Technical manuals and training on the soil behaviour of pre-emergent herbicides and modes of action (MOA's) of post-emergent herbicides

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Summary With the rapid and widespread increase in herbicide resistance in Australian cropping landscapes, it is increasingly important to include greater diversity in weed management programs. Inclusion of non-herbicide weed management tactics such as harvest weed seed control, crop competition, or other non-herbicide techniques, has become a mandatory requirement for sustainable farming systems. Similarly, herbicides when used must be effective and perform to their optimum level. In environments where post-emergent herbicides have developed resistance at levels rendering them no longer effective, the inclusion of pre-emergent herbicides has become common place. Technical manuals and training workshops have been developed, detailing the science that underpins how herbicides work. Greater knowledge of how herbicides work will enable grain advisors to better optimise their advice to growers on herbicide use. Manuals and training cover the following key topics: the soil behaviour of pre-emergent herbicides – volatility, photodegradation, influence of organic matter, soil binding coefficients and cation exchange capacity of the soil; water solubility, breakdown pathways and DT50 values; how these product features coalesce to inform how different herbicides behave in the soil; and modes of action of post-emergent herbicides – how different modes of action work, herbicide entry through the leaf, translocation and metabolism and; the complexities of herbicide resistance and the implications these factors have in optimising performance of particular modes of action.

Keywords Binding coefficient, water solubility, DT50, breakdown pathway, translocation, leaf entry, herbicide metabolism, herbicide resistance.

INTRODUCTION

This paper reviews an extension program targeted to tertiary trained grains advisors. The program was developed to enhance industry knowledge of herbicides and their key performance criteria. This Grains Research and Development Corporation (GRDC) initiative was developed and run by Independent Consultants Australia Network (ICAN), with training activities conducted across the northern grains region of Australia between 2014 and 2018.

The genesis of this project was a desire to arm decision-makers with a better technical understanding of the key factors influencing herbicide performance.

With herbicide resistance now very common in Australian farming systems, it is increasingly important to ensure effective herbicide application. Several of the weaker resistance mechanisms are dose responsive within the constraints of registered application rates. With the objective of achieving maximum levels of control to drive the weed seedbank down over time, this translates to farming systems with a low tolerance of weed survivors to re-supply the weed seedbank for following seasons. In systems with low tolerance of weed survivors, there is increased pressure to ensure that there is a diversity of weed management tools used and that each and every time herbicides are used, they are targeted to optimise performance and minimise risk.

Understanding how herbicides work within the plant and behave in the environment will assist advisors to correctly target their use in accordance with label directions.

MATERIALS AND METHODS

What was done? To improve industry knowledge and understanding of herbicide modes of action and their key performance criteria, it was determined that technical resources needed to be developed. These resources give users a practical, science-based understanding of the key factors influencing field performance of herbicides. These resources consolidated information from a wide range of global sources into a single resource designed for agronomists and weed specialists in the Australian grains industry.

While herbicide technical information is available from a range of global sources, the location and format of much of this material can make it difficult for agronomists to find and interpret this information for provision of advice to growers. The manuals and associated videos developed in this project curate this body of knowledge into language and formats relevant to the needs of Australian field facing agronomists and weeds advisers.

In addition to the manuals, a series of face to face small group training workshops were conducted. These

workshops targeted grains agronomists and key influencers. The factors dictating herbicide performance were explained and then contextualised to show how differences in chemistry can impact field performance. Case examples relevant to local experiences were used to bring to life the background science.

Who did we target? In broadacre grains production, the majority of growers utilise the advice of an agronomist for their crop protection advice. By engaging an agronomist, growers benefit from specialised expertise and experience gained from the provision of similar advice to other growers in the region. It is increasingly common for grain growers to rely heavily on the advice of their agronomist. This is particularly evident in areas related to crop protection and weed management where mistakes can be costly and specialist knowledge reinforced through regular use is often required. This is driving an increasing number of growers to delegate many of the crop protection decisions to their agronomist.

For this reason, the primary target audience for the resources developed and associated training, was grains agronomists and key influencers. While most of the promotion for training workshops was directed to this group, approximately 10% of participants were growers.

