruger and William Padzholt of Blue River technology. In addition, I greatly appreciate the many farm visits where I had the pleasure to learn, question and expand my knowledge with the help of these world-class operators, who made my scholarship such a valuable experience.

Abbreviations

Agtech	Agriculture technology
GRDC	Grains Research and Development Corporation
HA	Hectare
IWM	Integrated weed management
OU	Ohio university
R&M	Repairs and Maintenance
ROI	Return on investment
USA	United States of America
USD	United states dollar
USDA	United States Department of Agriculture
US	University of Sydney
UWA	University of Western Australia
WUE	Water use efficiency

Objectives

1. Identify Potential Technologies that can be used in a system to combat problem weeds
2. Explore alternative control measures for weed control
3. Identify the potential of best fit for these practices in an integrated weed management system

Introduction

Australian grain producers are facing a more challenging future with the developing issue of resistance in certain problem weeds. Australia is 2nd (Heap, 2024) in the world behind only the United States with known herbicide resistant weeds. As an industry we are utilising minimum-till and no-till systems to maximise productivity and water use efficiency. The focus for Australian producers to maximise production from its limited resources has seen a fundamental shift in farming practices, resulting in a more sustainable system in general, whilst still focussing heavily on profitability.

One of these shifts in farm practices was the reduction of tillage in our systems, as a result we are relying on weedicides as our main control method for weeds. The shift in production technique has given problem weeds such as fleabane or ryegrass the perfect environment to impact production systems, through their ability to develop resistance to herbicides and thrive in a minimum tillage system. With tillage significantly reduced or eliminated from our systems, herbicide has become our primary weed control method: this, in conjunction with poor control of certain weeds, is resulting in herbicide resistance in those weed species, forcing producers to use more and more expensive mixes to try and control them. In extreme cases we are increasingly relying on the development of a new mode of action to simply hold weed numbers and keep resistance at bay and at best slightly improve the situation. This highlights the purpose behind this report, which is to find alternatives to the current self-defeating strategy of using herbicides to control a herbicide-derived problem.

Given there are three timings for weed control in our production systems, there are certain technologies that are applicable at different times. The use of these with the current best practise should be able to lessen our reliance on herbicide. We tend to be using herbicide to control a herbicide problem, which is like drinking more beer to fix a hangover. Although, in short term, it may seem like an effective method, really we are just kicking the can further down the road. Accepting this situation can seem that we are marking time, hoping that there is a silver bullet just around the corner to fix all our problems. Such inaction has the potential to impact profitability, to the extent that producers will exit the industry, resulting in the problem being inherited by someone else.

We as producers must take responsibility for what is happening on our farm and assess what is the best fit for integrated weed management (IWM) in our systems. Typically, Australian farmers are managing larger farms than some of our competitors and in a drier and more varied climate. This scale, when combined with limited human resources, in most cases has prioritised labour efficiencies and water conservation, given most of us are moisture farmers. As a result, wider row spacing was adopted to aid tyned machines to get through as much residue as possible via interrow sowing, but that comes at the cost of the reduced ability to use crop competition to help control weeds, even when using suitable crop types and varieties. The extra workforce and logistics required to capture seed set by making hay from the crop can result in a reluctance among many due to the extra work it creates about harvest-time. This puts more pressure on weedicides as the main control method creating an environment that breeds resistance.

This report will ask the question, what are the options? What extra can we as producers adopt into our production program that suits our systems? And what should we be keeping an eye on for the future, especially as new technology is developed and brought to market. Artificial Intelligence and automation are opening the door to methods of control that were not seen as viable options previously.

“By destroying only 50% of weed seed prior to being deposited in the soil seed bank, resistance development may be delayed by nearly 10 years” (Somerville et al., 2018). This report isn’t aimed at suggesting we go organic, but more to highlight what novel alternatives are out there that we as an industry should be looking at, either now or in the future, and how they would fit in an IWM system.

The three key areas addressed will be fallow or pre-seeding, in-crop options and harvest weed-seed control, focussing on technologies that may or may not be as well known, and the new and emerging options we may have in the future.

