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Grains Research UPDATE

Warren GRDC Grower Grains Research Update

Friday 27th February, 2015

Warren & District United Services Club
8:30am registration for a 9am start, finish 3:00pm

Time	**Topic**
9:00 AM	Welcome
9:10 AM	**Regional crop nutritional trial results in wheat and canola** (*Greg Brooke & Leigh Jenkins, NSW DPI*)
9:40 AM	**A new and more effective way to use and interpret variety trials to select winner varieties.** &, **Selecting varieties for sowing dates.** Is it better to go for a stable yield across sowing dates or switch to a shorter season at later dates? How big is the bet and what are the odds? (*Peter Martin, Howqua Consulting & Greg Brooke, NSW DPI*) (Page 15)
10:20 AM	**Disc and tyne seeders, crop establishment and crop safety with pre-emergent herbicides** (*Sam Kleemann, University of Adelaide*) (Page 22)
11:10 AM	Morning tea
11:40 AM	**Herbicide resistance survey - what's out there?** (*Maurie Street, GOA*) (Page 28)
11:55 AM	**Local weeds research** (*Greg Brooke, NSW DPI & Maurie Street, GOA*) • Row orientation Nth/Sth data from local trials • Crop competition - barley variety & sowing rate • Field trials on Group I resistant wild radish • Field trials on spiny emex
12:35 PM	**The nuts and bolts of setting up for efficient windrow burning, & impacts on weed and fallow storage.** (*Maurie Street, GOA*) (Page 46)
1:05 PM	Lunch
1:50 PM	**Chickpea research** on plant population and row spacing in current varieties to maximise yields. (*Leigh Jenkins, NSW DPI*) (Page 59)
2:25 PM	**Ascochyta**: Is the pathogen changing and what are the implications for management? (*Kevin Moore, NSW DPI*) (Page 66)
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Wheat variety response to sowing time

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Key words

Wheat variety, sowing date, maturity, genotype response, risk management

GRDC codes

DAN00167 – Variety Specific Agronomy Packages, HCP00001- Variety Extension for QLD

Take home messages

- Variety response to sowing time data can be used to better match variety to sowing date.
- Variety selection and response to sowing time needs to be considered in the context of a risk management strategy.
- Trial result case study scenarios highlight the potential yield and economic outcomes, of targeting sowing window opportunities with differing genotypes.
- Growers are encouraged to retain a number of varieties with a range of maturities (yield response curves), to ensure that yield potential is maximised and risk is minimised.

Introduction

Wheat needs to flower when the probability of frost at flowering and heat stress during grain filling are as low as possible. Varieties with large differences in maturity have been released by breeding programs. This maturity difference allows the late maturing varieties to be sown when the break is early and the earlier maturing varieties to be sown when there is a late break. These differences between varieties are implicit in the 'sowing window' reported in the NSW "Winter crop variety sowing guide" (Matthews et al., 2014) and the QLD Wheat variety information booklet (Anon, 2014a)

Maturity of wheat varieties is controlled by vernalisation (Vrn) and photoperiod (Ppd) genes (Eagles et al., 2010). Australian varieties have been characterised for presence of some of the Vrn and Ppd genes (Martin et al., 2011). Varieties have been classified into categories of winter, facultative and spring. Varieties grown in NSW include varieties with winter, facultative and spring habit and those grown in QLD facultative and spring habit.

Variety response to changes in sowing time have been estimated using data from both sowing time and National Variety Trials (Martin and Matthews, 2013). This NSW DPI Primefact publication has been updated regularly since 2006 with the most recent version available from the NSW DPI web site (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0017/280115/Yield-response-of-wheat-varieties-to-sowing-time-2013.pdf).

There seem to be three basic types of genotype response - genotypes that yield better when sown early (negative slope), those that yield better when sown late (positive slope) and those that perform similarly (flat slope) across all sowing times. A range of response types exist in each of the habit groupings, refer to graphs in Primefact for examples. The different response curves indicate that there is the potential to use response to sowing date as an aid in identifying the best genotype for a particular sowing date.

Yield estimates from the Primefact can be used to better estimate the best time to change from varieties suited for early sowing, to varieties suited to later sowing. Yield estimates for some varieties with different responses in the Primefact have been graphed in Figure 1. Many of the yield response curves intersect between about year day 125 and 135, which correspond to May 5 and May 15 respectively. The data suggests for example, that if you are growing EGA Gregory⊕ and Spitfire⊕, then the best time to change from EGA Gregory⊕ to Spitfire⊕ is about year day 132, whilst if you are growing EGA Wedgetail⊕ and Spitfire⊕ the best time to change from EGA Wedgetail⊕ to Spitfire⊕ is about year day 127. Whilst Suntop⊕ was shown to be high yielding across all sowing times.

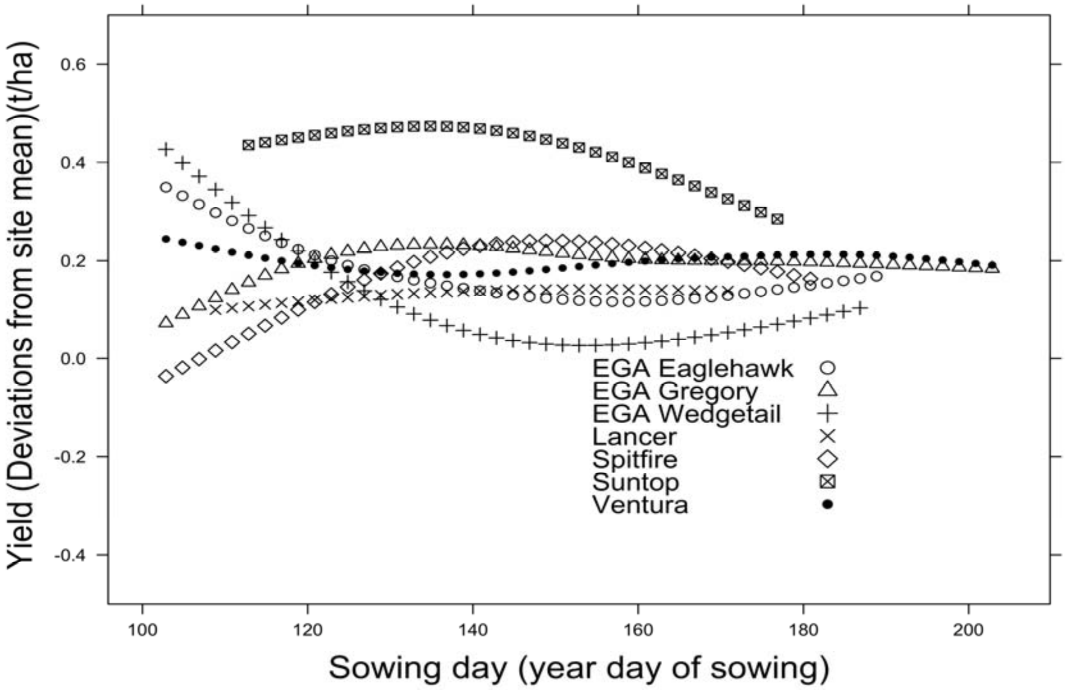

Figure 1. Variety by sowing day response curves of selected varieties

Variety response to sowing time

The combination of variety and sowing date determines the probable timing of environmental stresses (frost and *heat stress*) at key developmental stages, such as anthesis and during the critical post- flowering grain fill period. The relative maturity of a variety can vary widely and change with changes in sowing time and location. The optimum flowering window is considered an agronomic compromise between avoiding excessive yield loss due to frost and ensuring that flowering occurs early enough to allow a long grain fill period before heat and moisture stress reduce yield. Early maturing varieties sown before their recommended 'sowing window' predisposes them to increased risk of frost as well as quickening crop development. On the other hand, earlier than recommended sowing of mid to late maturing varieties, can increase total plant biomass pre-anthesis, potentially reducing the amount of plant available water for grain fill.

Variety response to sowing time trials help to determine how new varieties compare in maturity and yield with existing varieties across the sowing window at a regional level. This provides data to better inform growers about varietal response to sowing window options and therefore to better match variety with sowing time. Overtime, these trials provide greater confidence in varietal performance estimates and flowering behaviour. This is a key trial series for the VSAP project. Recent results suggest for example, that Lancer⊕ can vary in maturity relative to EGA Gregory⊕ (either earlier or later), depending on sowing time and prevailing seasonal conditions. Suntop⊕ has also been observed to vary in relative maturity with changes in location and sowing time.

Trials in the NSW northern grains region

The autumn break and subsequent sowing window in NSW can occur anywhere between March and June, with the reliability of the break being more inconsistent in Northern NSW in comparison to Southern NSW. There are also wheat varieties with a wide range of maturities available to growers in NSW and QLD, which coupled with no till farming systems, has increased the length of sowing date opportunities.

Variety selection (maturity type/genotype response) for a given sow time opportunity and potential implications, in terms of risk management are critical issues for growers. In other words, what genotype response options are available for a sowing date and what are some of the possible outcomes from these options. Although the best estimate of variety response to sowing time is from response curves reported in the Primefact, considerable variation in responses between trials/environments occurs.

To illustrate the variability of variety responses to sowing dates, data has been taken from a selection of VSAP sowing date experiments from the Western Plains, Liverpool Plains and North West Slopes and Plains. Varieties included both commercially available and advanced breeder lines, with a range of maturities and agronomic characteristics. All experiments were replicated with sowing dates spanning the growing season (April – July). Experimental details are reported in the NSW Department of Primary Industries publication 'Northern Grains Region Trial Results Books' (www.dpi.nsw.gov.au/agriculture/broadacre/guide/ngrt-results). To compare possible varietal selection yield implications, examples using VSAP sowing date experiments as 'case studies' are reviewed.

Case Study 1: Long season variety on early sowing

This first example from Trangie in 2014 highlights the potential implications of sowing a long season variety, in this case EGA Eaglehawkᶲ across a number of sowing dates rather than moving to a main or short season line. On the first sowing date of April 15 (year day 105) EGA Eaglehawkᶲ yielded 5.8 t/ha (Table 1). This was on average more than 2t/ha than the earlier maturing varieties Dartᶲ and Spitfireᶲ. EGA Eaglehawkᶲ was more than 1 t/ha higher yield than the main season lines EGA Gregoryᶲ, Lancerᶲ and Suntopᶲ. Yield differences between varieties in the second sowing date (29 April, year day 119) were much lower than in first sowing date. In the third sowing date (14 May, year day 134) however the shorter season lines Spitfireᶲ and Dartᶲ yielded 0.8 and 0.5 t/ha, respectively more than EGA Eaglehawkᶲ. The main season lines EGA Gregoryᶲ, Lancerᶲ and Suntopᶲ also yielded between 0.5 and 0.6 t/ha more than EGA Eaglehawkᶲ. In this case there is a strong argument to adopt varieties according to their appropriate sowing window (Matthews et al., 2014), and variety response sowing curves (Figure 1) based on yield (Anon 2014b). The gross returns based on listed GrainCorp contract prices also reflect the differences in yield (Table 1).

Table 1. Grain yield (t/ha) and gross economic returns ($/ha) of selected wheat varieties sown at three sowing times at Trangie 2014

	Grain Yield (t/ha)			Gross Return ($/ha)		
Variety	15th April	29th April	14th May	15th April	29th April	14th May
EGA Eaglehawkⓟ[1]	5.76^{a}	4.10^{abc}	2.92^{c}	**$1428**	***$1016***	***$724***
EGA Gregoryⓟ[2]	4.40^{b}	4.14^{abc}	3.18^{bc}	$1214	$1143	$878
Dartⓟ[2]	3.78^{c}	3.91^{bc}	3.42^{ab}	$1043	$1079	$944
Lancerⓟ[2]	4.61^{b}	4.42^{a}	3.49^{ab}	***$1272***	**$1220**	$963
Spitfireⓟ[2]	3.33^{c}	3.85^{c}	3.69^{a}	$919	$1063	**$1018**
Suntopⓟ[2]	4.45^{b}	4.28^{abc}	3.42^{ab}	$1228	$1181	$944
Benefit $/ha				**$156**	**$204**	**$294**
lsd (p=0.05) (TOS x Var)	0.48					

Values within columns with the same letters are not significantly different at the 95% confidence level
**(http://www.graincorp.com.au/daily-contract-prices/NorthernNSW-Wheat.pdf?55 January 2015)*
[1]H1 = $248.00/t, [2]APH2 = $276.00/t delivered Trangie

Case Study 2: Main season variety across sowing dates

The second example, a 2014 time of sowing by variety experiment sown at the IA Watson Research Centre at Narrabri, demonstrated that in some situations some varieties are high yielding across a range of sowing dates (Table 2). The varieties Suntopⓟ and Lancerⓟ for example were high yielding across all sowing dates. Even on a very late sowing date of 4th July, the yields of Suntopⓟ and Lancerⓟ were equivalent to the early maturing lines Dartⓟ and Spitfireⓟ. These results highlight the yield and economic benefit of sowing in the earlier part of the optimum sowing window, with the main season varieties EGA Gregoryⓟ, Lancerⓟ and Suntopⓟ achieving significant yield advantage, when sown in the correct sowing window. Sowing both Dartⓟ and Spitfireⓟ, both early maturing lines on April 23 (year day 113), well before their recommended sowing windows, resulted in significant yield reductions of 2.4 and 1.8 t/ha or 42% and 28% respectively. This is likely due frost induced sterility. The economic consequence of varietal choice versus sowing date can be seen when gross returns are compared (Table 2).

Table 2. Grain yield (t/ha) and gross economic returns ($/ha) of selected wheat varieties sown at four sowing times at Narrabri 2014

	Grain Yield (t/ha)				Gross Return ($/ha)			
Variety	23rd April	15th May	12th June	4th July	23rd April	15th May	12th June	4th July
EGA EaglehawkⒹ[1]	5.34^{a}	4.14^{b}	3.13^{b}	2.06^{b}	$1371	$1063	$803	$529
EGA GregoryⒹ[2]	5.68^{a}	5.10^{a}	4.07^{a}	2.74^{a}	$1606	$1442	$1150	$775
LancerⒹ[2]	5.86^{a}	5.71^{a}	4.18^{a}	2.79^{a}	$1656	$1614	$1182	$789
DartⒹ[2]	3.31^{c}	5.68^{a}	4.23^{a}	3.12^{a}	$936	$1605	$1196	$882
SpitfireⒹ[2]	4.07^{b}	5.68^{a}	4.55^{a}	2.97^{a}	$1151	$1605	$1286	$840
SuntopⒹ[2]	5.65^{a}	5.55^{a}	4.65^{a}	3.13^{a}	$1597	$1569	$1314	$885
lsd (p=0.05) (TOS x Var)		0.67						

Values within columns with the same letters are not significantly different at the 95% confidence level
**(http://www.graincorp.com.au/daily-contract-prices/NorthernNSW-Wheat.pdf?55 January 2015)*
[1]H1 = $256.67/t, [2]APH2 = $282.67/t delivered Narrabri

Case Study 3: A comparison of maturity types across sowing dates

The third example from Tamworth, highlights the benefit of targeting the early sowing window with the correct genotypes. Results from 2014 at Narrabri (Table 2) and Breeza on the Liverpool plains (results not shown), also report the yield penalty from sowing varieties too early and or outside their maturity/sowing window.

Although earlier maturing varieties have the potential to perform well from earlier than optimum sowing dates, for example the 2012 Tamworth experiment (Table 3). The yield advantage is often small (e.g. Yield difference; SpitfireⒹ vs. LancerⒹ or SuntopⒹ not significant) whilst the potential yield penalty shown in Table 2, brings the risk management considerations into focus.

Table 3. Grain yield (t/ha) of selected wheat varieties sown at three sowing times Tamworth 2012

Variety	26th April Yield (t/ha)	20th May Yield (t/ha)	20th June Yield (t/ha)
EGA EaglehawkⒹ	5.82^{a}	4.85^{b}	3.87^{ab}
EGA GregoryⒹ	5.26^{b}	5.23^{a}	4.16^{a}
DartⒹ	5.32^{b}	5.44^{a}	3.58^{bc}
LancerⒹ	5.91^{a}	4.23^{c}	3.59^{bc}
SpitfireⒹ	6.19^{a}	4.90^{b}	3.25^{c}
SuntopⒹ	5.99^{a}	5.06^{ab}	3.71^{b}
lsd (p=0.05) (TOS x Var)		0.41	

Values within columns with the same letters are not significantly different at the 95% confidence level

Summary

Variety selection to best match sowing date and variety needs to be considered in the context of a risk management strategy. Trial results show the importance of targeting varieties to their appropriate sowing window, taking into account potential yield penalties of early sowing or delayed sowing, past the optimum window. Genotype yield response curves also help to quantify varietal response to sowing date and can assist in varietal selection. Given the variability of the seasonal break and hence sowing window in any given season, growers would be encouraged to retain a number of varieties with a range of maturities (yield response curves), to ensure that yield potential is maximised and risk is minimised. Importantly, when considering variety selection, growers and advisors need to consider a wide range of information including long term NVT trial analysis results, market demand and disease ratings.