Another reason for targeting agronomists and key influencers was that each individual typically influences 10–100 growers. There are significant multiplying factors at play when technical training is delivered to this group.

RESULTS

What did we achieve? There were two primary deliverables in this extension project:

1. development of technical resources; and
2. workshop training of agronomists.

Two technical manuals were produced. The first manual was titled 'The soil behaviour of pre-emergent herbicides' which focuses on their interaction with the soil and the environment. This manual covers herbicide volatility, photo degradation, herbicide binding to stubble, solubility and binding properties influences on mobility of the herbicide and herbicide degradation. These influence the length of residual control and the crop rotation constraints. The manual explains the understanding of how these factors influence herbicide availability and then seeks to collate technical information by individual herbicide to explain how that herbicide is likely to perform under specific soil types and environmental conditions.

This manual was first produced in 2014, with a second edition published in 2018 and is available for download from the GRDC at: www.grdc.com.au/Soil-BehaviourPreEmergentHerbicides. Two associated videos were also produced in collaboration with Anvil Media. These videos can be found at: https://www.youtube.com/watch?v=s63GYYyflzw&t=2s https://www.youtube.com/watch?v=LJNjuMWS57U&t=0s

The second technical manual covers post-emergent herbicides, including their place in the management of grass and broadleaf weeds, their mode of action (how, where, when and why they kill weeds), plant uptake and translocation to the site of activity and the role of metabolism in herbicide breakdown and crop selectivity. This understanding then leads into detailed explanation of herbicide resistance and the mechanisms involved, and the key factors in maximising the performance of different modes of action. (At the time of writing this paper a specific URL for this manual was not yet available. The manual will be available at www.grdc.com.au).

Associated training workshops have been conducted across Queensland and New South Wales grain growing regions. Between 2014 and 2018, 30 half-day pre-emergent herbicide workshops were completed. In addition, 27 half-day post-emergent workshops have now been completed during 2017 and 2018. Exit survey ratings of the workshops demonstrated most participants found the workshops to be of very high value (Table 1).

While the fundamental knowledge of how herbicides work is generic to the herbicide and/or mode of action, herbicide examples used in each workshop are typically those most relevant to the geographic location.

Generally, the intent was to keep an individual workshop series to a particular time of year and grouped to locations running a similar farming system. This allowed workshop materials and herbicide examples selected to be of most immediate value to participants (e.g. a workshop series targeting summer fallow use of residuals in the northern region would focus on different herbicide examples to a series of workshops run in March in southern New South Wales where examples might be focused on ryegrass management).

Participant feedback, via exit surveys and questions raised during the workshops provided insights into the key learnings and take-away messages obtained by participants and their unmet needs.

DISCUSSION

What did we learn? Having completed 57 workshops (with more than 1000 participants) across Queensland and New South Wales, several observations can be made. The workshops attracted all levels

Table 1. Workshop exit survey ratings 2014 to November 2017 (a more detailed exit survey separately evaluating the individual workshop components was used for the post-emergent workshops).

		1 Waste of my time	2 Not very helpful	3 Workshop needs improvement	4 Some good stuff here	5 Excellent	Weighted average
27 pre-emergent workshops	Overall workshop value	–	–	0.4%	33%	66%	4.7
20 post-em workshops	Leaf entry, translocation and metabolism	–	–	0.7%	29%	71%	4.7
	Understanding herbicide resistance	–	–	1%	28%	71%	4.7
	Maximising the performance of each MOA	–	–	0.7%	30%	69%	4.7

of agronomists – from highly experienced through to new graduates.

Through exit surveys, the key areas of benefit most frequently cited were:

- troubleshooting product complaints;
- understanding herbicide resistance in the context of what is seen in the paddock;
- matching herbicide application with herbicide properties; and,
- in the context of pre-emergent herbicides, matching herbicide selection with soil type, stubble, weed seed location and environment.

There was a significant trend for agronomists to prefer morning workshops over afternoon workshops (where both were offered).

Average workshop attendance was approximately 20 participants. Workshop sizes of 15–20 appears to be the ideal 'sweet spot', having enough diversity of shared experience in the room while not being too large. In almost all workshops, it was noticed that as attendance increased above 20, discussion from the audience decreased proportionally. As a rule of thumb, workshops were closed when registrations approached 25 participants (however, up to 30 individuals participated in some workshops).