Fallow/ Pre-seeding Methods

Cover Cropping

Cover cropping has been reported to date back up to 3,000 years ago, with the Chinese using forms of green manures to reduce weed growth. Cover cropping has the capability to supress weeds if enough biomass is produced to hinder germination. To achieve the best results the biomass of the cover crop should be around 11tonnes to the hectare (t/ha). This then creates the effect of the mulch-like layer inhibiting the ability of weeds to survive and push through the thatch. There is also a reduction in weed numbers that starts at about 6.7t/ha, but producing anything less than this results in an increasing loss in the ability of the thatch to affect weed germination. Below is a photo demonstrating this:

Figure 1 Cover Crop trial Virginia Tech (source: author)

The left side of picture is no cover crop, each tray demonstrates a 2t/ha increase in biomass with the far right being 11.2t/ha of cover with cereal rye. The closest is pots growing Palmer Amaranth and the rear plots are sown to Pigweed.

6.7t ha is being proven to be the most achievable in both growth and management, specifically allowing planting of the following crop. Cover cropping is being increasingly seen in the US, combined with no-till and conservation farming practices. This is due to the government subsidising the cost of the seed to incentivise growers to implement these practices under conservation framework. Those who are using this method in their system are now aiming to plant into the growing cover then terminate the crop either before emergence of the new crop or at early growth stages, if the new crop has herbicide tolerance traits that allow this to happen.

Cover-cropping is largely seen in the higher-rainfall production areas and is used to grow through the wintertime in the USA, as opposed to Australia's summer period for the winter crops. That being said the row crop farmers in Australia could utilise this method if water was in abundance and would like to grow a suitable cover crop prior to either a cotton, corn or sorghum crop.

Water use is still a concern in some production areas with those in one metre rainfall zones cautious to use cover crops prior to a corn crop, so that it there isn't a negative impact to yield.

One role of cover cropping in the Australian winter cropping program could be aimed at suppression of fleabane and/or ryegrass. The reason to do so would be the willingness to put a crop in for a possible loss of yield, with no other gain than weed reduction. An additional risk is of potentially not growing enough biomass to see the weed control benefit and using precious moisture to do so.

If this system could be adopted there could be some follow-on benefits of nitrogen fixation from leguminous cover crops, as demonstrated on some of the farms I visited in USA. Cover cropping seed mixes using woolly pod vetch were able to fix 22kg of N per ha on Paul Davis's farm in Virginia. Cover-cropping could be useful in high rainfall summer-cropping areas in Australia with the ability to sow legumes to convert excess moisture and into useful amounts of N, providing the season is favourable.

Flaming

Flaming has been used in row crop situations since the early 1960's. It is the use of using LPG to fuel a flame to damage the leaves of the plants and eventually kill them. The ideal size of the plants is 25–100mm tall, to obtain the best results while ensuring there is no need to repeat the treatment. The row crop unit can also be used in fallow situations where it can control weeds prior to planting. A trial was conducted to see if flaming would be effective in controlling interrow weeds in the vegetable industry at the University of Maryland. Their findings have seen mixed results with the efficacy being 60 – 70% control. The major constraints that were observed were the weeds in the interrow. If there were a large number of weeds present several applications were needed for adequate levels of control of weeds, unless paired with interrow cultivation. Kill rates were purely dependant on the flame hitting and affecting the growing point of the weeds. If the flame did not hit the growing point the process inhibits and wounds the plant, but unless there is an additional method of control used the plant will recover over time. Post-application the treated plants exhibit leaf burn but are not killed, even if the plant leaves are turned purple.

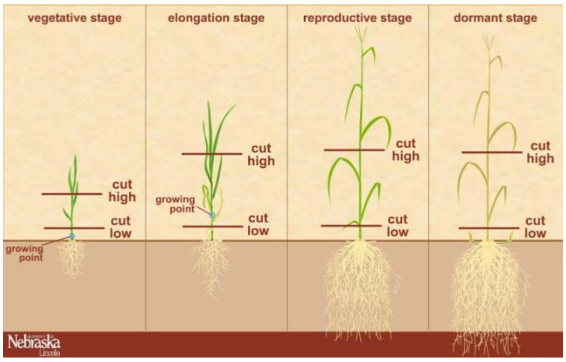

Figure 2 Growing Point Diagram (source: (Flick, Schact, & Sandall, 2005)

During a visit to Fehr farms in West Bend, Iowa, flaming was a control method discussed. Being organic producers, they did own one but described its use as a salvage operation more than a preferred method of control. If it was being pulled out of the shed, they were just as likely to consider terminating the corn crop and starting again with cultivation to regain control; either option was still costly.