Acknowledgements

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Reviewed by

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Seeding systems & pre-emergence herbicides

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Key words

Crop safety, weed control, soil throw, knife-points, disc seeders

GRDC code

UA00113 & UA00134

Take home messages

- Keeping the weed seeds on the soil surface will improve control by pre-emergence herbicides, so minimise soil disturbance.
- Pre-emergent herbicides can cause crop damage. Separation of the product from crop seed is essential, this is more easily achieved in knife-point & press wheel seeding systems but considerably more difficult with low soil disturbance discs.
- Choose the right herbicide for the job – not all pre-emergent herbicides behave the same so follow label recommendations closely. Be mindful that volatile herbicides like trifluralin and triallate (Avadex® Xtra) require some incorporation to limit herbicide losses from volatilisation and sunlight degradation.

Background

Pre-emergent herbicides play an important role in cropping systems by providing broad-spectrum residual weed control. Applied to the soil they can provide effective early weed control, often controlling multiple germinations to reduce early weed competition with crops.

Because of their diverse chemistry, pre-emergent herbicides are represented across several different mode-of-action groups, from inhibitors of microtubulin assembly (Group D, trifluralin) to very long chain fatty acid synthesis (Group K, Sakura®).

At present growers in south eastern Australia are relying heavily on pre-emergent herbicides because of widespread resistance to Group A (fop & dim) and B selective herbicides. However, their widespread use can also be attributed to their relative low cost and mixing compatibility with non-selective herbicides like glyphosate and Spray.Seed® thus often allowing a single timely application prior to sowing.

Maximising weed control with pre-emergent herbicides and minimising crop damage requires an understanding of how various products interact with the crop, the distribution of weeds seeds in the seedbank; soil type, surface residues, rainfall and seeding system. Herbicide behaviour can vary greatly between sites and seasons and factors such as water-solubility, binding affinity, volatility, sunlight degradation, weed uptake and site of action (i.e. root, shoot or both), longevity of herbicide persistence can all influence herbicide behaviour (Table 1).

Influence of different seeding systems on pre-emergent herbicides

Over the last two decades seeding equipment used by the growers has changed considerably to enable greater stubble retention and more uniform seed placement, whilst creating minimal soil surface disturbance. As a consequence growers have now widely adopted knife-point and press wheel seeders, and more recently there has been some adoption of disc seeders.

Table 1. Water-solubility and binding of some common pre-emergence herbicides

Herbicide	Trade name®	Solubility (mg L^{-1})*		Binding K_{OC} (mL g^{-1})**		Safety margin for wheat in adverse conditions
Trifluralin	TriflurX®	0.22	Very low	15,800	Very high	Very low
Pendimethalin	Stomp®	0.33	Very low	17,500	Very high	Low
Triallate	Avadex Xtra	4.1	Low	3000	High	Low
S-metolachlor	Dual® Gold	480	High	200	Medium	Low
Prosulfocarb	Boxer® Gold***	13	Low	2000	High	Medium
Pyroxasulfone	Sakura	3.9	Low	223	Medium	Medium-high

*at 20 C & neutral pH; ** in typical neutral soils; ***Boxer Gold also contains *S*-metolachlor

The behaviour of pre-emergent herbicides from both a crop safety and weed control perspective can vary considerably depending on the seeding equipment used and the level and type of soil disturbance it creates.

Given that most pre-emergent herbicides are non-selective, herbicide safety at sowing is often obtained by creating '**positional selectivity**', that is the physical separation between crop seed and herbicide. Achieving this separation involves the seeding system displacing and throwing herbicide treated soil into the inter-row to create a clean slot from which crop seed can safely germinate. This objective is more easily achieved by tined seeding systems fitted with knife-points which can more aggressively engage the soil than low disturbance discs.

Seed bed conditions, including soil type, soil moisture, soil compaction, row spacing, seeding depth and sowing speed can also influence the ability of seeding system to create adequate herbicide separation from crop seed and provide crop safety.

Knife-points & press wheels

The no-till, knife-point press wheel has seen the revival in old products like trifluralin and triallate (Avadex), because controlled soil throw under these systems often provides adequate separation between the germinating crop seed and treated soil to provide sufficient crop safety. This has enabled the use of higher herbicide rates than previously with conventional full cut seeding systems. In addition, volatile pre-emergence herbicides such as trifluralin and triallate require mechanical incorporation via soil throw at seeding to reduce losses from sunlight degradation and volatilisation.

Issues surrounding crop safety under knife-points can sometimes arise from the use of herbicides with high water solubility, which can move into the furrow after heavy rainfall events soon after seeding. Under some situations, herbicide treated soil can be displaced across adjacent rows because of excessive sowing speeds or inappropriate machine setups. When determining an appropriate speed for sowing, consideration should not only be given to row spacing but also to seed bed conditions because soil throw behaviour can vary considerably depending on the soils moisture status (wet vs. dry). In addition be mindful to knockdown/desiccate weeds prior to sowing, this will help to avoid large weeds from wrapping around the tine, preventing excessive soil throw and widening of the furrow. Melons are often a culprit of this, leaving a large furrow void of herbicide, from which weed escapes will be more common.

Good weed control can be achieved under these low soil disturbance systems because weed seeds are mostly present on the soil surface, which maximises their exposure to concentrated band of herbicide. This was particularly evident in the early days of trifluralin use under knife-points where ideal soil throw and concentration of weed seedbank on the soil surface resulted in exceptional improvement in weed control compared to previous conventional full cut incorporation (from 50 to >90% control).

Disc seeders (triple vs. single)

Many no-till farmers have now adopted disc-based zero-till cropping. Disc seeders enable growers under higher stubble loads to either maintain or even narrow their crop row spacing (5"). With low disturbance disc seeders, reliable separation of seed from pre-emergent herbicides can be difficult and may result in crop damage. Consequently no pre-emergent herbicide labels currently provide specific advice or recommendations for their use with disc seeders, with the TriflurX label specifically stating that it is not to be used with disc opening systems. The situation is complicated by the large number of disc seeders available to growers, which can differ enormously in their level of soil disturbance (pers. comm. J Desbiolles).

Disc seeder setups can vary greatly in the angle of disc entry into the soil, disc arrangement (triple vs. single), size, shape and width, seed placement, closing plate or wheel, depth gauge and press wheel size and shape. Their operation can also vary depending on soil type, soil moisture, soil compaction, residue conditions, row spacing, seeding depth and sowing speed. All these factors combined can influence the level and type of soil throw they generate, and importantly the risk of herbicide damage.

Triple discs – influence of coulters

Recent research by the University of Adelaide and University of South Australia has shown that pre-emergent herbicides were consistently safer under triple disc (i.e. KHart, Bertini) than single disc systems (JD90 series, NDF 650 series). In triple discs, the engagement of rippled coulters (Figure 1) with soil can provide adequate soil throw and herbicide displacement, which often leads to similar crop safety and establishment as tined seeders fitted with knife-points. The role of coulter induced soil throw in crop safety was clearly illustrated in field trials by using coulter skids. Herbicide damage from pre-emergence herbicides was significantly increased when coulter skids were fitted to Bertini coulters to minimise soil throw. These skids are 'soil throw controllers' designed to limit the amount of soil movement out of the furrow by preventing soil from riding up the coulter and thus keeping herbicide treated soil within or close to the furrow, thus increasing herbicide damage.

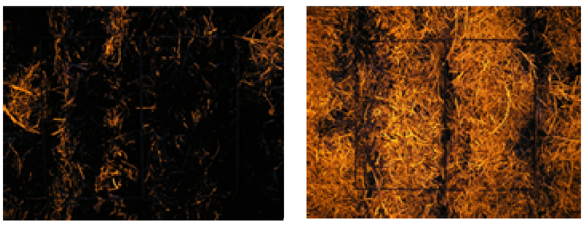

Figure 1. Soil surface disturbance created by KHart triple disc with rippled Yetter coulter (80%; left) compared with JD 90 series single disc (<35%; right). Percentage soil surface disturbance (%) was determined by using fluorescent pigment Blaze-Orange & digitial image analysis software.

Leading coulters can also limit potential for stubble hairpinning where the disc opener rolls over the residue rather than cutting through it. Hairpinning often results in poor seed placement, placing the germinating seed in direct contact with herbicide treated residue and soil.

Single discs – Influence of disc design, sowing speed & depth of sowing

Disc seeding system design and setup can also influence pre-emergent herbicide behaviour. For example, greater soil throw by the seed banding boot deflector of the DayBreak Duodec disc seeding system significantly improved crop safety as compared to other single disc configurations investigated.

Closing the seed slot/furrow and achieving adequate seeding depth were also critical to avoiding herbicide damage from pre-emergent herbicides. This is particularly important for water-soluble herbicides that are more likely to wash into and concentrate in an open seed furrow after rainfall. Disc seeders are often operated at fast travel speeds (i.e. in a 2007 disc seeder survey, 50% of SA farmers operated between 11-13 kph, with some up to 16 kph), but higher speeds can reduce the uniformity of seed placement. Shallow seed placement can increase the risk of herbicide damage in situations where the pre-emergent herbicide has not been effectively removed from the furrow by the seeding disc. In our trials, increasing the sowing depth reduced herbicide damage when a double shoot version of NDF 650 single disc seeding system was used, which created greater soil disturbance and achieved deeper sowing depth. Such disc configurations are likely to increase herbicide removal from the furrow and increase the separation between the herbicide and germinating seed.

In addition fitting air diffusers, which slow the rate of seed delivery to the boot, and use of seed tabs to firm soil around the seed, help reduce seed bounce and poor seed placement associated with fast operating speeds, and can promote greater crop safety.

Single discs – Influence of closing furrow wheels & residue managers

There has been considerable speculation amongst growers and advisors that some closing furrow wheels contribute significantly to herbicide damage by dragging herbicide treated soil from the furrow side wall into the seed slot. However, trial results showed that there was little or no effect of closing furrow wheel design on herbicide damage, but the furrow needs to be properly closed. In some single disc treatments, where the furrow-slot was deliberately left open, herbicide damage caused near complete crop failure. In the field this situation can occur with excessive bouncing of the closing wheel at speed, particularly with solid cast wheels. However, some growers have overcome this issue by fitting spoke wheels (i.e. Thompson closing wheel) which tend to bounce less whilst crumbling the furrow side wall. Growers have also reported that closing the seed slot is made more difficult when weeds are present at sowing, suggesting their root systems bind the surface soil to reduce the amount of friable soil that can be pressed back into the furrow.

Use of residue managers fitted in front of single disc openers were shown to significantly improve crop safety. The managers appear to sweep both herbicide treated stubble and soil ahead of the disc opener thereby limiting the interaction between the disc blade &/or closing furrow wheel, resulting in greater crop safety. However, the ability of residue managers to operate under certain residue situations (i.e. tall stripper front residue) can be compromised and careful consideration is needed at harvest to ensure the residue is suitable for handling at sowing.

Similar to the knife-point & press wheel system, research has shown that weeds seeds accumulate on or near the soil surface in disc opening systems. As a consequence most weed seeds germinate in close proximity to a concentrated herbicide band that can result in consistently greater weed control, in addition to hastening natural seed mortality.

Our trials have shown that some herbicides and rates of herbicides were better suited to disc systems than others. Inadequate soil throw and poor incorporation of trifluralin with single disc systems **often causes** crop damage and poor weed control, and can result in massive weed seed set and hence the label specifically recommends against using disc opening systems. Such large build-up in weed seed bank would be expected to have serious effects on productivity of subsequent crops grown in the rotation. Therefore careful consideration should be given to choosing the right herbicide for the job, and remember not all herbicides behave the same **so follow the label recommendations closely**.

Acknowledgements

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Report on the 2013 GOA herbicide resistance survey

Maurie Street, Grain Orana Alliance

Keywords

Herbicide, resistance, survey, testing, Central West NSW, GOA

GRDC code

GOA00001

Take home message

Testing revealed that herbicide resistance was common place and that in the vast majority of the samples submitted multiple resistances were most dominant. In a number of cases the broadness of multiple resistances was such that there are only a few potentially effective herbicide options left that might control those weeds.

This survey has proven herbicide resistance is not an issue confined to Western Australia or other regions only. This survey has identified many populations in the Central West of NSW that rival and possibly surpass the severity of Western Australian herbicide resistance. It should no longer be considered “someone else’s issue” and that “it’s not that bad”.

The results of this survey are damning and its strength may be the force that has been needed to change attitudes, to acknowledge the issue of herbicide resistance which of course is the first step to better manage the issue of herbicide resistance into the future.

Background

Herbicide resistance could possibly be one of the greatest threats to the sustainability of our current grain production systems. The dominant minimum or zero tillage systems have evolved to place a heavy reliance on herbicides for weed control and, in many cases no other alternate methods of control are being employed. This reliance on herbicides has already led to the development of resistance in many cropping regions of the world with Australia being no exception.

So it lends to reason that the Central West of NSW is not immune from the development of resistance either but the extent of which resistance exists in the region has not yet been quantified. Prior to this survey the only formal confirmation of resistance was through ad-hoc resistance testing by advisors or growers mainly in situations where herbicides had previously failed. Or more informally, resistance was only diagnosed by “gut feel” or educated guess by advisors.

This survey is the first attempt to quantify both the extent and types of resistance presently in the Central West of NSW.

In contrast, other cropping regions in Australia have undertaken a number of surveys and these have started to form sound evidence of the level and types of herbicide resistance present. In other regions this evidence would be crucial in convincing growers for the need to address the issue of resistance and provide the insight into the characterisations of resistance to make informed decisions for its management.

Local advisors within the Central West region have suggested there is an inherent lack of recognition and acceptance by many growers of the presence of herbicide resistance in the region and the threat and severity it poses. Partly because of this many growers are not often prepared to act to prevent, slow or combat resistance. GOA’s engagement with local stakeholder groups expressed a clear need and desire to assess levels of resistance within the region and the products that were affected. In doing so it would help raise awareness of the issue through hard evidence, the presence of herbicide resistance.

Aims

The aims of this survey were to establish what the current level and types of herbicide resistance are in the Central West of NSW. In doing so, this would raise awareness of the issue to foster a change in attitude and following on from this, a greater willingness to address the issue. The information provided from this survey would aid growers and agronomists to make more informed decisions around herbicide choices or in fact even management strategies beyond simple herbicide rotations

Methodology

In November of 2013, all growers and agronomists on the GOA contacts list were offered an opportunity to submit weed seeds of any of four common species for testing for resistance to a range of common herbicides. The four weed species were:

- Annual ryegrass (ARG)
- Wild or black oats (BO)
- Wild radish (WR)
- Sow or milk thistle (ST)

These species were chosen as they were either already noted as key weeds in the region that were either commonly demonstrating herbicide resistance such as ARG and BO, or those that are thought likely to develop herbicide resistance such as WR and ST.

Samples were limited to two per grower in an effort to survey a wider cross section of the GOA region. Weed seeds were to be sampled from cropping paddocks in the local region with no stipulation as to their suspected resistance status. That is they could be taken from paddocks regardless of whether they were suspected resistant or not.

Samples were to be collected in accordance with commercially accepted sampling instructions provided by Plant Science Consulting (www.plantscienceconsulting.com/seedtest), the commercial testing service that undertook the herbicide testing on the seed samples provided. The herbicide testing was carried out to industry accepted standards in calibrated spray cabinets with control populations introduced to ensure confidence in testing procedures.

A range of herbicides specific to the weed species were applied and these are listed in tables 1 and 2 below. The herbicide types and rates used were developed with input from a number of sources with an aim to characterise the resistance status of each population to commonly used products and if for some products at multiple rates to examine any rate responsiveness. The options tested are not completely exhaustive as cost would have been prohibitive but the results do serve to give a significant characterisation of the resistance status of the populations tested.

Details regarding the herbicide history from the paddocks were also collected when samples were submitted for testing. Information such as the suspected resistance status, length of farming history and details regarding the number of herbicide applications of each mode of action that had been applied in the last 10 years.

A total of 123 weed seed samples were collected, 79 ARG, 41 BO and 3 WR. No ST samples were received. The WR samples have been combined into Dr Christopher Prestons project monitoring WR for resistance and the results have not been included in this report.

GOA returned the individual results growers or agronomists who submitted the samples so as to allow them to make informed decisions regarding the management of those weeds. This report however concentrates on the combined results and the broader overall impact of the survey.

Table 1. Herbicides and rates tested on annual ryegrass samples

Herbicide tested	Common trade names	Rate applied L/ha or g/ha
Haloxyfop	Verdict®	0.1L
Clethodim	Select®	0.35 L
Clethodim	Select	0.5 L
Butoxydim	Factor®	180 g
Pinoxaden	Axial®	0.3 L
Triasulfuron	Logran®	40 g
Iodoulfuron-methyl sodium	Hussar® OD	0.1 L
Imazamox & Imazapyr	Intervix®	0.6 L
Atrazine	Gesaprim®	2000 g
Trifluralin	Triflur X®, Treflan®	2 L
Glyphosate 540 g/L	Roundup PowerMAX®	1 L
Glyphosate 540 g/L	Roundup PowerMAX	1.5 L
Glyphosate 540 g/L	Roundup PowerMAX	2 L

Table 2. Herbicides and rates tested on wild/ black oat samples

Herbicide tested	Common trade names	Rate applied L/ha or g/ha
Clodinafop	Topik®	0.1 L
Haloxyfop	Verdict	0.1L
Clethodim	Select	0.35 L
Clethodim	Select	0.5 L
Pinoxaden	Axial	0.2 L
Mesosulfuron-methyl	Atlantis® OD	0.33 L
Flamprop-M-methyl	Mataven® 90	1.8 L

The herbicide resistance testing reported upon two measurements:

1. The percentage of the treated population that survived the herbicide quoted as % survival
2. A rating of the herbicide effect on the surviving plants as follows
    - "R" indicates surviving plants were significantly stunted and only recovered with a few tillers
    - "RR" indicates plants suffered stunting in the order of 40-70% relative to untreated plants
    - "RRR" rating which indicates survivors showed virtually no herbicide effect.