The half-day workshop format was appreciated by many, allowing agronomists to get back in the paddock after lunch. This format was well suited to the pre-emergent workshop content. However, the depth of content required to be covered in the post-emergent workshop indicates that future workshops would be better suited to a three-quarter day format.

Some agronomists indicated a preference to participate in both workshops back to back, (e.g. post-emergent herbicides in the morning and pre-emergent herbicides in the afternoon), while another significant cohort of participants appeared to prefer a 'short and sharp' stand-alone half-day workshop format.

A small, but significant, percentage of participants have repeated a workshop, with feedback that their understanding was improved the second time around.

While growers were not the primary target of these workshops, the growers who did attend reported that they found the workshops highly beneficial. Many of these growers indicated that 'all' growers should be exposed to this level of detail of herbicide understanding and should participate in the workshop 'in full'. However, it should be noted that these participating growers are highly interested, and therefore invested, in this topic (which can be observed by them actively seeking out participation in these workshops), and are likely to place a higher value on the content of these workshops.

In the first few years of delivery of the pre-emergent workshop series, workshop participants were asked an exit survey question "Does this information need to be delivered to growers? If so, in what format?" The grouped responses can be seen below (Table 2).

These data suggest that there is an opportunity to further enhance grower knowledge (at least for pre-emergent herbicides where this data was collected).

Areas for further research, development and extension Through questions asked during the workshops and exit surveys, we have been able to compile a list of knowledge gaps that would benefit from either further research or extension. These are as follows:

Table 2. Should the information contained in these technical workshops be delivered to growers? If so, in what format?

Delivery to growers	No. of mentions
YES = 157 (55%)	
Absolutely. Growers need to know this	23
Yes. Same workshop format (at least for interested growers)	42
Yes. But interactive format / case studies / not as technical	52
Yes. Via small group grower meetings (focusing on application in particular)	19
Yes. But delivered by their agronomist	7
Yes. Via demo plots and spray application day	11
Yes. Needs to be mandatory for younger / newer agros	3
MAYBE = 61 (21%)	
Probably. But general guidelines only. Product names only	14
Possibly. Via development of an App / Decision support tool where they enter their paddock information and it tells them what is important. Or video.	4
Possibly at some level by fact sheets / press article / manual	27
Maybe. But needs to be very simple. Updates?	16
NO / NOT SURE = 66 (23%)	
Not sure / maybe. Some info is very technical & important bits might be missed	22
No. Leave this to advisers. Too complex / not interested	44

- there were numerous requests to extend the workshops to other grains regions outside of New South Wales and Queensland (and a few requests to extend the training to non-grains industries, specifically horticulture and sugar cane); and
- that while the current post-emergent workshop focuses on herbicide activity from leaf entry through to activity at the target site, adjuvants and application are only covered in minimal detail. While there are other detailed workshops dedicated to herbicide application, there have been numerous requests to develop a similar technical training workshop for adjuvants.

Specific to pre-emergent herbicides

- Continual on-going extension is required regarding the use of winter cereal grass pre-emergent herbicides, specifically in relation to:
  - different seeder types (i.e. use patterns with various disc seeders);
  - use in stubble retained systems;
  - quantifying interactions with stubble burning;
  - for northern New South Wales and Queensland, understanding the impact of no rainfall at planting (crops and weeds germinating on stored soil water only), or large rainfall events at planting to emergence (autumn storms in the north).
- Additional herbicide registration opportunities including:
  - pre-emergent herbicides in fallow systems; and
  - pre-emergent herbicide(s) for use at planting of mungbeans and adzuki beans to control *Chloris* species.
- Improved plant back guidance for many older herbicides, especially when used in fallow situations, including regionally specific information where applicable e.g. summer *vs* winter dominant rainfall regions.
- Potential for the development of robust, cost effective in-paddock test kits to measure residual herbicide levels, including sampling protocols.
- Enhanced microbial degradation is known to occur with many herbicides when used relatively frequently, however practically no data is available under Australian broadacre farming systems. Enhanced degradation will lead to reduced longevity of weed control and possibly shorter rotational constraints. Microbial breakdown is the primary dissipation pathway for pre-emergent modes of action B, C, D, J and K, so leading candidates from these modes of action should be targets for investigation.