The burning time on Palmer amaranth is shown in the attached photo:

Figure 3 University of Maryland flaming trial (source: author)

Starting from the left side of the photo is a trial demonstrating two seconds flaming on the left, with the middle being four seconds and six seconds on the right. The highest kill rate is that of the six second burn but there are still survivors as well as the new additions currently emerging. It was thought that the flaming process could also kill surface or near-surface weed seeds, but that is yet to be demonstrated in trial data.

Weed Chipping

An Australian invention that was funded by GRDC and led by Andrew Guzzomi and Michael Walsh, both of (UWA), saw the development of the weed chipper for fallow weed control and aimed at developing the concept of targeted tillage. This concept aims to control weeds without the use of chemicals and without having to use full scale cultivation. It is achieved by using a Weed-it camera system with cameras spaced at a distance of 4-6m with a tyne spacing of 30cm and with a 45cm sweep on a hydraulic-tyned cultivator. Each camera controls five tynes with a coverage area of 1.5m. The Weed-it system detects the green colour of the chlorophyll in the living plant, which then triggers a rapid response tyne to drop the point 10cm into the soil for less than a second and then retracting it to the holding position. With this engagement technique soil disturbance is only 1.8% when used in a weed density of one plant/10m^2.

During testing it was found that the original shaped points used for cultivation were not suited to the short engagement times of the chipper resulting in reduced kill rates in the wings of the point. The point was then changed to a flatter-faced design which is currently being widely used. Figure 5 (below) shows the difference between the two points.

Figure 4: New point design (source: author) **Figure 5 Point Comparison New Vs Old (source: author)**

Testing of targeted tillage was done at a speed of 10kph and a weed density of one weed to 10 square meters. The benefit of using the camera technology was the fact that it can be used in all conditions, increasing its potential utilisation time compared to spraying technology. Ryegrass proved to be the hardest weed to control, but research found at flowering the chipper was able to achieve 100% control.

This control method could be applicable to grain production areas on the east coast of Australia where control of low-density populations is crucial in the control of herbicide resistant populations of summer weeds, including fleabane, to prolong the efficacy of glyphosate and paraquat.

The largest barrier to adoption currently is that the machine is currently not commercially available. The manufacturer of the individual components was not willing to take the machine to market but was more inclined to supply componentry for the farmer to assemble, making it difficult to get multiple units out in the field.

Hand Weeding

This was one of the most crucial methods used by many of the farmers I visited on my travels, especially those that are in the organic production system. Fehr Farm in Iowa used hand weeding as their main control method for in-crop weed control once plant growth exceeded the ability to interrow cultivate. It was also seen as the most effective given the thorough process of walking every row to remove weeds.

This was not achieved by using American workers but those from Guatemala that lived on farm and sole job was to weed and provide an income to their families back home. But it was also the most expensive method used in organic production, given the housing and accommodating costs for the workers, and the low productivity of the workers.

Figure 6 Hand weeding in Iowa (source: author)

I was also able to discuss this process with Caleb Ames in Iowa where he utilised this and other organic weed control measures. In his area he was able to get contract crop walkers to do the hand weeding process but at a cost of $247 per ha, making it a very costly exercise. Also, as expected efficacy depended on the attention to detail that the walkers possessed.

Hand weeding at the first signs of resistant weeds has a huge payback if total control is achieved. In Virginia I met with Paul Davis, a former weed scientist now full-time farmer who farmed alongside his wife. He described that hand weeding had the best return on investment (ROI) for weed control, so much so that if he was harvesting and came across a patch of Palmer Amaranth he would stop the harvester and get out to pull them all by hand. As a result, he did not have a problem with the weed that is seen as a major problem in the cropping farming systems in most of the US.

The size if Australian farms lends us to discount this method, especially given the scarcity of the labour force that is usually available to our businesses. However, a rethink is necessary when there are examples like Paul's, where he has avoided the costly exercise of chasing widespread resistance simply by using his time and effort to address a problem in the early stages and stopping it in its tracks. Wide-spread uses of this method are not plausible in our farming systems, but the possibility of utilising farm management apps to highlight areas of early resistance, followed by a conscious effort to weed these patches before harvest could have significant gains.