This report concentrates mainly on the percentage survival to the individual herbicides as this gives a better indication of the potential frequency of resistance in the region. The second measurement aims to offer some insight into the relative "strength" of the resistance in the surviving plants.

The industry accepted terminology for herbicide resistance is that:

1. "Developing Resistance"-Survival of up to 19% but no more of the treated population
2. "Resistant" -Survival of 20% or more of the treated population

However, to simplify the reporting of the findings of this survey, any populations with survival greater than 10% is termed resistant. This approach has been taken for the following reasons-

- To report on the levels of both "developing resistance" and "resistant" would serve only to complicate the message, lengthen the report unduly and potentially confuse the reader.
- We cannot be 100% certain that very low levels of survival are not just an anomaly in testing
- Differences in resistance between 10 to 20% survival would be indistinguishable in paddock situations and therefore irrelevant to managing such populations
- Growers could expect a higher % survival to herbicides applied outside the "ideal" conditions under which testing so even these lower level of survival would be considered commercially unacceptable.

Results

Ryegrass

79 samples of annual ryegrass were submitted, of which, one seed lot was unviable (poor germination) so 78 samples underwent testing. 91% of samples were collected and logged by advisors and only seven samples were collected and submitted by growers.

The distribution of the sample locations is detailed in Figure 1 below and provides a reasonable cross section of the GOA region, with the notable exceptions of the western area beyond Trangie and Warren and the north eastern areas around Coolah where no samples were submitted.

Figure 1. Locations from where ryegrass samples were taken from.
NB Multiple samples may have been taken from the general locality marked by only a single pin marker

There appeared to be little clear correlation between the patterns of past herbicides usage or the length of cropping history indicated in the survey questions to the demonstrated resistance to those herbicides. However a number of populations demonstrated resistance to a particular herbicide where there has been no or very little previous use indicated. For example,

- 15 populations demonstrated resistance to Axial where it was indicated it had not been used in the past
- Two of the four populations demonstrating resistance to trifluralin where it was not reported to have been used in the past.
- Two populations had been reported to have not used a Group B applied however demonstrated 100% resistance to Logran
- 22 samples reported having less than two Group B applications yet all demonstrated resistance, 12 of which demonstrated 100% resistance to Logran.

Of all the samples submitted, 30% of samples were predicted to be “possibly resistant”, 70% of samples were predicted to be “resistant” but no samples submitted were predicted to be “susceptible” in the submission questionnaires.

There were no samples submitted that were susceptible to all the herbicides tested. In other words there was not one sample that was not resistant to at least one of the herbicides tested. Table 3 below details the demonstrated resistance of the submitted ARG samples to individual herbicides tested.

Table 3. Number of AGR samples demonstrating resistance to the various herbicides and rates tested

Herbicide and rate tested	No of samples > 10% survival	% of samples with > 10% survival
Verdict 0.1L/ha	59	75%
Select 0.35L/ha	17	22%
Select 0.5L/ha	6	8%
Factor 180g/ha	1	1%
Axial 0.3L/ha	47	60%
Logran 40g/ha	77	99%
Hussar 0.1L/ha	64	82%
Intervix 0.6L/ha	44	56%
Atrazine 900WG 2000g/ha	7	9%
Triflur X 2L/ha	4	5%
Glyphosate 540 1L/ha	5	6%
Glyphosate 540 1.5L/ha	4	5%
Glyphosate 540 2L/ha	3	4%

Only ten samples, or 13%, demonstrated resistance to only one of the herbicides tested. **Multiple herbicide resistance**, where a sample demonstrates a resistance to more than one herbicide types, was found in 86% of the samples tested as detailed in Table 4 below. 54% of samples demonstrated resistances to four or more herbicide groups or sub-groups and the largest single group, constituting 37% of the samples demonstrated resistance to only four groups or subgroups.

Note that for the purpose of this table Fops, Dims and Dens are considered as subgroups of Group A because it has been previously shown that differential levels of control can be expected when using these herbicides. Similarly for the Group B's they are in two subgroups being the sulfonylureas (SU's) and the imidazolinones.

Table 4. Number of ARG sample populations demonstrating resistance to multiple herbicide groups and sub groups.

No. of herbicide groups or sub groups with demonstrated resistance#	No of samples	% of samples submitted
1	10	13%
2	15	19%
3	10	13%
4	29	37%
5	12	15%
6	1	1%
7	1	1%

Herbicides groups and subgroups considered- Fop, Dim (Select® only), Den, SU, Imi, Triazines and Glycines.

Further analysis of the levels of cross resistance due to the significant number of resistance combinations over such a number of herbicides is quite difficult and potentially unsound. However it is interesting to note some of the variations within a particular herbicide group and/or over a number of rates.

Group A's - Fops, Dims & Dens

- 59 (75%) samples were resistant to Verdict but only 17 of those were resistant to Select @ 350ml/ha and only six to the higher rate of 500mL/ha.
- Of the samples resistant to Select, all were also resistant to Verdict.
- Only one sample demonstrated low level resistance (10% survival) to Factor and it was already resistant to both Select and Verdict.
- 47 (60%) samples demonstrated resistance to Axial, of these 100% demonstrated resistance to Verdict but only 17 populations were also resistant to Select® (350mL/ha)

Group B's - SU's and imidazolinones

- Logran was all but ineffective with 77 of the 78 (99%) samples demonstrating resistance
- 64 (82%) of the samples demonstrated to be also resistant to both Hussar OD and Logran
- 43 samples were resistant to Intervix and both Logran and Hussar OD.

Group M

- Only five samples demonstrated resistance to Glyphosate 540
- Three of these demonstrated significant levels of cross resistance to more than two other herbicide groups or sub groups

This is only a small sample of resistant populations so any characterisation of a glyphosate resistant population based on this would be not well founded. However it should be noted that for most populations tested glyphosate is still effective but for some of the more resistant populations tested (multiple resistances) found it was one of the last few effective options left.

Wild oats

41 samples of wild or black oats were submitted to the survey. All samples were collected and submitted by advisors.

The distribution of the sample locations is detailed in Figure 2 below where a reasonable cross section of the GOA region has been taken in by this survey but noticeably the area around and east and north east of Dubbo had no samples submitted.

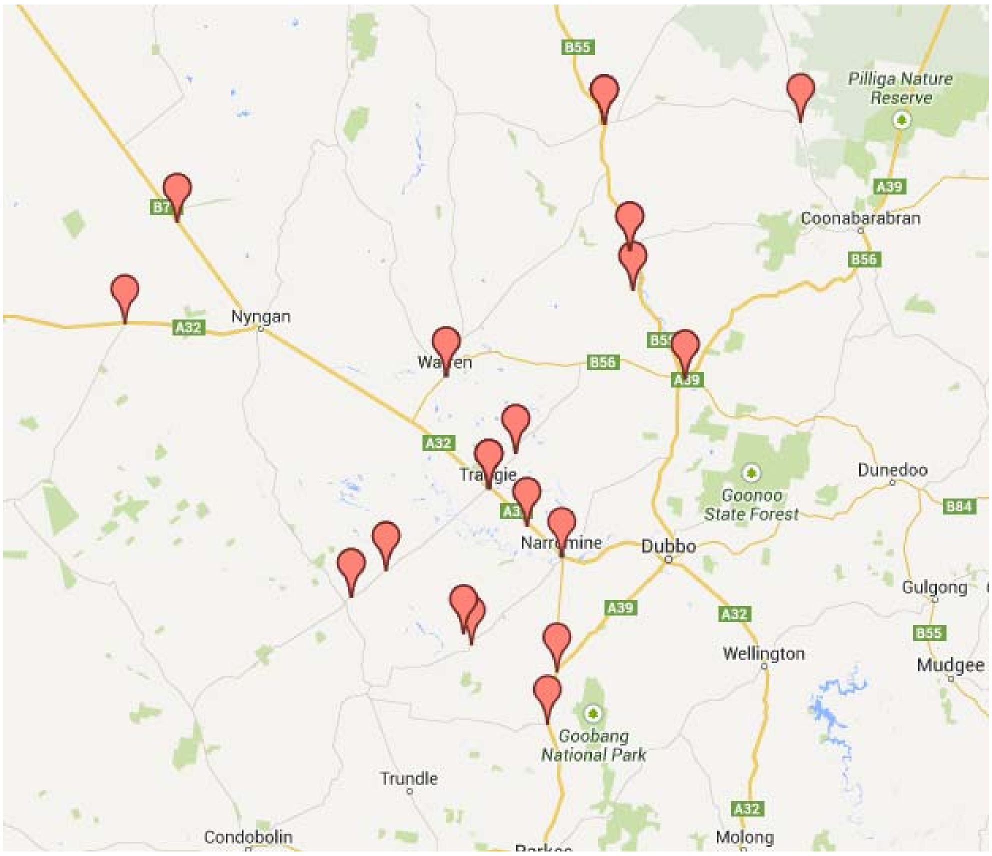

Figure 2. Location of wild oats sampling locations
NB Multiple samples may have been taken from the general locality marked by only the one pin marker

There appears to be little clear correlation between the patterns of past herbicides usage or the length of cropping history indicated in the survey questions to the demonstrated resistance to those herbicides. But similarly to the ARG samples, a number of herbicides demonstrated resistance where it has been indicated that no applications of that herbicide had been applied. For example,

- 16 samples demonstrated resistance to Mataven where no Mataven had been applied.
- Four samples demonstrated resistance to Axial where no Axial had been applied

Of all the samples submitted, 56% of samples were predicted to be “resistant”, 41% were predicted to be “possibly resistant” and none were predicted to be “susceptible”, and two samples did not indicate their suspected resistance status on the submission questionnaires.

Despite the strong predictions for the samples to be resistant, 29% of the samples demonstrated no resistance to any of the herbicides tested with five of these predicted to be “resistant” and the balance only “possibly” resistant.

73% of the samples submitted demonstrated some level of resistance to the herbicides tested as detailed in table 5 below. The most common resistance in these samples has been demonstrated to be Topik (56%) but closely followed by Mataven 90 (51%). Resistance to Axial® has been demonstrated to be 37%, nearly three times greater than that for Verdict® at 12%. Interestingly there was no demonstrated resistance to Select in the samples tested and only two samples resistant to Atlantis OD®.

Table 5. Number of samples demonstrating resistance to the various herbicides and rates tested

Herbicide and rate tested	No of samples >10% survival	% of samples with >10% survival
Topik 0.1L	23	56%
Verdict 520 0.1L	5	12%
Select 0.5L	0	0%
Axial 0.2L	15	37%
Atlantis 0.33L	2	5%
Mataven 90 1.8L	21	51%

Table 6 below details the level of multiple resistances in the samples submitted. 22% of samples demonstrated to be resistant to two herbicide groups or sub groups and a similar number (22%) were three herbicides groups or sub groups. A much smaller number were resistant to four, at 7% of the samples submitted.

Table 6. Number of sample populations of black oats demonstrating resistance to multiple herbicide groups and sub groups.

No. of herbicide sub groups with demonstrated resistance#	No of samples	% of samples submitted
0	11	27%
1	9	22%
2	9	22%
3	9	22%
4	3	7%

Herbicides groups and subgroups tested- Fop, Dim, Den, SU, Grp Z.

Of the six herbicides tested on these samples they all belong to only three different herbicide groups, Group A, B's and Z.

- Of the 23 samples that demonstrated resistance to Topik only five were resistant to Verdict which is also a Fop herbicide, but 15 demonstrated to be resistant to Axial, a Den herbicide.
- All samples resistant to Axial® were also resistant to Topik
- In those cross resistant samples, the level of resistance demonstrated to Verdict and Axial was much lower than that was shown to Topik in the majority of cases - but not all
- As shown above there was no demonstrated resistance to Select.
- There were only two samples with Atlantis OD® resistance at a low level - for one sample it was the only resistance demonstrated, the other sample was also resistant to Topik, Axial and Mataven as well but susceptible to Verdict.
- 15 of the 21 samples resistant to Mataven were also resistant to Topik, 11 were resistant to both Topik and Axial.
- Six samples were resistant to Mataven but demonstrated no cross resistance to the other herbicides tested.

Discussion

Acknowledgement should be first given to the collection method and the potential bias that may have given to the samples submitted to this survey. This was not a random survey of the region and most likely growers and advisors would most likely sampled weed seeds from more suspicious populations than not. This is highlighted in the sample submission questionnaire where all samples were either suspected to be “resistant” or “possibly” resistant. Therefore it should be considered the outcomes and information presented from this survey maybe a “worst case scenario”.

In defence of this approach, testing is carried out through seed testing and that the target populations for this survey are from cropping paddocks. Therefore it is most likely the only seed available to sample would be those from plants at maturity that have survived in crop herbicide applications. This scenario would by definition support a theory they are possibly resistant to at least some herbicides. Another way to put it is that susceptible plants would have been controlled by herbicide applications and simply not available to sample- suggesting seed tests will always bias towards a greater level of resistance whether the collection method is random or directed.

A “Quick Test” which samples live seedling plants from populations not already “selected” for a resistance by a herbicide application and as such may not have as stronger bias for resistance applied.

Given this bias towards sampling populations suspected of resistance the finding of some levels of resistance is no surprise. That said though for both ARG and BO, the samples that were submitted have overwhelmingly demonstrated a high level of resistance to many of our common herbicides. Nearly all (99%) the samples of ARG and 73% of BO samples submitted were resistant to at least one of the herbicides tested.

The higher level of susceptibility in the BO samples is interesting given that 27% of the samples submitted showed complete susceptibility to the range of herbicides tested yet sufficient survivors were available to sample from (assuming the paddock was treated for BO) which does fly in the face of the above comments. There are a number of potential explanations however no clear evidence in the data set is available to confirm as to which one. BO is well noted for seed dormancy and possibly the plants sampled germinated after the paddock was treated with herbicides. Alternatively does the presence of susceptible plants at maturity suggest reduced effectiveness of the herbicides through poor application or the impact of plant stresses? This could suggest that more attention and care should be paid to application of BO herbicides to ensure the highest level of control.

Multiple resistances

As detailed above in tables 4 & 6, multiple resistances are common with only 13% of ARG samples and 22% of BO samples demonstrating resistance to just a single herbicide group or subgroup. The clear majority of the samples submitted from both species demonstrated multiple resistances. Therefore within this set of samples, multiple resistances are significantly more common than no resistance or just single product resistance. Put another way, samples with no resistance or single product resistance is a rarity.

It was found that the levels and types of cross resistances, as discussed below, for each population tended to be unique. Hence the reader should exercise caution as what is demonstrated in this data will not necessarily be applicable to all populations. Further to this the complexity of relationships between the large numbers of herbicides tested can be overwhelming and the results potentially completely unrelated.

Source of resistance

As detailed in the results above there are a number of samples that have demonstrated resistances to a number of products where it has been indicated that the particular herbicide group has not previously been used.

For example there were-

- 15 populations of ARG that demonstrated resistance to Axial where use of Axial was not indicated,
- Two of the four populations of ARG demonstrating resistance to Trifluralin had not reported its application,
- Two populations of ARG had not reported the use of a Group B herbicide yet demonstrated 100% resistance to Logran
- Four BO samples demonstrated resistance to Axial where its use was not reported
- 16 BO samples demonstrated resistance to Mataven where its use was not reported.

This phenomenon is not uncommon and potentially could occur through a number of mechanisms.

- The population is naturally resistant to the herbicide, explained by simple genetic variability within species
- Some resistances can simply be selected for indirectly. That is selection for resistance by use of one particular herbicide may at the same time select for a resistance for another unrelated herbicide.
- Resistant plants or seeds can be introduced into your system, carried in on machinery and stock or in seed, wind or flood waters.

There is no way to confidently identify which mechanism has resulted in the outcomes in the examples listed above but their occurrences do highlight challenges for management of herbicide resistance. There are unfortunately no defence growers and advisors can employ to manage the natural presence of resistance in a population. For the second mechanism there is also little that can be done to avoid this other than sound and informed chemical rotations. However for the third mechanism sound farm hygiene for machinery, seed and stock can slow the spread or incursions of resistant weeds.

Knowing your resistance status

For the set of samples provided to this survey we have detailed the frequencies of individual resistances as well as a number of generalisations about levels of cross resistances between some herbicides. However it should be again noted these apply to this set of samples only and may not apply beyond these in the wider farming systems or other regions. There is no unique and distinct characterisation of a “resistant” ARG or BO plant- each one can be different.

As growers and advisors this survey showed our predictive skill for identifying resistance without testing may be variable. For ARG, all samples were predicted to either possibly or definitely resistant and that was shown to be true. For BO however 29% of the samples that were predicted to be possibly or definitely resistant were not resistant to any of the products tested.