Specific to post-emergent herbicides

- Hydrophilic herbicides (particularly glyphosate) are particularly sensitive to conditions affecting spray drying and resulting leaf cuticle penetration. Different plant species have different leaf cuticle properties, which alters the rate of hydrophilic herbicide entry, before the spray has dried. Practically no data exists to show different leaf uptake speed by species, and what little data does exist is old and generated with historical formulations and adjuvants. This issue is particularly relevant for summer spraying and will be exacerbated with the onset of resistance that will require higher levels of

herbicide penetration to achieve control. Studies are required to demonstrate level of leaf penetration x difficult to control species x formulation x climatic conditions x adjuvant.

- The surfactant package (in the formulation, or tank mix) is extremely important in aiding herbicides (in particular lipophilic herbicides) to penetrate the leaf. Better information is required to show which surfactant systems are optimal for individual species, especially when applied under challenging climatic conditions (e.g. summer spraying), or when herbicide resistance compromises performance.
- Frosts often occur at the time of season when it is desired to use Group A herbicides in winter crops. More information is sought on how to maximise performance in these situations i.e. apply during frosts and accept poorer control, or delay application and target larger weeds?
- Herbicide 'safeners' are often included in the formulation of some Group A, B and H herbicides. These safeners increase metabolic activity, increasing safety to the crop. However, these safeners are likely to be having the same effect on the weeds. Questions that arise include:
  - what is the magnitude of increased safety to key weeds?;
  - is the use of safeners leading to increased selection for metabolic resistance in weeds?; and
  - is it possible to develop some form of safener delivery that only treats the crop and not the weed?
- Tank mixing 'dissimilar' herbicides is poorly understood and requires further attention. Most users appear primarily concerned with physical tank mix compatibility, with available resources more focused on tank mixing procedure. In addition to physical compatibility, further information is required:
  - explaining biological compatibility / incompatibility between different herbicides;
  - understanding different application requirements for various herbicides and what compromises are being made e.g. preferred application setup (droplet size, spray volume) is very different for glyphosate and Group A or Group G, so will be a compromise if these herbicides are tank mixed; and
  - understanding the correct choice of adjuvant for tank mixes (and that tank mixing may require a compromise in the choice of adjuvant).
- Better understanding of the implications of tank mixing foliar fertilisers. Most available information focuses on physical spray tank compatibility, with little information available on biological interactions. Some foliar fertiliser formulations are known to impact on herbicides when tank mixed. Effects can be negative (foliar fertiliser cations acting like 'hard' water) or possibly positive (overcoming herbicide induced micro nutrient unavailability).
- Additional herbicide registrations opportunities include:
  - conversion of remaining optical sprayer permit claims to full label claims;
  - registration of isoxaflutole for post-emergent control of *Chloris truncata* R.Br. in fallow (in conjunction with paraquat); and
  - development of Group G 'contact' herbicides as additional second knocks in a double-knock strategy.
- Development of some form of in-field resistance testing to enable results prior to herbicide application.
- Enhanced understanding of the resistance mechanisms in individual populations. Certain resistance mechanisms are known to be dose responsive, so understanding the mechanism, or more importantly the dose responsiveness, is important for development of management strategies.

CONCLUSION

Outstanding feedback in terms of participation attendance at workshops and commentary on the associated technical material that was produced in this extension project indicates that it has met, or possibly exceeded, expectations of the target audience: that is broadacre agronomists across Queensland and New South Wales.

Participants have been exposed to the underlying factors that are important in optimising field performance of their selected herbicide tools, and now have access to technical reference materials that will assist in furthering this understanding, especially as herbicides at our disposal come under increasing challenge with herbicide resistance.

There is further opportunity to enhance knowledge by additional investment to address knowledge gaps identified across the delivery of this training.

While a significant percentage of agronomists across Queensland and New South Wales have now participated in this training, feedback indicates that there is a similar need to extend learning to other grain production areas across Australia. In addition, there continues to be an on-going need to facilitate training to those entering the broadacre grains agronomy (recent graduates or those transferring from other regions or cropping systems).

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