Direct energy

Use of blue light isn't new but repurposing it to alter seeds and plants is. Global Neighbour in Xenia Ohio are utilising blue light to either kill or stimulate seeds. The same technology can be modified to achieve either outcome; only the treatment application and duration changes.

For a seed to be receptive to this technology it needs to be respiring and the outer seed coat needs to be heated to 75 degrees Celsius, so that the seed is receptive to the blue light. Once the seed is at this temperature it is then exposed to both mid infrared light and blue light. The exposure to the blue light is 20 times the amount that it would be exposed to in a normal growing situation. To stimulate a seed it is only exposed to a short duration of light which early tests have shown can increase the germination rate. Killing the seed requires a longer duration of the same light, as shown below in photos of the harvester prototype.

Figure 7 (Left) Header Mounted HWSC unit (source: author).

(Right) Blue Light affected Pigweed seeds (source: Doohan, D & Herms, C 2021)

A. Untreated Seed, B. Deformed Radicle, C. Split seed coat, D. Non respirating seed

The above photo on the left shows the harvest weed seed control (HWSC) unit that is mounted just after the sieves underneath the harvester and collects the seeds prior to them being combined into the straw portion and being put through the residue management on the header.

Effective weed seed capture is dependent on the correct machine setup to minimise the weed seeds exiting with the straw. Once the weed seeds enter the unit there is a hydraulically driven that conveys the product down the tube and whilst doing so the weeds seeds are heated and introduced to the light source. The clear holes in above photo are where the blue light will be introduced.

The prototype unit is currently made to suit a John Deere combine, as they can run a second alternator that can generate the electricity required to power the electronic components. The conveying and removal of the product is done by hydraulics which are powered by the machine's hydraulics. Once the weed seeds have been exposed to the blue light they are then blown up into the spinners for dispersal. By powering the machine this way the estimated horsepower draw is 10HP to run the unit making significantly less power requirement than that of the mechanical mills.

The above model is for the use of the smaller harvesters like the class 6. Given that the unit has such low power requirement, there is the ability to duplicate the treatment tubes to cater the larger capacity harvester's throughput without lowering efficacy. This unit is aimed to be on a harvester for field trials for the 2024 harvest with an increase to multiple units for 2025. Indicative pricing puts these units at a very competitive price compared to the mills currently on offer. Wearing parts are also minimal and the lifespan of the lights is approximately 10,000 hours, giving it a long service life.

The whole-plant application of blue light is much the same as for the seed, in that the exposure length determines the outcome. For a plant to be killed it requires the light exposure duration to be long enough to penetrate down to 5cm in the soil. A small weed needs 2-5 seconds of exposure, whereas a larger weed 30-45cm tall will need 20 seconds. If the blue light doesn't penetrate the root far enough it will result in the plant being stunted but not killed. Once a plant is killed by the blue light the root system is completely decomposed in four weeks.

Field trials of this technology are currently in place, with an eight-row machine with tractor driven generator traveling at a field speed of 3 to 5kph, exposing weeds to the correct duration to kill them. Given the width and speed, in-field productivity wasn't high and the fuel usage just to run the equipment was 28 litres/per ha and when associated with tractor and operation costs it will be a relatively expensive exercise. Eary studies have shown the penetration of blue light into the soil can also kill the weed seeds if duration is long enough, and soil conditions are favourable. Currently there are field trials being conducted which appear to show significant reduction in germination of weeds compared to the nil treatment area. Verified kill rates are currently unavailable but show promise.

In-crop Control

Laser weeding

The carbon robotics laser weeder is a relatively new method being used in organic production systems in the USA, with the first machine operating in field commercially from early 2022. The machine has a 6m working width and I was able to talk to the Fehr farming family about its use in their cereal grain operation. The machine is powered by a front-mounted generator with the unit trailing behind the tractor. It uses 42 cameras with an AI system that communicates with 30 150W CO_2 lasers with the ability to fire every 50 milliseconds, and a kill rate of 99%. When the laser hits a targeted plant the cell structures in the walls explode resulting in instantaneous elimination.