So given our questionable skill at predicting resistance and that it can occur somewhat independent of past herbicide resistance testing is a must. The results from this survey have demonstrated populations where some products have retained effectiveness when it could easily be assumed that they would be ineffective and visa-versa. To highlight this point;

- 56% of BO samples demonstrated resistance to Topik, but only 12% demonstrated resistance to Verdict® with both herbicides in the same herbicide group

- 99% of ARG samples demonstrated resistance to Logran, only 82% demonstrated resistance to Hussar OD and 56% to Intervix- all Group B herbicides
- 51% of samples demonstrated resistance to Mataven but only one quarter of those had Mataven applied previously.

This highlights the value in herbicide resistance testing not so much to confirm that a particular product has not worked due to resistance, but to identify which products may still work in the future.

Worthy of a mention

As discussed above, the identification of resistance to a number of key products such as the Fop herbicides and Group B herbicides such as Logran have come as no surprise. Alarmingly though the testing has highlighted some cases of resistance to a few "less used" products thought to be safe and still effective and which many growers would be potentially relying on for herbicide control in the future.

Atrazine and trifluralin have had much less reliance or use in the region compared to many other products for the control of these weeds. Experience from other regions also indicated that resistance can take much longer to develop and are much less common. However six populations (10%) of ARG samples demonstrated resistance to atrazine with another six populations demonstrating 5% survival in testing which could indicate very early stages of developing resistance. There were also four populations of ARG that demonstrated resistance to trifluralin.

Similarly Intervix, as a product mainly utilised in Clearfield canola and hence only a small proportion of our annual cropping area, demonstrated resistance in 56% of the ARG samples.

Identification of resistance to Select in the region is not a total surprise but for many populations of ARG it was the only reliable in crop selective herbicide available and is therefore a key in the management of ARG. But nearly a quarter of the samples submitted (22%) of ARG samples demonstrated resistance at the lower application rate of 350 ml/ha. All of these populations were already resistant to Verdict, Axial, Logran, and Hussar OD. Increasing the application rate to 500ml/ha did decrease the survival to 8% of the populations but this for many populations is the last lever to pull for ryegrass control.

Mataven is often talked of as an alternate herbicide product for the control of BO and in recent times had very little use with only six samples indicated to have received any applications of Mataven in the past 10 years. However 51% of the BO populations demonstrated resistance to Mataven. As an alternate product to control Topik resistant BO only 36% of the Topik resistant populations would be susceptible. There are currently questions over the continued manufacture and supply of Mataven but its usefulness on these populations would be limited.

Finally, herbicides play a pivotal role in our current minimum-till or zero till farming systems. Possibly the most important product in the northern farming region is glyphosate. This herbicide is invaluable in the control of weeds in our fallow systems which are essential to conserve out of season rainfall to achieve profitable crop yields. It is also important for managing pre-planting flushes of weeds, potentially the largest germination of winter weeds. Loss of the effectiveness of this herbicide will seriously challenge the sustainability of this otherwise profitable system.

Testing of the ARG samples submitted to this survey has revealed 6% of them demonstrated resistance to Glyphosate 540 @ 1lt/ha. Higher application rates improved control but only marginally. Although this is only a small proportion of the samples tested the importance of the product and lack of comparable alternatives is reason enough to be very alarmed by these results.

Conclusion

As intended, the survey included weed seed samples from a healthy cross section of the GOA region of the Central West of NSW. Both AGR and BO were submitted to the survey with ARG samples attributing approximately two thirds of the total samples and BO one third.

Testing revealed that herbicide resistance was common place and that in the vast majority of the samples submitted multiple resistances were most dominant. In a number of cases the broadness of multiple resistances was such that there are only a few potentially effective herbicide options left that might control those weeds.

This survey has proven herbicide resistance is not an issue confined to Western Australia or other regions only. This survey has identified many populations in the Central West of NSW that rival and possibly surpass the severity of Western Australian herbicide resistance. It should no longer be considered “someone else’s issue” and that “it’s not that bad”.

The survey was also invaluable in identifying what some of the most challenged herbicide groups are in terms of effectiveness. But the survey also served a warning to growers particularly for what many have thought to be “safe” and “effective” herbicide options such as Select®, atrazine and trifluralin and even glyphosate with clear signs of resistance developing.

The results of this survey are damning and its strength may be the force that has been needed to change attitudes, to acknowledge the issue of herbicide resistance which of course is the first step to better manage the issue of herbicide resistance into the future.

Acknowledgements

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The nuts and bolts of efficient and effective windrow burning

Maurie Street, Grain Orana Alliance

Key words

Windrow, burning, herbicide, resistance, HWSM, GOA

GRDC code

GOA00001

Take home message

- Herbicide resistance is rapidly becoming more widespread and growers need to act to save what effective herbicides that are left. Harvest weed seed control is a suite of tools to combat this and narrow windrow burning the cheapest and easiest to implement.
- Narrow windrow burning (WB) has proven to be successful in other regions on key weeds such as annual ryegrass and wild radish
- There is no reason to doubt its effectiveness here on those same key weeds. WB effectiveness on other species that shed seed early such as wild oats may be less reliable.
- Successful WB is not hard and may take some practice to become an expert. Following some simple suggestions may help avoid mistakes
- The biggest factor to success - you must cut the crop low, less than 15 cm
- There are some downsides to WB such as selection for weeds resistant to WB, negative impacts on fallow efficiency or nutrient implications but these must be weighed up against the positive for weed control and resistance management.

What is narrow windrow burning and why do it?

Narrow windrow burning (WB) is the process where the crop residue during grain harvesting is placed in a narrow windrow and then burnt.

Why?

Research has shown that a large percentage of weed seeds present at harvest that enter a header, exit in the trash fraction with the chaff and to a lesser extent, the straw fraction. If you can capture and concentrate those seeds and render them sterile by burning them, they're not going to be there to germinate and compete with next year's crop, hence breaking the weed's reproductive life cycle.

It is a technique that has been widely adopted in Western Australia over the past 10 years and has shown to be a very effective tool to manage herbicide resistance for a number of key weeds such as annual ryegrass and wild radish.

But with any new tool there are some tricks of the trade to ensure the best results which will be discussed here.

Tips for successful windrow burning

For WB to be successful, growers should plan for its use a long time before you strike a match so let's start at the beginning.

Ahead of harvest

Well ahead of harvest time consider which paddocks and crops you might like to WB. Your choice will be influenced by many characteristics but here are a few of the main considerations:

Which crop?

The trick with WB is to just burn the windrows and not the whole paddock. Despite many growers doubting this possible, it has been proven in over tens of thousands of hectares every year in Western Australia. The majority of growers in WA now use WB to some extent on their farms.

Two simple things make this possible:

1. The crop is cut short to capture the weed's seeds into the header front. Then the entire trash from the header is deposited in a defined, narrow windrow not spread back over the paddock. This means the fuel load is in the windrow and not outside of it and the fire can only burn where there is fuel. This is demonstrated in figure 1 below showing the residue distributed over the soil surface in the conventionally harvested section on the left, which allows the fire to spread. In contrast the soil surface on the right has less residue left on the soil surface for the fire to carry on.

Figure 1. Remaining trash loads when a paddock is harvested for windrow burning on the right compared to the trash load being redistributed by the header when conventionally harvesting on the left. Photo taken Narromine June 2013

2. Weather conditions when windrow burning need to be calmer and cooler than what is required in more traditional paddock burns which need a little more heat and wind to ensure the fire carries.

However despite these points the fire can still get away to burn the whole paddock. Bulky cereal crops with thick stubble will be most prone to the fire getting away. So it is recommended, especially if inexperienced, to **target lighter yielding cereal crops or break crops such as canola, chickpeas, lupins or field peas** that tend to have lower levels of trash remaining outside the windrow.

Barley stubbles in particular have a reputation of being more difficult to burn without fire escapes and maybe better left for when more confident in WB. Experienced “windrow burners” have shown that burning wheat stubble in excess of three ton per hectare or even barley is possible as shown in the photo below.

Figure 2. 4.5T/Ha Hindmarsh barley stubble windrow burnt 22nd March 2014. Photo taken 27th March 2014

Think of this: You must cut low when WB and when 2T/ha or 4T/ha crops are cut off both at 15cm they don’t often look that different. In regions with summer rainfall, large amounts of that flammable basal leaf has also long been smashed up by rain leaving behind just the stalks which limits the potential for fire escapes.

Another point to consider is heavier windrows resulting from larger crops or wider header fronts have more fuel to burn. This increase in fuel load and concentration can help insure a more complete burn in cooler or damp windrows (although not recommended). Figure 2 below shows a windrow missed in the main burn from the same paddock above that was burnt on a cool, damp and overcast 26th of April 2014. Note the white ash indicating a hot fire and no unburnt residue.

Figure 3. 4.5T/ha Hindmarsh barley stubble windrow being burnt on 26th April 2014. Weather conditions: 23 degrees C, 55% humidity. The soil surface and windrows were wet from 0.5mm rain previous day and 49mm total rainfall since 4th April 2014.

Which paddock?

You most likely won't be looking at WB the whole farm at your first attempt so it is worth identifying which paddocks you intend to do well ahead of the rush of harvest time. Below are a few things that may help identify what paddocks are most suited to WB.

- Weed types.
    - WB has shown to be very effective on weeds that retain their seed at harvest above 15cm such as ryegrass and wild radish as this makes it easy to capture into the header front. So target tall weeds.
    - Wild oats, brome or barley grass that shed or drop their seed may do so before the header has a chance to capture those seeds to put in the windrow so these may not be reliable candidates for WB.
    - Short weeds that set seed lower than practical to capture in a header front are not capable of targeting, an example may be wireweed.
    - Weeds that are able to re-sprout or re-seed after harvesting such as fleabane and sow thistle are also not likely to be good targets for WB. These two culprits also have seeds that are very mobile by air and as such could drift from the trash stream at harvest anyhow.

- Paddock conditions: To successfully capture those weeds you must cut low. Obstructions or hindrances such as rocks, sticks, gilgais or poor header driving skills that stop you getting low can reduce the effectiveness of WB. Address these issues ahead of time if possible.

Preparation of the harvester

To successfully sterilise the weed seeds during the burning process the fire must burn hot enough and long enough. This can really only be reliably achieved when the trash is concentrated into a narrow windrow. Research has shown that simply dropping the residue out of the back of the harvester in a wider windrow or a broad scale burn will not achieve the results possible from a narrow windrow burn.

To achieve this narrow windrow there will be a need for some simple modifications to the rear end of the header to simply direct the trash stream into a narrower windrow. These need not be too complicated and only need to observe a few important characteristics.

- The chute design should aim to form a windrow that is around 60cm wide however the lower opening of the chute can be slightly wider than this as the angled sides of the chute will direct the trash stream towards the middle of the machine.
- The ability to adjust the sides of the chute or the lower opening to influence the windrow width may be of some advantage in adapting to varying trash levels. In very heavy trash loads a wider windrow is suffice but crops with less trash such as chickpeas may benefit from a narrower windrow to ensure a critical mass in the windrow for burning. However many chutes are not adjustable and work fine so this may be an undue complication.
- Ensure the chute does not unnecessarily restrict the airflow from the rear of the header as this could affect grain separation
- Obstructions: Modern harvesting rates and the extra trash feeding through the header when harvesting low mean the throughput of trash is enormous. Do not underestimate what catastrophic ramifications can occur and how quickly blockages form from the smallest obstruction in flow. Design chutes that minimise the use of bolts, brackets or sharp angles near the trash flow as these tend to be problematic and should be avoided. Also aim to keep the bottom of the chute open and avoid any horizontal or near horizontal ledges where trash will need to slide as this slows the materials exit and can build up very quickly.
- Ideally build a unit that is easy to remove, particularly if you don’t intend to windrow all paddocks.

A few photos are shown below.

Figure 4. Various windrow chutes fitted to headers
(Source: Bing Images, search term "Windrow Burning chutes" January 2014)

A number of videos are available concentrating on the design of chutes along with other tips on successful WB at www.weedsmart.org.au

At harvest

Hopefully by this time you have a clear plan of which paddocks are to be windrowed and the header chute has been prepared.

Driver training

It is important for header driver to understand what is trying to be achieved at harvest. That is to get the weeds seeds in the header front. For many years', drivers have been directed to get the maximum speed and efficiency out of headers and that often means taking minimal straw and harvesting high. Cutting low is a new concept and old habits can be hard to break. Harvesting low can bring in other considerations as well such as:

- **Cut low** and observe that you are getting the weed's seeds in the front. Adjustments to reel speed, height as well as the condition of the knife can be important particularly if weeds have begun to lodge.
- Blockages: The fitment of the chute on the rear of the header means that trash exits in a very small space. If a header comes to a stop suddenly in the paddock this space is quickly filled and the header can block from the rear forwards within seconds. Drivers need to be educated to swing out of the crop to let the residue clean out of the header unrestricted or in the least, reverse immediately to avoid costly downtime in unblocking the machine.

- Monitor grain losses. Extra straw is taken in when cutting low and this can increase the load on grain separation and if not addressed there is potential for increased grain losses. Modern headers are certainly capable of operating with much larger crops than common in Australian conditions so capacity is not the issue but adjustments may be required to the header setup and operation to cater for the increase in load.

  Operators should refer to the header manufactures instruction to identify and minimise harvest losses and maintain efficiency but below are a few key considerations:

  - The increase in throughput is in straw volume not chaff, so rotor or straw walker losses are more probable. Operators should concentrate on the rotor or drum setup to ensure grain is not carried over the back as rotor or straw walker losses. Even if the grain is separated from the stalk evidenced in the windrow, it can still be carried out in the large trash load. Rectification may involve different setups. Changing concave clearances or rotor/drum speeds or changing concaves to larger sizes to allow the grain to exit easily and quickly. Other options maybe available such as extended concaves or adjustments or modification to increase opportunity for grain to exit from the rotor.
  - Don’t over thrash the crop. This could increase the load on the sieves, unduly slow the machine down and the resultant windrows are chaffier and can be more prone to smouldering.
  - Slow down a bit?

- Cut low - getting the message?

  Despite these adjustments to machine setups there still may in some cases simply be no other option but to simply slow down to minimise losses.

  This is a common concern when considering WB however the perceived reduction is often worse than it really is. Foremost for many is the concept that the increased trash load taken into the front of the header has a huge drain on engine power which slows harvesting rates.

  However it should be remembered that for many, there will be no requirement to run the straw choppers and or spreaders. This will save on a significant power requirement that can be directed to the increased throughput.

  Another point to consider is that in a number of cases growers may already be harvesting at a height that captures a large percentage of weed seeds already. Take for example chickpeas, field peas, shorter or lower yielding wheat or barley crops or crops that have lodged. In many cases there will be little or no need to alter harvesting height simply the fitting of a chute on the rear of the header.

After harvest

For the most part a paddock harvested for windrow burning should be managed not too dissimilar to any other paddocks. As for any fallow, weeds should be controlled to both minimise moisture usage but also maximise N mineralisation and accumulation. Below are a few extra considerations for managing windrowed paddocks during the fallow.

- Delayed and staggered weed emergence: The thick layer of the stubble in the windrows can delay or hinder the emergence of weeds. The increase in groundcover can also hold moisture closer to the surface for longer supporting continued emergences resulting in stagged germinations of weeds. This condition may require the first fallow spray to be delayed to allow for the weeds to emerge from the windrow and a spray target to develop which is often only 1-2 days. However this condition seems only apparent for the first fallow spray as assumedly the windrow settles and increases density with rain often suppressing future germinations.

- Grazing of paddocks harvested for windrow burning can also have negative impacts on the effectiveness of WB. Foraging livestock will tend to seek out grain and weed seeds in the windrow, hence spreading the stubble and affecting the integrity of the windrow, resulting in lower and uneven burning temperatures and duration leading potentially to a poorer control.

Burning the rows

Burning the windrows is the most critical phase of the technique and arguably takes the most amount skill and experience. The key to getting this part right involves burning when the conditions are warm and mild enough to ensure the fire gets enough heat to sterilise the weed seeds but not too supportive of fire to see it escape from the windrows and burn the whole paddock, or worse still, the neighbour’s paddock.

The potential risk for fire escapes is influenced by four main conditions: temperature, humidity, wind speed and the curing of the fuel load. Striking the right balance of these conditions is a large part of successfully burning windrows. Many growers who have burnt many windrows in the past will be comfortable identifying the right balance through experience but less experienced growers may benefit from a tool that helps do this for them.

The McArthur fire danger index is one such tool that can do this. Developed by the CSIRO in the 1960’s it uses algorithms based on the four key characteristics listed above to produce a single number to estimate the fire risk. Originally developed and adapted to help manage and predict grass fires it is also useful to growers wishing to burn windrows safely.

The McArthur fire index is available from a number of sources but most useful to growers may be the “Pocket Fire NSW” App for iPhones.

Growers can use this App live in the paddock to help identify when conditions are most suitable for burning the windrows. Growers should aim for an index value between 5 and 15. An index value below 5 indicates conditions are too suppressive to result in a hot enough burn to completely burn the weed seeds. A value above 15 indicates conditions are too supportive of fire and the risk of the fire escaping possibly beyond acceptable levels.

