Nyngan GRDC Grower Research Update
Friday 28th February 2014
Nyngan Bowling Club

8:30am registration for a 9am start, finish 3:05pm

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<td>9:00 AM</td>
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<tr>
<td>9:10 AM</td>
<td>Bridging the yield gap - how much are we leaving behind? Environmentally achievable yields vs. actuals (Zvi Hochman, CSIRO Ecosystem Sciences)</td>
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<tr>
<td>9:40 AM</td>
<td>Practical process for better soil water management. Classifying soil types and measuring plant available water capacity (PAWC); use of fast processes such as EM38; identification of subsoil constraints; crop ability to access deeper soil water. (Neal Dalgliesh, CSIRO Ecosystem Sciences &amp; Jenny Foley, DERM Qld)</td>
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<tr>
<td>11:00 AM</td>
<td>Morning tea</td>
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<tr>
<td>11:30 AM</td>
<td>Nitrogen management in central western NSW. The economics of chasing protein and issues of nitrogen use efficiency and timing in drier environments  (Rohan Brill, NSW DPI &amp; Jim Laycock, Incitec Pivot)</td>
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<td>12:10 PM</td>
<td>Integrating soil water and nitrogen nutritional strategies in Central Western NSW. Panel Session: Rohan Brill (NSW DPI), Jim Laycock (Incitec Pivot), Leigh Jenkins (NSW DPI), Breil Jackson, Graeme Callaghan (Delta Agribusiness), Neal Dalgliesh (CSIRO Ecosystem Sciences), Zvi Hochman (CSIRO Ecosystem Sciences) &amp; Greg Rummery (Greg Rummery Consulting)</td>
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<td>12:40 PM</td>
<td>Lunch</td>
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<td>1:40 PM</td>
<td>Canola agronomic research review for the Central West. Depth of sowing, P and N response, plant populations. (Leigh Jenkins, NSW DPI)</td>
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<tr>
<td>2:10 PM</td>
<td>Herbicides and weeds – regional research and issues. (Tony Cook &amp; Greg Brooke, NSW DPI)</td>
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<td>2:55 PM</td>
<td>Weed management panel session</td>
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THE 2013–2015 GRDC
NORTHERN REGIONAL PANEL

CHAIR JAMES CLARK
Hunter Valley grower James brings extensive knowledge and experience in dryland and irrigated farming systems to the Northern Panel. He has been a member of the panel since 2005 and chairman since 2008. James says the panel’s role is to capture and invest in growers’ priorities and empower them to adopt new production gain opportunities. He strongly believes the grains industry needs to continue building RD&E capacity to ensure growers remain competitive.
M 0427 545 212  E colane@bigpond.com

DEPUTY CHAIR JOHN SHEPPARD
John, a panel member since 2006, has a wealth of practical farming experience and brings a wheat breeder’s perspective to the panel. He views the panel as an opportunity for growers and professionals to work together to shape the future of the industry, and develop best management practices, as well as new varieties and products. He is particularly interested in genotype-by-environment interaction and the preservation of genetic resources.
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LORETTA SERAFIN
Loretta has more than 12 years’ experience as an agronomist in north-west NSW and currently works with the NSW DPI in Tamworth. She is a technical specialist for northern farming systems and provides expertise and support to growers, industry and agronomists in the production of summer crops. She has a passion for helping growers improve farm efficiency and sees her role as a conduit between advisers, growers and the GRDC to ensure that growers’ needs are being met.
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JACK WILLIAMSON
Jack, a private agricultural consultant, runs a broadacre commodity production farm in Goondiwindi. Previous roles as a territory sales manager for Nufarm and as a commercial agronomist for McGregor Gourlay Agricultural Services have given Jack extensive farming systems knowledge, and diverse crop management and field work experience. Jack is a member of the Northern Grower Alliance (NGA) local consultative committee and Crop Consultants Australia, and was previously president of the Macintyre Valley Cotton Field Day Committee.
M 0438 907 820  E jack.williamson1@bigpond.com

JULIANNE DIXON
Jules is manager of AMPS Research and a passionate agronomy consultant, communicator and industry advocate. Her role involves the development and expansion of self-funded, privatised research, development and extension. Her experience in project management and strategic development extends across all facets of an integrated grains business. She has an established network in eastern Australia and Western Australia, including researchers, leading growers, agronomy consultants and commercial industry.
M 0429 494 067  E juliannedixon@bigpond.com