Over the Fehr families first year of use the speed of operation was 1.96kph but as the AI learned and adapted the groundspeed was able to be increased to 4.5kph resulting in productivity going from 1.15ha an hour to 2.7ha an hour. The machine lends itself to being scaled up in size by running 3 machines off one tractor, therefore having the ability to cover 8.1ha an hour. Whilst this isn't a great productivity when compared to that of herbicide application technology, the possibility for automation would enable a much larger operating window improving the productivity. The reason this is possible is that the machine generates its own light for plant analysis and targeting to ensure that the highest level of accuracy from the AI system. Once the machine is set up in the paddock the operator is essentially there only to turn machine around and monitor the performance, making it a very good candidate for autonomic control.

The machine costing comes in at approximately $1.2 million USD to purchase the 6m unit. The best operating conditions occur when the crop is less than 30cm, which limits the efficiency of the machine for broadacre crops. The maximum coverage ability of the laser weeder would be in the vicinity of 1,400ha calculated on the 2.7ha an hour productivity with an 18-hour window with 30% down time. If the machine had a lifespan of ten years assuming there is minimal R&M required, then generator maintenance costings would be around the $180/ha mark, assuming minimal value for machine at end of life.

Weed Zapping

Electrical weeding is a commonly used practice in organic row crop production in the US. Most commonly it uses a tractor with a PTO driven generator to power the machine. It consists of a bar that is mounted on the front of a tractor, with a live piece of pipe that works on picking the height difference between problem weeds and the crop.

In doing this the application is limited to later in the season as more of a preventive to weed seed set and control than a method to limit crop competition. The most commonly used scenario involves three applications in soybeans and sugar beet with the last being just prior to harvest. However there have been machines fitted with droppers that reach into the interrow that are able to touch those weeds that are otherwise too short to be controlled. The requirements to operate such a machine are a minimum of 325hp to power the 200kw generator, front mounted linkage and an operator who is capable of ensuring the electricity bar is in the correct position. Environmental factors also have a heavy influence on the efficacy of the machine with four discs mounted on the zapping frame that are used to earth the machine to the soil. This requires moist soil for the most effective earthing.

Figure 9 & 10 Weed Zapper (source: author)

The cost to purchase this system in 2023 was $88,500 (USD) for a 12m unit. An 18m self-propelled unit on a sprayer platform is $280,000 (USD) (Kruger, P 2023). How the machine is used and settings that are utilized has a big bearing on the lifespan and the R&M costs, with the typical generator lasting 150 – 1000hrs. If the grass setting is used, which ups the amperage from 380 to 420 amps, it drastically reduces the lifespan, putting it closer to 150 hours instead of the potential 1,000 hours.

If the generator lasts 500hrs it costs approximately $30hr for maintenance. with a productivity of typically 8.1ha an hour with the 12m machine, using on average 4.7 litres per ha in fuel. For the operators who are contracting out with the machine the typical rate is $66.70 per ha. With up to three passes being required to gain control of problem weeds, this would cost over $200 per ha. The Australian agricultural sector would be very hesitant to absorb these costs in addition to the current growing costs.

In saying that there is a possible case for method of weed control in high value crops that favor the growing conditions required for its effective use such as horticulture, although there are some possible uses in grains. Wild oats in cereals or milk thistles and other large broadleaves in legumes, where the method is used in early to late Spring, providing a tool bar could be manufactured to fit within existing tramline tracks. This may prove difficult with the width of sprayers most commonly used, making the electricity requirements significant and the generation and transmission of electricity quite difficult on a large machine. Its best-case scenario would be to use a swarm farm robotic system using multiple 12m sprayers.

Zapping could also lend itself to summer weed control in a situation of a resistance clean up where the initial spray has occurred and the larger and more herbicide tolerant weeds are not controlled initially. This system could then use a modified robotic platform incorporating a boom spray height sensor to ensure good contact to weeds and soil for the earthing discs. The environmental conditions in summer are also more suitable for a larger operating window as dew lowers efficacy and also increases the wear and is harder on components due to the low conductivity of the plants, which increases the power requirement. In moist conditions the machine tends to earth through the tyres: Pat Kruger informed me that he had been through 6 tyres in 1,000hrs of operation, due to the electricity heating the wire inside the rubber.