A word of warning though is that wind speed can have a significant influence over the index value for any given situation. High wind speeds can often see the fire move too fast along the windrows often quickly burning the straw off the top of the windrow and leaving the chaff fraction containing the weeds seeds unburnt. It is suggested growers should place an upper limit on the acceptable wind speed for windrow burning of around 10km/hr to avoid disappointing results.

Green weeds in the windrow or along the edges can also be problematic as they reduce introduce moisture to the fuel load and can reduce the effectiveness of the fire. Growers should aim to keep weeds controlled ahead of burning periods.

Figure 5. A burnt windrow demonstrating unacceptable control in the background possibly due to less than ideal weather conditions at burning leading to lower temperatures, duration and incomplete burning of the chaff fraction containing the majority of weed's seeds.

The fire index will help serve as a good guide for growers to indicate when **might** be a good time to burn the windrows but there is nothing like actually giving it a go.

So provided growers have undertaken the other necessary precautions suggested below and conditions are indicated as OK by the fire index, actually lighting up a windrow may be the best test for ideal conditions. Growers can easily pick a typical windrow on the downside of the prevailing wind, use a garden rake to break the row say three meters apart and light one end of this section and observe how it burns. In many cases it may seem that the flames die down before the windrow is completely burnt to the ground but wait until there is no more smoke before making your final judgement as the fire may smoulder for some time whilst burning the chaff fraction on the underside of the windrow. If the burn is not achieving the desired result you may need to wait for more ideal conditions.

Before all this, growers need to prepare for burning taking the normal precautions for a stubble burn. There are the obvious considerations such as preparing firebreaks in case the fire does escape and making ready your firefighting equipment such as filling tanks and checking pumps.

If WB is a new technique in your district, warning neighbours of your intentions and filling them in on what you plan to do may avoid unnecessary panic or alarm. You may also require fire permits or permission to burn in some districts. Secure these once you have entered a period where you think you might burn and try not to stipulate one particular day as not all days are suitable. Seek permission for a longer period.

Lastly, when conditions are ideal, be prepared to act. Not every day is ideal to burn windrows and even the ones that are can change as the day gets later. Growers needs to take full advantage of suitable days when available.

A common misconception is that the entire length of the windrow needs to be lit this is wrong. You do not have to drive up and down each row to light them. Growers often light the windrows at points 200-300 meters apart by travelling perpendicular to the windrows. By lighting them at one point, the fire will burn along the windrow till that windrow ends or it meets the fire burning along the other way. How close you choose to light each row depends on you. If you have a large area to get over and you suspect weather condition will remain kind, light them further apart but if conditions are likely to decline or you want rows to burn out quickly, light them closer together.

Drip torches are an obvious choice for lighting the windrows but if large areas need to be lit an Accufire may be a better choice. An Accufire is a unit that can be mounted on the tray of a utility with an arm that mounts off the side that acts similar to a drip torch to light the windrows. The advantage of this system is that the lighting can be controlled from within the cab and the vehicle can travel up to 30km/hr to light the windrows. This allows for larger areas of windrows being lit in very little time.

Other considerations

Although WB has been shown to be effective for many growers, and despite the best advice here and from elsewhere, it doesn't always go right and WB is not without other side effects either.

The greatest opportunity for the failure of WB is not killing the weed seeds as a result of the burn not being hot enough. This can leave large populations of weeds where the windrows were. An alternate view would be that this is quarantining the problem weeds into a distinct zone and allowing the larger areas beyond the windrow to thrive with less weed burdens. A 60cm wide band of uncontrollable (resistant) weeds has to be better than a full paddock as shown in the photo below of unburnt windrows in a paddock sown to canola with no herbicide applied to date.

Figure 6. Concentrated, high populations of ryegrass in an unburnt windrow after paddock has been sown to canola without any pre-emergent herbicides. Burroway July 2013

In fact this very scenario has been adapted by a number of growers in Australia where the chaff fraction containing the weeds seeds is dropped in distinct areas such as tramlines and wheel tracks and growers are relying on this isolation only as a key control technique that is they are not burning them. This technique has been referred to as “windrow rotting” or “chaff lining”

In either case, not achieving a kill of the weeds seeds’, the subsequent crop should experience less competition through this quarantining and there is always the opportunity to get those seeds in a windrow next time and incinerate them then.

What about wet windrows? Well there has been plenty of experience with autumn rain ahead of burning windrows. Experience shows that 10-14 days dry weather is sufficient for the rows to dry out enough to achieve acceptable results while 3-4 days is enough to see the rows dry enough to allow the larger bulk of the windrows to be burnt to allow seeding without trouble (though with sub-optimal weed control????). Growers need to monitor predicted weather patterns and as discussed above, when conditions are ideal be prepared to act.

As with any control technique imposed on a weed population there is a risk that you will select for a characteristic that makes it resistant to that control and WB is no exception. Continued reliance on WB may select for more prostate weeds, weeds that shed seed early, quicker or even delayed maturities. As such WB or any control technique should not be relied on as the single or main control method but form part of an integrated approach to weed management.

For growers in the northern region that rely heavily on out-of-season rainfall and its conservation in the soil for crop profitable production, any action that could negatively affect this is of serious concern. The technique of WB which actively moves crop residues to the windrow and burns it rather than redistributing on the surface will have an impact on groundcover distribution. There are concerns that this could have serious ramifications to fallow efficiency and subsequent crop yields. GOA has established trials in 2013-2014 and again in 2014-2015 investigating this and preliminary results from the 2013-2014 trials have indicated a limited impact but further work is required to confirm this.

Whether or not there is an impact on fallow efficiency, the growers need to consider the control options available to them. If resistant weeds are failing to be controlled by other means, their suppressive effects on crops yields will easily exceed any reductions in fallow efficiency due to the effects of WB. Which is the lesser of the two evils?

Similarly this relocation and concentration of crop residues can affect nutrient availability and distribution. Large amounts of nutrient held in stubbles are transported and deposited in the windrow zones leaving the remaining area with lower levels of available nutrient.

WA growers have observed nutrient deficiencies, particularly potassium, outside the windrow zone and replacement fertiliser strategies come at some increase in costs compared to standard approaches.

This scenario is likely to be more acute in WA with their sandy soils with low inherent nutrition. Cropping soils of the eastern seaboard with higher clay contents generally have greater levels of nutrition particularly potassium, and as such may be buffered against these induced deficiencies. However with repeated use of WB some adjustment to fertiliser strategies may be required over time. One other strategy suggested is to alternate harvesting direction to avoid placing windrows in the same position each year to avoid compounding any effects. However this may not be possible in Control Traffic Farming systems using permanent tramlines.

In summary

Windrow burning has been proven to be effective in other Australian cropping regions on key weeds and there is no reason to doubt its effectiveness on those same weeds in other regions. But WB may not be effective in every paddock and on every weed species so planning where and when to use it is the first step to success.

To undertake WB, growers will need to make modifications to their header but these are simple and cheap to build and fit with flexible designs only needing to adhere to a few key principles. Header operators need to clear on what's to be achieved and remember don't stop dead.

Burning the windrows is the difficult thing and getting the weather right is the most important. Growers need to plan ahead, watch the forecast and be prepared to go when things are good.

There are some downsides to WB as with any control tool but growers need to weigh up their options and remember weed control has always had a cost. And finally WB is a terrific tool in the battle against herbicide resistance but it should be only one of many otherwise its effective lifespan may be limited.

Acknowledgements

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Chickpea and mungbean research to maximise yield in northern NSW

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Take home messages

- When sowing chickpea within the optimum sowing window (mid May – early June):
  - for yield potential ≥ 1.5 t/ha - sow at ≥ 30 plants/m^2,
  - for yield potential ≤ 1.5 t/ha - sow at ≥ 20 plants/m^2.
- When sowing chickpea very late (not recommended) consider sowing at the higher target plant density, to compensate for potentially poorer establishment.
- Mid-late May should be considered the optimum sowing window for chickpeas. A substantial yield penalty is likely to be incurred when sowing is delayed until mid-late June.
- Kabuli chickpea types can have equal yield potential to desi types if sown early, but greatly reduced yields if sowing is delayed.
- An optimum plant density of at least 30 plants/m^2 for mungbeans is recommended under irrigated conditions, with further research required to justify an increase to 35 or 40 plants/m^2.

Introduction

Chickpea (a winter-grown pulse crop) makes a significant contribution to the northern farming systems region as a key rotation crop for both winter and summer cereal production. Mungbean (a summer-grown pulse crop) is considered more of an “opportunity” crop in the northern region when adequate rainfall or irrigation conditions are available. Both pulse crops, as well as being viable (profitable) in their own right, contribute to nitrogen fixation, disease control, weed control and herbicide resistance management when used in cereal crop rotations.

The Northern Pulse Agronomy Initiative (NPAI) project was established in 2012 with the specific goal of achieving greater adoption, productivity and profitability of summer and winter pulse crops in the Northern Grains Region. A key output of this project is the development of improved agronomic management strategies to achieve seasonal yield potential and grain quality.

This paper provides an update on some of the recent research trials being conducted by NSW DPI in the Western Plains region for both a winter pulse crop (chickpea) and summer pulse crop (mungbean). The common theme of these trials is to investigate management aspects which maximise yield potential.

1. CHICKPEA – Optimum plant density targets to maximise yield

Current advice from both NSW DPI (Matthews *et al*, 2014) and Pulse Australia (Cumming & Jenkins, 2011) consistently recommend a target plant population of 20-30 plants/m^2 for the northern region of NSW. It is suggested that a population of 25 plants/m^2 will optimise yields in the northern region, with slightly higher or lower target populations (i.e. still within the range of 20-30 plants/m^2) allowing for establishment conditions at the time of sowing.

These recommendations have been endorsed through a series of variety x plant density factorial experiments conducted by NSW DPI across central and northern NSW since 2011, with previous results up to 2013 reported at the 2014 Updates (Verrell *et al*, 2014). This series of trials has been continued in 2014 to achieve greater cross-seasonal validity.

Methods

In 2014 five chickpea varieties – PBA BoundaryⒶ, PBA HatTrickⒶ, KyabraⒶ, CICA0912, and CICA1007 – were sown at six target densities of 5, 10, 15, 20, 30 and 45 plants/m^2. The variety treatment CICA0912 has been excluded from these results due to a seed supply issue. In this paper only the main effect of yield response to plant density will be reported.

The Coonamble site was sown on a grey vertosol soil on May 24 with adequate moisture conditions at sowing. Growing season rainfall in 2014 (162 mm) was below the long term average (LTA = 179 mm) with October only receiving 5 mm (LTA = 42 mm).

The Trangie site was sown on a red brown chromosol soil on May 28 into good moisture conditions at sowing. The crop received only 130 mm during the growing season, well below LTA (180 mm). September and October were very dry with falls of 9.8 mm and 2.6 mm respectively, compared to long term averages of 31.4 mm and 45.7 mm respectively.

In addition to lower than average rainfall, potential yield at the two sites was reduced due to both flower abortion caused by frosts and cold periods during flowering, and pod abortion due to moisture stress/terminal drought during grain fill.

Results

The response of grain yield to increased target plant density at Coonamble and Trangie sites are shown in Figures 1 and 2 respectively. Actual plant densities achieved were slightly below target at Coonamble site (average 82%) and slightly above target at Trangie site (average 111%) based on plant count data (not included here).

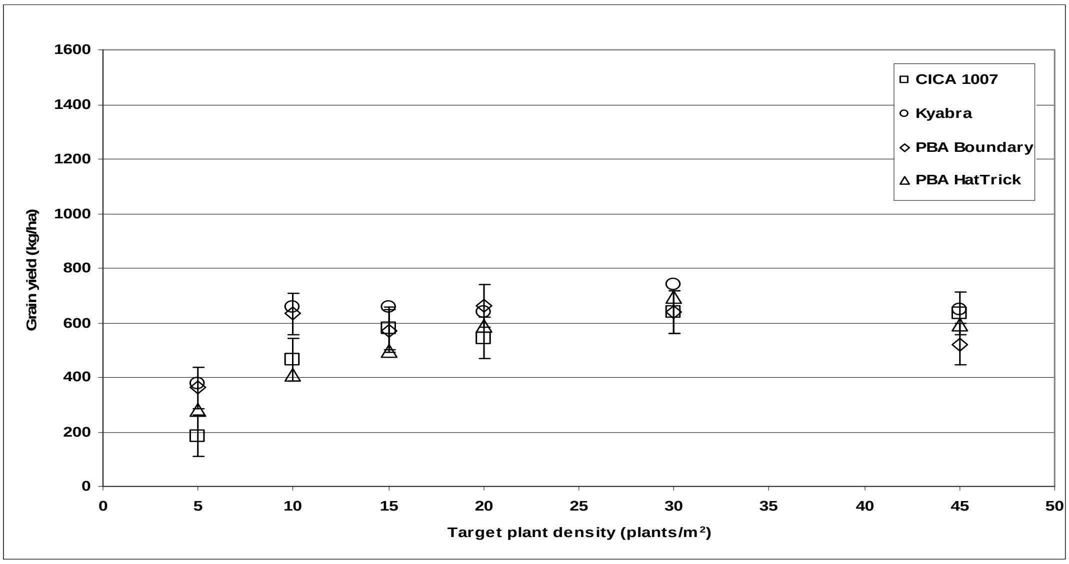

Figure 1. The effect of plant density on chickpea grain yield at Coonamble, 2014 (s.e. 77.21 kg/ha)

At the Coonamble site the response of grain yield to plant density was significant from 5 to 15 plants/m^2, resulting in a 90% increase in yield from 301 kg/ha to 576 kg/ha (averaged for all varieties). Response at higher plant density was flat (i.e. not significant) from 15 to 45 plants/m^2. The maximum plot yield achieved at Coonamble site in 2014 was 740 kg/ha. This trend is consistent with previously reported 2012 and 2013 Coonamble results (yield ≤ 1.5 t/ha), whilst in 2011 (yield ≤ 3.5 t/ha) there was a significant increase in yield at higher plant density up to 45 plants/m^2 (Verrell *et al*, 2014).

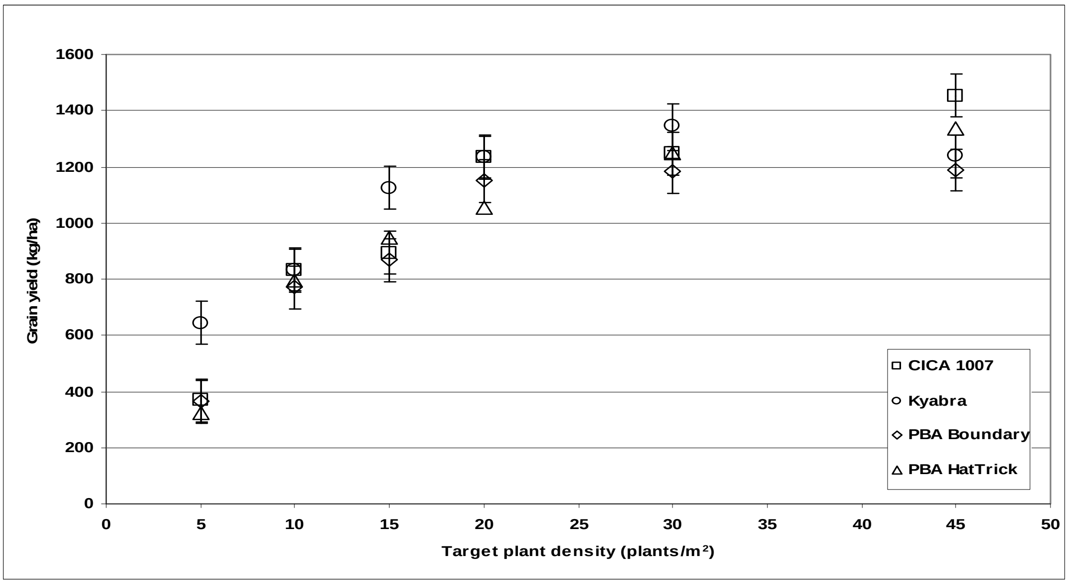

Figure 2. The effect of plant density on chickpea grain yield at Trangie, 2014 (s.e. 76.238 kg/ha)

At the Trangie site the response of grain yield to plant density was significant from 5 to 30 plants/m^2, resulting in a 195% increase in yield from 425 kg/ha to 1256 kg/ha (averaged for all varieties). There was only a slight response (i.e. not significant) from 30 to 45 plants/m^2. The maximum plot yield achieved at Trangie site in 2014 was 1454 kg/ha. This trend is also consistent with previously reported 2013 Trangie results where optimum yield was achieved at around 30 plants/m^2 (Verrell *et al*, 2014)

Conclusion – Chickpea plant density

These two trials have confirmed the relationship between rainfall-limited yield potential, optimum plant density and yield response as follows:

- When sowing within the optimum sowing window (mid May – early June)

  for yield potential ≥ 1.5 t/ha - sow at ≥ 30 plants/m^2

  for yield potential ≤ 1.5 t/ha - sow at ≥ 20 plants/m^2
- When sowing very late consider sowing at the higher target plant density

2. CHICKPEA – Optimum sowing window to maximise yield

Choosing the optimum sowing time for chickpeas is a compromise between maximising yield potential and minimising disease levels. Earlier sowing can increase the risk of Ascochyta and Botrytis grey mould (BGM) disease, lodging, and soil moisture deficit during grain fill. Later sowing can attract increased heliothis pressure and lead to harvesting difficulties, but may reduce exposure to Ascochyta and Phytophthora infection events and lessen the risk of BGM (Matthews *et al*, 2014).

Chickpea time of sowing trials were conducted by NSW DPI at Trangie in 2010, 2011 and 2012, to evaluate the impact of sowing date on phenology and yield of current and potential release cultivars. The 2010 trial succumbed to in-crop waterlogging and wet weather at harvest and was not harvested. The results of the 2011 and 2012 trials were reported at the 2013 Updates (Jenkins and Brill, 2013). For currently grown chickpea varieties with a mid-season (Jimbour type) maturity such as PBA Boundary⚲ and PBA HatTrick⚲, optimum yields were achieved from mid May to early June sowing. Planting chickpeas in mid-late June produced significantly lower yields in both the 2011 (wet year) and 2012 (dry year) trials at Trangie.

A much simpler trial was planted at Trangie in 2014 which demonstrates the comparative impact of time of sowing on desi vs. kabuli varieties of chickpea.

Methods

In 2014 fifteen desi types and five kabuli types of chickpea varieties were planted at two sowing dates. Time-of-sowing 1 (TOS 1) was planted on May 28 under the same conditions described above for the Trangie chickpea x plant density trial, whilst time-of-sowing 2 (TOS 2) was planted three weeks later on June 19. TOS 2 was sown into marginal seed-bed conditions, and received no significant follow-up rainfall until mid-July. In this paper only the main effect of yield response based on chickpea type (i.e. desi vs. kabuli) to time of sowing will be reported.

Results

The comparative grain yield response of desi and kabuli types of chickpea to time of sowing at Trangie site is shown in Figure 3. It should be noted that establishment was reduced by the delayed sowing time, with all varieties in TOS 1 achieving an average plant density of 32 plants/m^2, compared to only 25 plants/m^2 for TOS 2, a reduction of 22% (based on plant count data, not included here). Sowing rates were calibrated for seed size of each individual variety but otherwise unchanged between sowing dates (target plant density 35 plants/m^2).

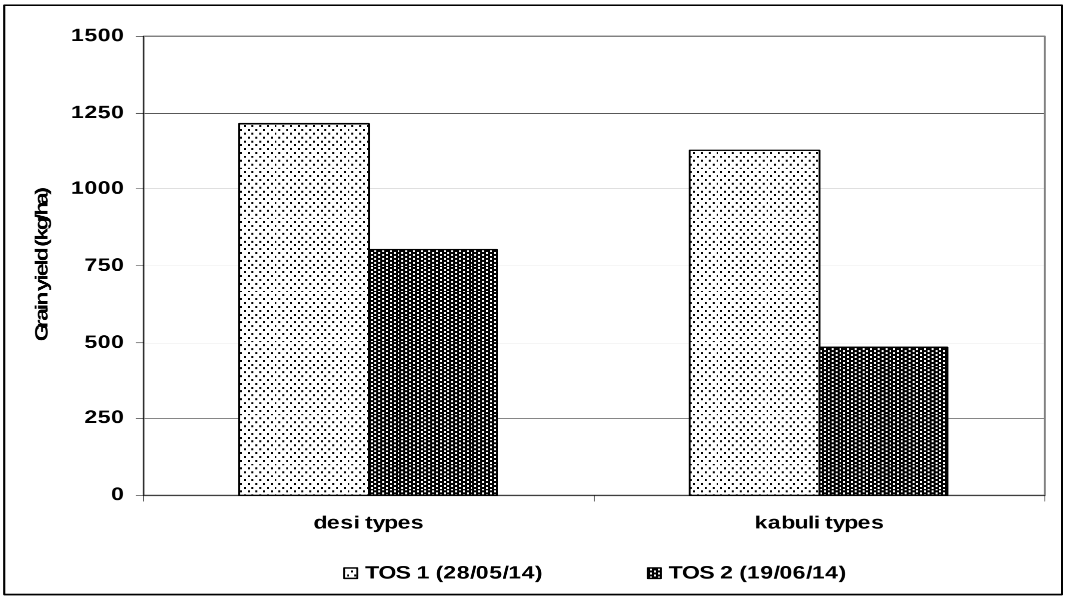

Figure 3. The effect of time of sowing on desi and kabuli chickpea grain yield at Trangie, 2014 (data not analysed at time of publication)

The graph shows the potential grain yield of current desi vs. kabuli types to be similar when sown at what is considered to be an optimum sowing time for chickpea (i.e. mid-late May). For TOS 1, averaged across all varieties within each group, desi types yielded an average of 1216 kg/ha and kabuli types yielded only 7.5% less at an average of 1125 kg/ha (TOS 1 mean 1193 kg/ha).

The three week delay in sowing until mid June resulted in reduced grain yield, with the kabuli types appearing to be affected to a greater degree than desi types. For TOS 2, averaged across all varieties within each group, desi types yielded an average of 804 kg/ha and kabuli types yielded an average of 486 kg/ha (TOS 2 mean 724 kg/ha). This yield loss equated to 34% for desi types, 57% for kabuli types, and an overall grain yield reduction of just on 40% between TOS 1 and TOS 2.

Contributing factors to the decline in yield between TOS 1 and TOS 2 could have included more marginal conditions at sowing, resulting in reduced establishment, and delayed phenology development, resulting in an inability to compensate for adverse environmental conditions during the flowering period (i.e. frost events, cold periods, and greater exposure at critical development stages to moisture stress).

Conclusion – Chickpea time of sowing

This trial has confirmed earlier research suggesting that mid-late May should be considered the optimum sowing window for chickpeas in this region. A substantial yield penalty is likely to be incurred when sowing is delayed until mid-late June. Kabuli types will have equal yield potential to desi types if sown early, but greatly reduced yields if sowing is delayed. This trial also confirms the conclusion above that a higher sowing rate should be considered if late sowing cannot be avoided, to compensate for potentially poorer establishment.

3. MUNGBEAN – Optimum plant density targets to maximise yield

Relative to other crop species, mungbean is a very short duration crop (90 – 120 days). Because there is little time for the crop to compensate for any adverse factors within that timeframe, establishing a uniform plant density is critical to achieve uniform plant maturity across the paddock. NSW DPI recommends an established density of 20 – 30 plants/m^2 for dryland crops and 30 – 40 plants/m^2 under irrigation situations (Moore *et al*, 2014).

Whilst these recommendations are generally applicable to the northern grains region, there has been no recent research in northern NSW to validate these guidelines for the newer varieties of mungbeans currently being grown. Under the NPAI project summer pulse trials commenced in the 2013-14 summer crop season with a simple trial to investigate the impact of plant density on grain yield of mungbean; a row spacing component has been added to this trial for the current 2014-15 season.

Methods

In 2013-14 three mungbean varieties – Berken, Crystal⚖, and Jade_AU⚖ – were planted at four target densities of 20, 30, 40 and 50 plants/m^2. Sowing rates were adjusted for each variety and target density based on individual seed size and germination test results. In this paper only the main effect of yield response to plant density will be reported.

The Trangie site was sown on a grey vertosol soil on 17 Dec into good moisture conditions at sowing. The trial site was irrigated and received a total of 216 mm rain and 5.5 ML/ha in seven irrigation events (including pre-water) during the growing season. Insect pressure was relatively light with three insecticide applications through the season (helicoverpa and brown vegetable bug). The trial was desiccated then harvested on 17 April (121 days post-sowing).

Results

Plant count data (not included here) showed a much higher establishment percentage than was anticipated, with an overall trial mean of 147%. Sowing rates for each variety were based on individual seed size and an allowance of 80% to account for germination and field conditions. Actual plant densities achieved were 31, 46, 57 and 70 plants/m^2 for the target densities of 20, 30, 40 and 50 plants/m^2 respectively.

Grain yield response to increasing plant density is shown in Figure 4. Note this data has not been statistically analysed at time of publication. However averaged across all varieties, there appears to be little to no response in mungbean grain yield as plant density is increased, under irrigation conditions. The older variety Berken showed a very flat (i.e. nil) response. The two newer varieties, Crystal⚖ and its more recent replacement Jade_AU⚖, suggest a slight response with an optimum target density between 30 and 40 plants/m^2. Mean grain yield for this trial was 2.13 t/ha (averaged across all varieties and treatments). For comparison, the companion mungbean variety trial planted at the same time was sown using a target density of 35 plants/m^2 and achieved a mean grain yield of 1.73 t/ha (data not included in this report).

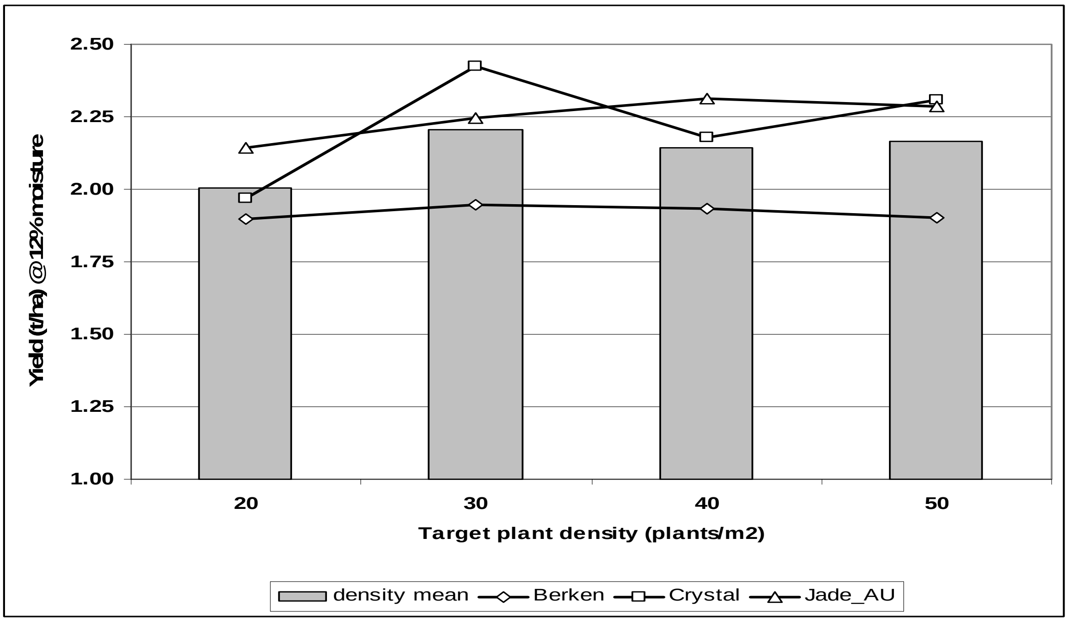

Figure 4. The effect of plant density on mungbean grain yield at Trangie, 2014 (data not analysed at time of publication)

Harvested seed size appeared to show no response to increasing plant density in this trial (data not shown). The older Berken variety had the smallest seed size of the three varieties (average 6.53 g/100 seeds); whilst Crystal⚪ and Jade_AU⚪ were slightly larger at 7.06 and 7.17 g/100 seeds respectively.

Conclusion – Mungbean plant density

This trial has confirmed an optimum plant density of at least 30 plants/m^2 for mungbeans under irrigated conditions, but was inconclusive as to whether there is any significant yield response from targeting a higher rate of 40 plants/m^2. The trial has been replanted in the 2014-15 season to further investigate both plant density and row spacing configurations on mungbean grain yield.

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Chickpea ascochyta – is the pathogen changing and what are the implications for management?

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Take home message

Ascochyta blight occurred in more chickpea crops (62 of 332 crop inspections) in 2014 than in 2012 and 2013 combined. Most infected crops were PBA HatTrick⚲ but PBA HatTrick⚲ was also the most commonly grown variety.

Inoculum for the 2014 Ascochyta infections resulted from dry summer (2012/2013 and 2013/14) conditions contributing to slow stubble breakdown and infection of volunteers.

Work to determine if the unexpected number of 2014 infections, especially on PBA HatTrick⚲, is related to the changes in the Ascochyta fungus has started. Initial results show that the population varies both in ability to cause disease (pathogenicity) and time to develop fruiting bodies (latent period).

Localities where Ascochyta was found on any variety in 2014 are considered high risk for 2015 crops and growers are advised to apply a preventative fungicide before the first post-emergent rain event to all varieties with less resistance than PBA HatTrick⚲, PBA HatTrick⚲ will also need to be sprayed.

The 2014 GRDC Northern Region chickpea season

Although all parts of north central NSW, northern NSW and southern QLD experienced a very wet March, the 2014 winter crop season in the GRDC Northern region was a mixed bag depending on where you were. Overall, southern areas (north central NSW) were wetter than the northern ones (northern NSW/southern QLD), especially early in the season with above average rain in June and July. However, from about mid-August onwards things started to get tough, with rainfall well below average throughout the region; some centres recording single digit falls in September and/or October. In those areas, many chickpea crops were harvested before the end of October. So how dry was it?

- At Trangie, from June to November, 137 mm fell on 16 days with 6 days >1.0mm, compared with a long-term average of 225 mm on 41 days (28 days >1.0mm).
- At Dubbo, for the same period, 167 mm fell on 37 days with 20 days >1.0mm, compared with a long-term average of 277 mm on 46 days (32 days >1.0mm).
- Moree had 129 mm on 20 days with 12 days >1.0mm, compared with a long-term average of 258 mm on 36 days (26 days >1.0mm).
- Goondiwindi had 101 mm on 21 days with 15 days >1.0mm, compared with a long-term average of 254 mm on 35 days (26 days >1.0mm).

The season also had some unusual temperature events. June was milder than normal which encouraged rapid growth and many crops sown mid-May had 10-15 nodes by the end of June. In most areas, July and August had considerable extremes in daily temperatures with warm days and cold nights and some severe frosts. The cool weather continued with frosts and low temperatures common well into spring. The average daily temperature in all districts fluctuated above and below 15°C until several times from early September to mid-October and did not stay above 15°C until the 3rd week in October. These milder conditions led to intermittent flower and pod abortion from August to mid-October, which, coupled with the lack of decent spring rain, resulted in missing pods, ghost pods and pods with single seed. Many growers were disappointed in that crops looked better than they were. In most areas, yields were restricted to 800 to 1500kg/ha; however, in more favourable areas yields reached 2t/ha and higher. Hail storms on 25 Oct and 5 Nov caused some losses in a strip from east of Gilgandra to west of Armatree.

These seasonal conditions did not favour diseases and across the region they were uncommon and generally had no or little impact on yield. Most chickpea crops in northern NSW west of the Newell highway did not receive a single fungicide spray. However, two diseases did occur in 2014 that warrant discussion because they highlight some basic elements of epidemiology. One disease also raises the question of "has the pathogen changed ie has resistance broken down"?

There were two noteworthy cases of Phytophthora root rot (PRR) both illustrating the key drivers of PRR. At Gilgandra, PBA HatTrick$^{\phi}$ had been direct drilled with a tyne planter on 19 May into a paddock with a history of PRR (although no chickpeas had been grown in the paddock for 10 years). From the end of May till 14 Jun, there were 6 rain events totalling 60mm. When inspected on 25 Jun, the planter furrows in low spots had 5-10mm water. Seedlings in these spots were chlorotic, wilting and dying; laboratory work confirmed PRR. The second crop, at North Star, had been sown into a paddock that had never had chickpeas but prior to wheat in 2012 and 2013, had been grass pasture with clover and medic. On 23 May, it was sown 25mm deep with a tyne and levelling bar; 13mm rain fell that night. When first inspected on 8 July, there was no sign of PRR; but when re-inspected on 1 September, there were several foci of chlorotic, wilting PBA HatTrick$^{\phi}$ plants (early flowering) but only where water had sat in the contours. Following a call from the concerned grower, a 3rd inspection was done on 12 October (crop turning). Scattered throughout most of the paddock were small circular patches of 2 – 10 dead or dying plants with black rotted roots. Laboratory work confirmed PRR. The problem was absent from the lighter areas of the paddock and the grower noted that medics were far less prevalent in those areas.

By far the most striking chickpea disease in the region in 2014 was Ascochyta.

Ascochyta in 2014 chickpea crops

Ascochyta Blight (AB) was first found in the GRDC Northern Region at North Star on 2 July as a small (2-5 plants) focus in a crop of Flipper$^{\phi}$. By the end of September, AB had been detected in 62 of 332 crop inspections (18.7%), considerably more than was found in 2013 (5/280 crops, 1.8%) and 2012 (11/213 crops, 5.2%). Most of the 2014 cases were in NSW but four were confirmed in QLD, including one crop of PBA Boundary$^{\phi}$ at Toobeah, west of Goondiwindi. The NSW cases covered an area from Yallaroi in the east, west to Mungindi, Nevertire and Tullamore and south to Forbes.

Four cases of AB were found in July, with the majority detected in August (25) or September (33) with none in October.

Two cases involved Flipper$^{\phi}$, two PBA Boundary$^{\phi}$, one PBA Slasher$^{\phi}$, one Yorker$^{\phi}$ (that the grower believed was PBA HatTrick$^{\phi}$) and the rest were PBA HatTrick$^{\phi}$. This distribution of cases by variety reflects the fact that in 2014, PBA HatTrick$^{\phi}$ was by far the predominant variety grown in north central NSW, northern NSW and southern QLD.