USDA

Whilst attending the Getting Rid of Weeds (GROW) meeting in Beltsville MD the USDA and university researchers openly described projects they had been working on to fight herbicide-resistant weeds, including the Image Repository that they were working on for corn, beans and cotton. The aim of the project is to develop a comprehensive database of weeds, involving a 3D cross sectional image of all weeds in all possible growing conditions, with the intention of being able to provide these images to researchers and developers to aid in bringing new “see and act” technologies to the market. The developers are currently required to obtain all of their own images, which is a slow and costly process.

With the use of a mobile machine-mounted camera and pots seeded with weeds, they are able to take multiple pictures faster than deploying a field unit to do the same job. The project also aims to have a camera capable of being mounted onto the boom of a sprayer to take images of the weed populations and also analyze the control efficacy of methods used, automatically inputting the data into a database that can be analyzed over time. With the help of researchers, they were also testing an organic “see and spray” technology that is aimed at the vegetable industry. Using an ink jet out of a commercial cardboard printer they were able to use minute levels of organic herbicide with high accuracy. This technology was still in the development phase but showed a lot of promise with the potential for significant return on investment, given the high cost of organic herbicides.

Emerging Challenges

Throughout my travels I saw some very innovative thinking and technologies that are in the early stages of application. The researchers and developers are consistently working together to find solutions to certain weed problems in the common systems. The most commonly researched areas are those with the highest potential return for both the developer and the user, which is most commonly that of row crop farming and organic food production.

With these industries pushing the development of new methods due to growing herbicide resistance and lack of non-chemical options for weed control. In some systems there is significant amount of money being invested into this rapidly changing area of Agtech. The benefit to the broadacre and small grains industries is the potential to capture and adapt these new technologies, allowing them to be implemented into broadacre systems to control some of our problem weeds. The USDA is investing $32.8 million in their 2022 budget (USDA, 2022) into their agriculture sector to face weed issues, compared to only $6.4 million of direct Australian government funding (Department of Industry, Science & Resources, 2022) with the GRDC contributing $11.1 million (GRDC, 2022).

The stark contrast to the facilities and the researchers working in weed science in the departments that I witnessed overseas points to one obvious problem with Australian agriculture. It’s not that we have fewer capable people to complete this research: it is actually the funding model is not suitable to maintain a world-leading ability to develop production systems designed for Australian agriculture. Reliance on grants or private investment leads to a small funding pool, so that Australian agriculture lacks the ability to attract and retain the current and next generation of weed scientists. For an industry that is aiming to have $100 billion worth of total export value (National Farmers Federation, 2019) we need a fundamental shift in funding to move towards the goals set by the consumer and industry, allowing our broadacre farming systems to become environmentally and economically sustainable.

Reliance on the chemical companies to produce alternatives methods of weed control is akin to relying on the petroleum industry to research and build electric cars. Although this report is not focussed on this problem, it is something I feel needs to be highlighted and taken to both government and industry to ensure we are in touch with the latest methods of weed control, considering that we are ranked second in the world for the number of herbicide-resistant weed species. As producers we are using the methods that we have at our disposal, which are cost-effective and also easy to implement. Farmers have a level of scepticism about new and improved methods, because they are unwilling to invest in untried technologies.

Conclusions

One thing that has been demonstrated time and time again during my studies, is that there is no silver bullet coming to solve our problem regarding herbicide resistance. To do our part as producers we need to set our acceptable rate of control at the highest standard. To do so these technologies must complement our systems to achieve that acceptable rate of 95% plus control. This is the target, not only for our own farms but getting neighbours and other stakeholders to have the same goal. Only then will we be making significant progress towards mitigating problem weeds and making acceptable progress towards eradication.

My investigations showed that the common control methods available fit into either two categories, high energy or soil disturbance. The least invasive methods require high energy to control weeds through non-chemical methods and this brings with it its own challenges such as power generation and scalability to meet minimum efficiency targets. The key to the adoption of these technologies isn't that they are completely new but in repurposing them for agriculture's benefit. The "see and act" technologies are aiding the ability to target the weeds that are needing to be controlled, resulting in the energy requirements or disturbance being minimised. The rapid advancement of AI will only improve this process.

Automation and robotics are going to aid the adoption of some of these methods. With the removal of a labour unit, the less efficient and time-consuming methods will become more attractive to those willing to try them. With the significant investment in, and the current rate progress of Agtech there is going to be no shortage of new ideas.

It seems that there are now options that are economically feasible when put in the correct system. Producers will soon be able to start shifting to a multi-faceted approach to control of weeds, rather than the current systems of heavy herbicide reliance employed by most producers. This change is simply not going to rely solely on the weed scientists or private industry but by the whole industry with all stakeholders involved. As producers the best thing we can do is be a part of the discussion and direct the change to where we see the greatest possible benefit for all involved, having a firm grasp on what is actually attainable, and functional.

For east coast growers the best fit for the summer fallow period is with the use of the weed chipper. Ideally this method would be used following a broadacre spray after an initial flush of weeds has occurred or following a "see and spray" system. In doing so adopting a zero-tolerance approach to survivors and reducing the glyphosate and the emerging paraquat resistance problems that are now becoming more common. The ideal situation for this system would be in conjunction with an autonomous tractor with a working width the same as the tramlines the farms currently use. This would have the two-fold benefit or reducing labour and allowing 24-hour operation to make up for the initial efficiency difference between spraying and chipping.

Blue light technology is something to monitor in the future., especially given the lower power consumption for HWSC, opening up a market for all harvester users, not just the high horsepower owners. This system may be able to eliminate the need for windrow burning or chaff management, resulting in the retention of more plant matter and minimising the carbon footprint. If we could have widespread adoption of HWSC there will be significant benefits to the industry as a whole. The plant application of blue light also lends itself to be used selectively in problem areas, whether it is in a stand-alone system or an adaptation to a boom spray type vehicle to have maximum efficiency in mop up situations.

Laser weeding is also something to watch as it adapts to different crop types and weeds. Given it utilises an AI platform, the potential growth in efficiency is very promising. Providing costing comes back to an industry accepted level and the 18m system has proven there is great growth potential. Given the most common controlled traffic systems are that of 12m and there is a very good potential use in controlling hard-to-kill weeds in the early emergence stage.

Both the weed zapper and flaming the obvious problem comes to mind with adoption into our production systems both come with some danger to the operator or the environment. The flaming unit relies on the fact that the operator is sitting in front of a gas which that has flames burning behind it. This has led to some hesitation from some staff to operate the machine and the fact that introducing a flame into anything other than winter in our dry climate is potential recipe for disaster. Similarly, there is a potential danger of off-target contact between the zapper and a live powerline in front of the tractor.

This report is just a snapshot of the technologies that are currently either in use or in development. There are many methods I was unable to cover fully, but this report is meant to give more of a snapshot on the best potential innovations for Australian producers. One thing that is apparent when you meet with industry and researchers is that there is no shortage of potential methods in the manufacturing or testing phase. Whether they are commercially viable is yet to be seen but one way to limit the barrier to adoption on some of these more expensive operations is to adopt the fee-for-use model. This may accelerate adoption of the technology and also fast- track the data collection process, increasing both efficacy and efficiency, especially when we are talking the potential cost of $3.6 million USD unit with a 6 week usage window in crop.

There are a few technologies already commercially available and soon there may be a system which will perfectly fit in our production systems. It seems probable that the least expensive will be the first adopted, backed up by hand-weeding the escapees and the problem areas prior to harvest. You can’t expect any of these methods to work without back-up. Producers need to adopt a plan to deal with any potential resistance issues, whether that applies to using a weed chipper for targeted tillage following a camera sprayed double-knock in a fallow operation. An IWM plan is essential to be able to maximise the potential benefits of any one of these technologies. Complacency will only lead to a longer road back if producers are already facing problems with weed control. As an industry we must change our methods, in order to achieve our goals of sustainability, as good environmental management and profitability are closely linked.

Recommendations

- Identify your key problems
- Develop a IWM plan and select technologies that work within your system
- Don’t dive straight into trying all technologies; find the one that has the fewest compromises and most upside to trial first.
- New technologies are always emerging; follow those researchers who are testing new technologies to be on the leading edge of adoption
- Alternative weed control can have a significant effect on profitability if a new system is successful.

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