Infected crops had typical symptoms of AB including ghosting leaf lesions, mature leaf lesions and stem lesions. In most cases, the disease was limited to isolated areas in the paddock but in several crops the infection was widespread with foci being detected every 10-30 seconds. In these crops, stem breakage was common. In spite of the incidence of AB infection and severity of symptoms, all growers were able to manage the disease with judicious use of chlorothalonil fungicides (up to four applications in the worst cases), further, all believed the disease had little if any impact on yield although it did impact on production costs.

Why was there more Ascochyta in 2014 than in the previous two seasons?

Although total winter crop rainfall was well below average across the region, June and July were above average in southern parts (57.4mm & 34mm respectively at Trangie; 57.6mm and 55.6mm at Dubbo). At Moree and Goondiwindi, Jun/Jul rain was 23.8/5.0mm and 29.2/15.4mm, respectively. The AB fungus requires the impact energy of raindrops to disperse its conidia so it has to rain for the disease to establish ie dews alone will not produce the initial infection. However, the pathogen only needs 3-6 hours leaf wetness to infect; a few mm of rain falling late on a winter's day or at night will satisfy that requirement. Although Moree Airport only recorded 23.8/5mm in Jun/Jul, the AWS at Kindee (north east of Moree) recorded 44.0/11.4mm for the same period with 5/2 days >1.0mm respectively. Kindee is only a few km from a local epidemic of AB in several PBA HatTrick$^{\phi}$ crops. That the disease did occur over such a broad geographical is evidence that sufficient rain fell to initiate and spread infections. As well as favourable weather conditions, another explanation for the amount of AB in 2014 is varietal impurity ie not every plant in a paddock of PBA HatTrick$^{\phi}$ was actually a PBA HatTrick$^{\phi}$ plant. Varietal purity is a concern in the GRDC Northern Region and the presence of plants of susceptible varieties in a crop of PBA HatTrick$^{\phi}$ would increase disease pressure on bona fide PBA HatTrick$^{\phi}$ plants.

Where did the inoculum come from?

The AB pathogen, *Phoma rabiei* (previously called *Ascochyta rabiei*) survives on volunteer chickpeas, on chickpea residue and on seed. Volunteers with AB were reported in fallows and nearby wheat crops. We tested some of the seed used to plant the crops in the above-mention local epidemic. Five thousand seeds (untreated) were surface sterilised and plated to detect any seed borne infections – none were found. This does not exclude seed as a source of primary inoculum, but together with the absence of any lesions on pods of 2012 and 2013 crops, presents a robust case against seed as the main source of inoculum for the 2014 infections.

We believe the main source of inoculum was infected chickpea residue from 2012 and 2013 crops. We propose the dry summers of 2012/13 & 2013/14 slowed residue breakdown both in situ and in the following years chickpea paddocks and that this provided inoculum for summer volunteers and the 2014 crop.

Has the Ascochyta pathogen changed?

The short answer is we don't yet know. Why? Because we have limited data on pathogenic variability in the pathogen population. However, as a population of living individuals (isolates), we should expect it to change. The little research that has been done shows that there are differences in pathogenicity among isolates. Table 1 classifies 35 isolates of *Phoma rabiei* collected from northern NSW chickpea crops in 2013. Isolates were rated low, medium or high based on their ability to cause disease on ICC3996 (R), Genesis™ 090 (R) and PBA HatTrick$^{\phi}$ (MR). We conclude from Table 1 that none of the isolates caused severe disease on the two resistant genotypes and that most did likewise on PBA HatTrick$^{\phi}$. Three caused severe, and three caused moderate, disease on PBA HatTrick$^{\phi}$. This establishes that the pathogen varies in pathogenicity.

Table 1. Pathogenicity ranking of 35 isolates of *Phoma rabiei* collected in 2013 (location and host shown) on three chickpea genotypes, ICC3996, Genesis™ 090 and PBA HatTrick⁽ᶦ⁾

Location	Variety	ICC3996	Genesis™ 090	PBA HatTrick⁽ᶦ⁾	Overall Pathogenic Rank
North Star	Flipper⁽ᶦ⁾	Low	Low	Low	Low
North Star	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	High	High
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	High	High
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Medium	Medium
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Medium	Medium
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	High	High
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Medium	Medium
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Tooraweenah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	High	High
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low
Garah	PBA HatTrick⁽ᶦ⁾	Low	Low	Low	Low

Another way of assessing pathogenic variability in the AB pathogen populations is to determine the latent period for individual isolates. The latent period is the time from infection to the development of pycnidia, the small dark fruiting bodies that develop in the leaf and stem lesions. Six isolates representing a sub-set of the pathogen population in Eastern Australia were evaluated in a growth cabinet (20°C/15°C 12h day/12h night) on four chickpea genotypes ICC3996 (rated R, coded ICC), Genesis™ 090 (rated R, coded GEN), PBA HatTrick⁽ᶦ⁾ (rated MR, coded HAT) and Kyabra⁽ᶦ⁾ (rated S, coded KYB). There were eight replicates (pots) for each of the 24 genotype by isolate combinations. The latent period was estimated by survival analysis with the status of a pot being whether pycnidia had or had not developed. For each pot, the data is the latent period or the day of last observation if pycnidia had not developed. Details of the isolates are:

- T12437 – 2010, Darling Downs, QLD, highly pathogenic on PBA HatTrick⁽ᵈ⁾ and ICC3996, moderate on Genesis™ 090 (glasshouse)
- 10TEM005 – 2010, Temora, NSW, highly pathogenic on PBA HatTrick⁽ᵈ⁾ and ICC3996, moderate on Genesis™ 090 (glasshouse)
- 13MUR002 – 2013, Murtoa, VIC, highly pathogenic on Genesis™ 090 (field and glasshouse)
- 13DON002 – 2013, Donald, VIC, highly pathogenic on Genesis™ 090 (field and glasshouse)
- TR6415 – 2014, Yallaroi, NSW, highly pathogenic on PBA HatTrick⁽ᵈ⁾ (field)
- 10MEL001– 2010, Melton, SA, extremely low pathogenicity

Latent Period (LP) varied with isolate and genotype (Table 2). All isolates had the shortest LP on the most susceptible entry, KYB and the longest LP on the most resistant entry, ICC. The isolate from Yallaroi (TR6415) had the shortest LPs on all genotypes and we interpret this as meaning that isolate was the most aggressive in the experiment. This LP experiment complements the pathogenicity work and confirms variability does exist in the pathogen population. However, it does not prove that it has changed in response to the widespread cultivation of PBA HatTrick⁽ᵈ⁾

Table 2. Mean Latent period (days) of six P. rabiei isolates on six isolates of P. rabiei on four chickpea genotypes, ICC3996 (ICC), Genesis™ 090 (GEN), PBA HatTrick⁽ᵈ⁾ (HAT) and Kyabra⁽ᵈ⁾ (KYB).

Genotype	Isolate	Latent Period	SE (mean)
GEN	T12437	7.13	0.117
HAT	T12437	6.75	0.153
ICC	T12437	7.75	0.153
KYB	T12437	6	0
GEN	10TEM005	7.25	0.153
HAT	10TEM005	7	0
ICC	10TEM005	7.88	0.117
KYB	10TEM005	6	0
GEN	13MUR002	7.38	0.303
HAT	13MUR002	6.88	0.212
ICC	13MUR002	8	0
KYB	13MUR002	6	0
GEN	13DON002	6.13	0.117
HAT	13DON002	6.38	0.171
ICC	13DON002	7.25	0.153
KYB	13DON002	6	0
GEN	TR6415	6	0
HAT	TR6415	6	0
ICC	TR6415	7.13	0.117
KYB	TR6415	6	0
GEN	10MEL001	7	0.25
HAT	10MEL001	6.88	0.117
ICC	10MEL001	7.88	0.117
KYB	10MEL001	6	0

Management of Ascochyta in 2015 chickpea crops

The following strategy should reduce losses from Ascochyta in 2015:

- Spray all varieties with less Ascochyta resistance than PBA HatTrick with a registered Ascochyta fungicide prior to the first rain event after crop emergence, three weeks after emergence, or at the 3 branch stage of crop development, whichever occurs first.
- For localities where Ascochyta WAS found on any variety in 2014 inoculum will be present in 2015 and the Ascochyta risk is high. Apply a registered Ascochyta fungicide prior to the first rain event after crop emergence to all varieties with less resistance than PBA HatTrick, PBA HatTrick will also need to be sprayed. Monitor the crop 2 weeks after rain and if Ascochyta is detected, consider a second fungicide spray.
- Localities where Ascochyta was NOT found in 2014 are considered low risk. PBA HatTrick or PBA Boundary and most Genesis™ varieties should not require their first Ascochyta spray until the disease is detected. Monitor these crops 2-3 weeks after each rain event from emergence onwards and spray if Ascochyta is detected in the crop or is found in the district on any variety.
- Ground application of fungicides is preferred. Select a nozzle such as a DG TwinJet® or Turbo TwinJet® that will produce no smaller than medium droplets (ASAE) and deliver the equivalent of 80–100 litres water/hectare at the desired speed.
- Where aerial application is the only option (e.g. wet weather delays) ensure the aircraft is set up properly and that contractors have had their spray patterns tested.

Further information

Further information on chickpea disease management can be found at the Pulse Australia website www.pulseaus.com.au and in the NSW DPI 2015 Winter Crop Variety Sowing Guide eg:

http://www.pulseaus.com.au/pdf/Chickpea%20Ascochyta%20Blight%20Management.pdf

http://www.pulseaus.com.au/pdf/2011%20Chickpea%20Disease%20Management%20Considerations.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Botrytis%20Grey%20Mould%20Management.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Integrated%20Disease%20Management.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Phytophthor%20Root%20Rot%20Management.pdf

http://www.pulseaus.com.au/pdf/Virus%20Contol%20in%20Chickpea.pdf

http://www.pulseaus.com.au/pdf/Pulse%20Seed%20treatments%20&%20Foliar%20Fungicides.pdf

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Chickpea Ascochyta – evidence that varieties do differ in susceptibility of pods

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Key words

chickpea, Ascochyta, management

GRDC code

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Take home message

- The susceptibility of pods to Ascochyta Blight is important as infection can cause pod abortion, blemish or kill seed, infected seed is also an inoculum source
- Field trial results indicate that the varietal resistance of chickpea pods are similar to that of vegetative tissue

Background

Understanding the susceptibility of chickpea pod tissue to Ascochyta Blight (caused by *Phoma rabiei* formerly known as *Ascochyta rabiei*) is important. Because if pods get infected early in their development they will abort; if fully developed pods get infected near the peduncle (as many do because the calyx holds water), they will abort; pods with developing seeds will either abort, or the seed becomes infected and is killed or the seed becomes infected, but remains viable and is a potential source of inoculum to initiate an epidemic.

Current Australian chickpea varieties and advanced breeding lines differ in susceptibility of their vegetative plant tissues to Ascochyta Blight (see paper on VMP14 trial in these proceedings). However, the chickpea industry believes that pods of all varieties are equally susceptible to Ascochyta (see http://www.grdc.com.au/GRDC-FS-ChickpeaDiseaseManagement). The 2011 Tamworth chickpea Ascochyta management trial, VMP11 suggested that may not be the case - anecdotal evidence indicated varieties with higher levels of resistance to Ascochyta eg Genesis™ 425 had less disease on their pods. For the past three seasons we have conducted trials at Tamworth designed specifically to capture data on susceptibility of pods of different chickpea genotypes to Ascochyta. Each season we protected the plants with fungicides until 50% podding, then waited for a rain event to inoculate the trials but no rain came. However, the 2014 Tamworth chickpea Ascochyta yield loss trial, VMP14, which was inoculated before flowering, provided an opportunity to collect data on susceptibility of pods of ten genotypes consisting of released varieties and advanced breeding lines.

Methods

Details of VMP14, including disease ratings of the varieties and breeding lines, are reported elsewhere in these proceedings. The trial was inoculated on 15 Jul and re-inoculated on 16 Aug using a new isolate collected from HatTrick⁽ᴰ⁾ at Yallaroi on 24 July. By the end of August, Ascochyta was well established throughout the trial, especially in the unprotected Nil plots (no fungicides). Podding commenced in the 2nd week of September. Eight mm rain fell on 24 Sep followed by 10mm on 25 Sep; 16.4mm fell on 13 Oct with 0.6mm on 14 Oct. On 29 October, 5-6 plants were collected from the outer 2 rows on each side of the 4m wide x 10m long plots. The pods were stripped from each plant, discarding the youngest two pods on each branch (these formed after the last rain event and could not have infected by Ascochyta). The pods were sorted into four classes based on their Ascochyta status: Clean = no Ascochyta lesions; 1 lesion = pods with a single lesion; 2-5 lesions and >5 lesions. A lesion was not called Ascochyta unless pycnidia could be seen either with the naked eye or under a low power dissecting microscope. For each variety the number of pods falling into each of the 4 Aschochyta classes was analysed using ordinal regression. The model estimates (+/- SE) the 3 cut points between the 4 classes and gives a coefficient for each variety.

Results

We acknowledge that this Ascochyta pod data could be confounded, as the plots (JIM and KYB) with the most infected pods and the greater number of lesions were also those that had the highest levels of Ascochyta infection in the vegetative stage. However, we are confident there was sufficient inoculum pressure in the trial. In particular during the two rain events, all pods in the trial would have been exposed to the same aerosol of conidia (40 unsprayed Nil plots in the trial with a combined area of 1600 m^2 and an estimated 48,000 infected plants, all with leaf and stem lesions bearing pycnidia). The 2015 trial will hopefully clarify the potential issue of susceptible variety effects on pod infection.

There were large differences in pod infection among the genotypes. Only about 0.3 (30%) of Jimbour and Kybara⁽ᴾ⁾ pods were clean (no disease), whereas about 96-99% of CICA1007, CICA0912, and Genesis™ 425 pods had no Ascochyta (Table 1). Not only did Jimbour and Kyabra⁽ᴾ⁾ have a greater proportion of Ascochyta infected pods, but these pods were more severely diseased with most of the infected pods having 2-5 or more than 5 Ascochyta lesions (Table 1).

Analysis showed that the varieties can be put into 4 groups with no differences between varieties within a group but significant differences between varieties in different groups. The four groups from least to most susceptible were (C1007,C0912,G425), (BOU,HAT,KAL,MON), (C1211) and (JIM,KYB) (Fig. 1).

Table 1. Percentages of pods in each of four Ascochyta categories for ten genotypes

Genotype	%Clean	%1 Lesion	%2-5 Lesions	%>5 Lesions
C0912	98.5	1.0	0.3	0.3
C1007	97.2	1.5	1.0	0.3
G425	96.8	2.5	0.3	0.5
KAL	86.7	7.5	5.5	0.3
HAT	86.2	9.3	4.0	0.5
MON	86.2	7.8	3.3	2.8
BOU	84.3	5.5	6.3	4.0
C1211	67.2	13.8	14.5	4.5
KYB	33.8	15.5	30.5	20.3
JIM	28.6	21.8	31.3	18.4

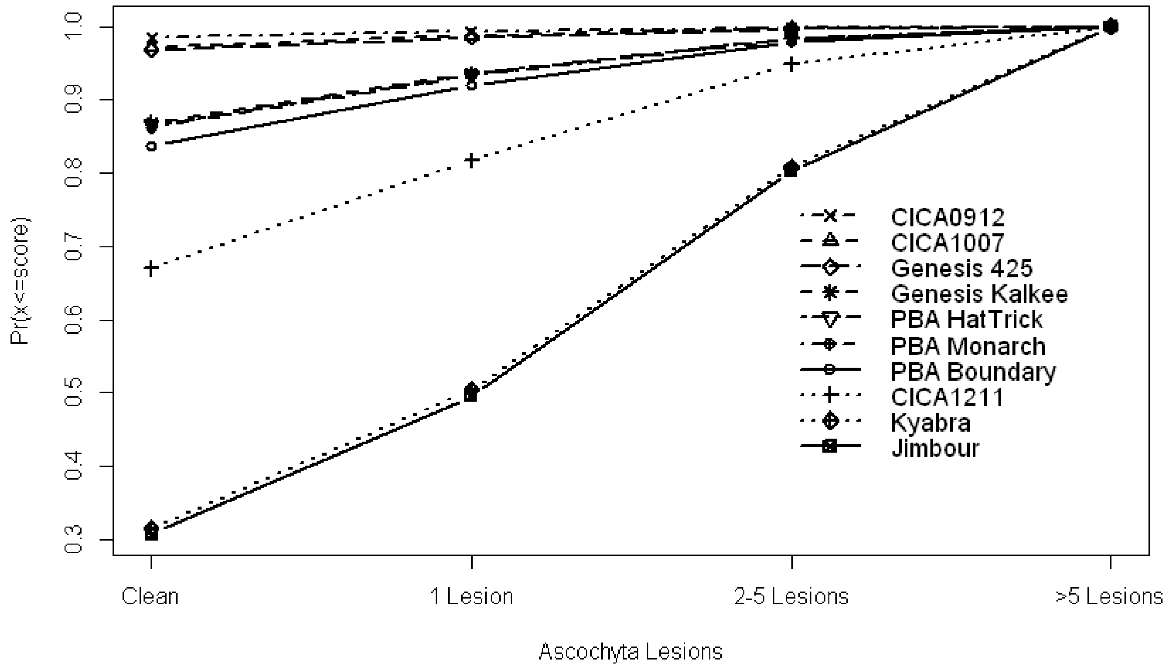

Figure 1. Predicted cumulative proportions of pods for each of four categories of Ascochyta lesions for ten chickpea genotypes in VMP14 trial

Key pod infection findings of VMP14 were:

- Genotypes differed in the number of Ascochyta infected pods.
- Genotypes differed in the severity of Ascochyta on infected pods.
- The ten genotypes fell into four significantly distinct groups in the four pod disease categories with (C1007, C0912, G425) > (BOU, HAT, KAL, MON) > C1211 > (JIM, KYB)
- This grouping agrees closely with current Ascochyta ratings for vegetative tissues

Further information

Further information on chickpea disease management can be found at the Pulse Australia website www.pulseaus.com.au and in the NSW DPI 2015 Winter Crop Variety Sowing Guide eg:

http://www.pulseaus.com.au/pdf/Chickpea%20Ascochyta%20Blight%20Management.pdf

http://www.pulseaus.com.au/pdf/2011%20Chickpea%20Disease%20Management%20Considerations.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Botrytis%20Grey%20Mould%20Management.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Integrated%20Disease%20Management.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Phytophthora%20Root%20Rot%20Management.pdf

http://www.pulseaus.com.au/pdf/Virus%20Contol%20in%20Chickpea.pdf

http://www.pulseaus.com.au/pdf/Pulse%20Seed%20treatments%20&%20Foliar%20Fungicides.pdf

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Effect of chickpea Ascochyta on yield of current varieties and advanced breeding lines – the 2014 Tamworth VMP14 trial

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Key words

chickpea, Ascochyta, management

GRDC code

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Take home message

Under medium to high disease pressure, Ascochyta can be successfully and economically managed on susceptible varieties such as Kyabra⊕ and Jimbour.

However, Ascochyta management is easier and more cost effective on varieties with improved resistance eg PBA HatTrick⊕, PBA Boundary⊕

The Ascochyta resistance of the advanced breeding lines CICA0912 and CICA1007 has been improved to the point that in a typical average rainfall to dry season neither will require fungicide sprays.

Background

Ascochyta first caused widespread damage to chickpea crops in eastern Australia in 1998. At the time, all Australian chickpea varieties were susceptible (some highly so) to the pathogen (*Phoma rabiei* formerly known as *Ascochyta rabiei*). Following the 1998 epidemic, efforts to develop chickpea varieties with resistance to Ascochyta were increased, aided by considerable support from GRDC. Fortunately Ted Knights, who led the National breeding program had already started incorporating Ascochyta resistance into desi chickpea types suited to the GRDC Northern Region. Howzat, released in 2002, had better resistance than Amethyst but it wasn't until 2005 when Flipper and Yorker were released that substantial gains in resistance were available to the chickpea industry. These were followed by PBA HatTrick⊕ in 2009 and PBA Boundary⊕ in 2011. Since 1999, Ascochyta management trials have been conducted at the Tamworth Agricultural Institute to determine yield losses caused by Ascochyta in current varieties and advanced breeding lines. We report here on the 2014 trial.

2014 Tamworth Ascochyta management trial, VMP14

VMP14 sought to match Ascochyta management to a variety's Ascochyta rating. The trial was sown into standing cereal stubble on 15 May 2014 using disc openers on 40cm row spacing in plots 4m wide by 10m long. Each plot was separated from its neighbour on all sides by a 2m x 10m buffer of Genesis™425 (rated R to Ascochyta). There were ten genotypes and four replicates. On 15 Jul, when most genotypes were at the 6-7 node stage, the trial was inoculated with a cocktail of twenty isolates of the Ascochyta pathogen collected from commercial chickpea crops from 2009 onwards at a rate of 233,000 spores per mL in 100L/ha water. Five and a half hrs elapsed before the rain started and whilst Ascochyta did develop, not all unprotected plants were infected and those that were had a limited numbers of lesions. On 16 Aug, when plants had 13-15 nodes, the trial was re-inoculated during a rainfall event with the same isolate cocktail that also included a highly aggressive isolate collected from PBA HatTrick⊕ at Yallaroi on 24 July (not included in the 15 Jul inoculation) containing 833,000 condia/mL. It rained for 3.5 days and this time, every unprotected plant had multiple Ascochyta infections. From re-inoculation to desiccation (6 Nov), the trial received 94mm rain in 16 rain days (8 days >1.0mm) compared with the 120 year average for the same period of 141mm and 20 rain days (15 days >1.0mm).

Table 1 lists the ten genotypes and their current ratings to Ascochyta and Phytophthora (S = Susceptible, MS = Moderately Susceptible, R = Resistant, MR = Moderately Resistant).

Table 1. Chickpea varieties and advanced breeding lines used in the Tamworth VMP14 trial and their current ratings for Ascochyta and Phytophthora

Genotype	Ascochyta (AB)	Phytophthora (PRR)	Notes
Jimbour	S	MS/MR	Industry standard
Kyabraⓟ	S	MS	Drought tolerant
PBA Boundaryⓟ	MR	S	High yield
PBA HatTrickⓟ	MR	MR	High yield, moderate AB & PRR
PBA Monarchⓟ	MS	VS	Medium/large seeded kabuli
Genesis™ Kalkee	MS/MR	VS	Large seeded kabuli
Genesis™ 425	R	S	Small seeded AB resist kabuli
CICA0912	R	MR/R	Potential release, good AB & PRR
CICA1007	R/MR	MR	Potential release, high yield
CICA1211	S	MR	Potential release, high quality

There were three fungicide treatments: a low disease scenario with regular applications of 1.0L/ha chlorothalonil (720g/L active) (5 applications were made), a high disease scenario with Nil sprays and a VMP treatment with low and off-label rates of chlorothalonil. Data for the VMP treatment are not presented here but we describe the strategies for each genotype as these reflect their Ascochyta rating. The first VMP spray for Jimbour, Kyabraⓟ and CICA1211 was applied before the first inoculation. The first VMP spray for PBA Monarchⓟ and Genesis™ Kalkee was applied on 14 Aug after two infection events, when the Jimbour, Kyabraⓟ and CICA1211 were getting their 2nd spray. The first VMP spray for PBA Boundaryⓟ, PBA HatTrickⓟ, Genesis™ 425 and CICA0912 was applied on 12 Sep after four infection events, when Jimbour, Kyabraⓟ and CICA1211 were getting their 4th spray. Conditions were not consistently favourable for Ascochyta and plants grew away from the disease between rain events. Nevertheless, unprotected (Nil) Kyabraⓟ plots were severely affected by Ascochyta and had no yield; unprotected Jimbour yielded only 22% of protected Jimbour.

In spite of treating all planting seed with metalaxyl (and thiram), Phytophthora root rot, PRR developed following 39mm rain on 18-20 Aug and 18mm on 25-26 Sep. By harvest, PRR had become quite severe in some areas of the trial; accordingly, %PRR infection was used as a covariate in the yield analyses The covariate adjusted yields for label rate and nil fungicide treatments only are summarised in Table 2, covariate adjusted yields were also used to calculate gross margins.

Key yield findings of VMP14 were:

1. Under moderate to high disease pressure, Ascochyta can be successfully managed on susceptible and MR varieties with registered rates of chlorothalonil
2. Under these moderate to high disease pressure conditions the Ascochyta resistance of two R and R/MR PBA breeding lines (CICA912, CICA1007) was robust and chlorothalonil application did not significantly improve yield

Findings for susceptible varieties:

- all susceptible varieties had significant improvements in yield with chlorothalonil for Ascochyta management
- Well managed Kyabra$^{\phi}$ yielded 2.4t/ha with a GM of $669/ha compared to zero yield and a GM of minus $377/ha where the disease was not controlled
- The desi line, CICA1211 was perhaps the surprise of the trial, as although yield losses were significant the unsprayed CICA1211 yielded 86% of sprayed treatment. CICA1211 was rated Susceptible to Ascochyta in PBA Chickpea screening nurseries under very high disease pressure. In this drier than average season CICA1211 certainly handled Ascochyta much better than the other two S rated entries, Jimbour and Kyabra$^{\phi}$

Findings for MR and R/MR varieties:

- The Ascochyta resistance of PBA HatTrick$^{\phi}$ was promising at 76% of the sprayed PBA HatTrick$^{\phi}$, although yield losses were significant. Treatment effects for PBA HatTrick$^{\phi}$ resulted in a significantly lower unsprayed GM value of $492/ha in comparison to value of $630/ha for the sprayed treatment
- Unsprayed PBA Boundary$^{\phi}$, yielded 88% of the well managed PBA Boundary$^{\phi}$ with GM of $637/ha
- The recently released kabuli, PBA Monarch$^{\phi}$, also performed well, with the unsprayed yielding 74% of the sprayed
- The potential desi release, CICA0912, performed exceptionally well with no significant difference ($P<0.001$) in yield between five sprays of chlorothalonil fungicide (2183 kg/ha) and no sprays (2132 kg/ha)
- There was also no significant difference ($P<0.001$) in yield of the desi line CICA1007 between five (2340 kg/ha) and no sprays (2343 kg/ha)

Table 2. Number and rate/ha of chlorothalonil sprays, cost of spraying, grain yield, and gross margin (GM) for ten chickpea genotypes in the Tamworth VMP14 trial (yield LSD 274.7 kg/ha; GM LSD 132.9 $/ha). (GMs also take into account other production costs estimated at $300/ha; chickpea price desi: $450/t, kabuli: $550/t)

Variety and treatment (rate/ha of chlorothalonil sprays)	**No. Sprays**	**Spray cost $/ha**	**Yield kg/ha**	**GM $/ha**
Kyabra⚭ 1.0L	5	105	2385	669
Jimbour 1.0L	5	105	2180	575
Genesis™ Kalkee 1.0L	5	105	1971	681
PBA Monarch⚭ 1.0L	5	105	2205	810
PBA HatTrick⚭ 1.0L	5	105	2301	630
Genesis™ 425 1.0L	5	105	2143	775
CICA1211 1.0L	5	105	2244	605
PBA Boundary⚭ 1.0L	5	105	2351	653
CICA912 1.0L	5	105	2183	577
CICA1007 1.0L	5	105	2340	649
Kyabra⚭ Nil	0	0	0	-377
Jimbour Nil	0	0	501	-76
Genesis™ Kalkee Nil	0	0	1461	504
PBA Monarch⚭ Nil	0	0	1625	594
PBA HatTrick⚭ Nil	0	0	1761	492
Genesis™ 425 Nil	0	0	1878	732
CICA1211 Nil	0	0	1936	571
PBA Boundary⚭ Nil	0	0	2080	637
CICA912 Nil	0	0	2132	659
CICA1007 Nil	0	0	2343	754

Further information

Further information on chickpea disease management can be found at the Pulse Australia website www.pulseaus.com.au and in the NSW DPI 2015 Winter Crop Variety Sowing Guide eg:

http://www.pulseaus.com.au/pdf/Chickpea%20Ascochyta%20Blight%20Management.pdf

http://www.pulseaus.com.au/pdf/2011%20Chickpea%20Disease%20Management%20Considerations.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Botrytis%20Grey%20Mould%20Management.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Integrated%20Disease%20Management.pdf

http://www.pulseaus.com.au/pdf/Chickpea%20Phytophthora%20Root%20Rot%20Management.pdf http://www.pulseaus.com.au/pdf/Virus%20Contol%20in%20Chickpea.pdf

http://www.pulseaus.com.au/pdf/Pulse%20Seed%20treatments%20&%20Foliar%20Fungicides.pdf

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Phytophthora in chickpea varieties –resistance rankings and yield loss

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Key words

Phytophthora root rot, variety, risk management

GRDC code

DAN00176, DAQ00186

Take home message

- Even in a dry season, substantial yield losses from PRR can occur in susceptible varieties such as PBA Boundary⊕
- do not grow PBA Boundary⊕ if you suspect a PRR risk
- avoid paddocks with a history of lucerne, medics or chickpea PRR
- there is no yield penalty in the absence of PRR associated with varieties with improved resistance to PRR

Varietal resistance to Phytophthora root rot

Phytophthora medicaginis, the cause of Phytophthora root rot (PRR) of chickpea is endemic and widespread in southern QLD and northern NSW, where it carries over from season to season on infected chickpea volunteers, lucerne, native medics and as resistant structures (oospores) in the soil. Although registered for use on chickpeas, metalaxyl seed treatment is expensive, does not provide season-long protection and is not recommended. There are no in-crop control measures for PRR and reducing losses from the disease are based on avoiding risky paddocks and choosing the right variety.

Detailed information on control of PRR in chickpea is available at:
http://www.pulseaus.com.au/pdf/Chickpea%20Phytophthor%20Root%20Rot%20Management.pdf

Current commercial varieties differ in their resistance to *P. medicaginis*, with Yorker⊕ and PBA HatTrick⊕ having the best resistance and are rated MR (Yorker⊕ slightly better than PBA HatTrick⊕), while Jimbour is MS - MR, Flipper⊕ and Kyabra⊕ are MS and PBA Boundary⊕ has the lowest resistance (S). PBA Boundary⊕ should not be grown in paddocks with a history of PRR, lucerne, medics or other known hosts such as sulla.

From 2007 to 2014 PRR resistance trials at the DAFFQ Hermitage research Facility, Warwick QLD have evaluated a range of varieties and advanced PBA breeding lines. Each year the trial is inoculated with *P. medicaginis* at planting. There are two treatments, (i) seed treatment with thiram, thiabendazole and metalaxyl and regular soil drenches with metalaxyl and (ii) seed treatment with thiram + thiabendazole only with no soil drenches. The first treatment has prevented infection by the PRR pathogen in all of these trials. The difference in yield between the metalaxyl-treated plots and untreated plots are used to calculate the yield loss caused by PRR i.e. % loss = 100*(Average yield of metalaxyl-treated plots – Average yield of nil metalaxyl plots)/ Average yield of metalaxyl-treated plots.

Yields in metalaxyl-treated plots were relatively high for the 2014 season with the lowest yielding varieties (CICA1328, CICA1007, PBA Boundary$^{\phi}$) yielding close to 2.8 t/ha (Table 1). The highest yielding variety, CICA0912, produced 3.2t/ha.

In 2014 the level of PRR in the trial was less than those of previous 2012 and 2013 seasons. However, the 2014 trial again confirmed the Yorker$^{\phi}$>PBA HatTrick$^{\phi}$> PBA Boundary$^{\phi}$ variety resistance ranking order (Table 1), which has been consistent across previous trials.

Results for this low disease pressure season showed that susceptible varieties still sustain substantial yield loss from PRR and that varieties with moderate resistance have reduced losses. For example, although disease pressure was less than that of previous seasons PBA Boundary$^{\phi}$ still had a very high yield loss of 74%. These losses were approximately 10% lower than the previous two seasons (85% in the 2012 trial and 82% in the 2013 trial). In contrast, Yorker$^{\phi}$ which has moderate PPR resistance had a yield loss of 10% in 2014 but had respective losses of 35% and 66% in 2012 and 2013.

The 2014 trial again confirmed the superior PRR resistance of the PBA breeding line CICA1328 which is a cross between a chickpea (*Cicer arietinum*) line and a wild *Cicer* species.

CICA1211 was included in the trial for the first time in 2014. Results were promising with a good yield where PRR was controlled (3 t/ha) and a yield loss from PRR of only 12%.

Table 1. Yields of commercial chickpea varieties and breeding lines protected from phytophthora root rot, and % yield losses from PRR in a 2014 trial at Warwick QLD. (P Yield<0.05; LSD Yield = 0.80)

Variety/line[A]	**Yield (t/ha) in absence of *Phytophthora* infection**	**Yield (t/ha) in presence of *Phytophthora* infection**	**% yield loss due to *Phytophthora* infection**
CICA1328[A]	2.76	2.71	1.8
Yorker$^{\phi}$	3.01	2.69	10.4
CICA1211	3.01	2.66	11.6
D06344>F3BREE2AB027[A]	2.93	2.13	27.4
PBA HatTrick$^{\phi}$	2.94	1.98	32.8
CICA0912	3.23	1.79	44.6
PBA Boundary$^{\phi}$	2.79	0.73	73.8

[A] These lines are crosses between chickpea (*C. arietinum*) and a wild *Cicer* species

We believe that the lower yield losses recorded in the 2014 trial compared to the 2012 and 2013 trials were due to lower in-crop rainfall between July and November. For the 2014 season at Warwick there were three months where the monthly total was ≤ 20mm (July 7mm, September 20mm and October 15mm). In the 2013 season when PRR was severe, there was only one month (August 9mm) when rainfall was ≤ 20mm. In 2012 when PRR severity was between the 2013 and 2014 seasons, there were two months when rainfall was ≤ 20mm. In 2014 immediate post-sowing conditions were cooler than normal with 17 days in July having a minimum temperature ≤ 1°C. The combination of low soil temperatures and low rainfall early in the season may have reduced the number of primary infections from the inoculum applied at sowing, and so reduced the capability of further disease development later in the season despite good rainfall in August (45mm).

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