KEITH HARRIS
Keith has served on the Northern Panel since 2011 and brings more than 30 years’ experience in property management. Keith, based on the Liverpool Plains, NSW, consults to Romani Pastoral Company on the management of its historic holdings ‘Windy Station’ and ‘Warrah’, near Quirindi. He sees the main aim of the panel as representing growers and conducting research that provides growers with the tools they need to maximise property performance and minimise risk.
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KELLY BECKER
Based at Theodore, Queensland, Kelly is a certified mungbean and chickpea agronomist and also advises growers on wheat, corn and sorghum crop production. She has been involved with variety trials on a commercial basis and industry farm practice trials as an agronomist. She strives to be proactive within the industry and aims to assist growers to improve farming operations by ensuring that they are up to date with new practices and technology.
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PENNY HEUSTON
Penny brings extensive experience to her second term on the Northern Panel. She is committed to maximising the profitability of grain production in a low-rainfall environment through increased productivity and good risk management practices. She was principal in a farm advisory business in central-west NSW and worked with growers across north-west NSW before joining Delta Agbusiness, where her main focus is the Warren, Nyngan, Tottenham and Gilgandra areas.
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ROB TAYLOR
Rob is a grain grower at Macalister on Queensland’s Darling Downs and farms 2300 hectares of maize, sorghum, wheat, barley and chickpeas on the Jimbour Plain. Rob is currently chair of the Agrifood Skills Initiative for the Western Downs Regional Council area. Rob views his role on the panel as taking information and feedback from growers, advisers and researchers to the GRDC to ensure research is targeted.
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WILL MARTEL
Central NSW grower Will has served on the Northern Panel since 2011. Previously he worked in a Quirindi grain trading company and with Brisbane-based Resource Consulting Services (RCS) where he benchmarked more than 400 growers across Australia on their performance, focusing on whole-farm profitability rather than individual enterprise gross margins. His main role on the panel is identifying investment areas that will enable growers to remain economic and environmentally sustainable.
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STEPHEN THOMAS
Before joining the GRDC Steve held a senior position with the NSW Department of Primary Industries at Orange. In early 2009 he was appointed executive manager practices at the GRDC and in 2011 was appointed executive manager research programs. Currently Steve holds the position of executive manager commercial. He sees the GRDC’s role is to interact with growers regularly to determine their needs and focus on the big picture across entire farming systems.
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PANEL SUPPORT OFFICER

DAVID LORD
David operates agricultural consultancy Lord Ag Consulting. For the past four years he has worked as a project officer for Independent Consultants Australia Network (ICAN), which has given him a good understanding of the issues growers are facing in the northern grains region. David’s new role is Northern Panel and Regional Grower Services support officer.
M 0422 802 105  E northernpanel@gmail.com
With the northern grains region stretching from Dubbo in central NSW to the top of Queensland, it is one of the most diverse cropping environments in Australia and as a result it is vital that the GRDC’s Northern Panel provides a responsive and focused research agenda for its northern grower stakeholders.

The GRDC Northern Panel comprises growers, researchers and agronomists from across the region with a variety of interests and skill sets and a determination to deliver for the grains industry.

The panel constantly interacts with local grain growers, industry and researchers to ensure that GRDC-funded research is regionally focused and delivers solutions to northern growers at a local level.

Its role is to strategically look at the GRDC’s investments and ensure that they will deliver against the regional issues and priorities identified by the panel. As part of this process, more than 1500 points of feedback were gathered from growers and considered last year.

The panel works within the GRDC’s investment themes to help establish short, medium and long-term strategies within the GRDC’s investment portfolio for delivery of research and development results that reflect the needs of growers in the northern region.

The GRDC Northern Panel continues to be driven by the aim of putting dollars back into growers’ pockets and ensuring their levy is the best investment they make each year.
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Have a rust management plan this season

1. Grow varieties with adequate resistance to stem, stripe and leaf rust.
2. Phase out very susceptible (VS) or susceptible (S) varieties.
3. Remove volunteer plants, called the green bridge, at least four weeks before sowing.
4. Know the seedling and adult rust resistance or susceptibility of varieties sown.
5. Monitor crops – early disease detection and management is best.
6. Identify chemical options, taking into account maximum residue limits and withholding periods.
7. Play your part in national rust management and report infections to your State agriculture department.
8. Send suspected rust infections to the Australian Cereal Rust Survey, Private Bag 4011, Narellan NSW 2567.

If you find rust, be proactive and tell other growers.

The Rust Bust is an initiative of the Australian Cereal Rust Control Program Consultative Committee, with support from the Grains Research and Development Corporation.
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**Bridging the yield gap – how much are we leaving behind? Environmentally achievable yields vs actual yields**

Zvi Hochman¹, David Gobbett², Heidi Horan¹, Di Prestwidge¹ and Javier Navarro Garcia¹

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2 Ecosystem Sciences/Sustainable Agriculture Flagship, CSIRO, Glen Osmond, Australia,

**Key words**
Wheat, yield, yield gap, exploitable yield gap, benchmarking, simulation

**GRDC code**
CSA00042 -Web based visualisation of spatial and temporal yield gap information for grain growers and strategic research investment planning.

**Take home message**
Wheat growers in the GRDC northern grain zone averaged 1.7 t/ha (Ya) over the 1996-2010 period. This represented 47% of the water limited yield (Yw) which could have been obtained under current technology with best practice and well adapted varieties.

Closing the exploitable yield gap (80% of Yw – Ya) would increase yields by 1.2 t/ha to raise the regional average to 2.9 t/ha.

The yield gap varies from season to season and from one statistical local area (SLA) to the next. CSIRO will be making these yield gap maps available online through a GRDC funded project so that farmers and their advisers can examine their own yields relative their farms’ location.

Farmers can use these maps as a benchmarking tool. Are they achieving better or worse than their SLA’s average yields over the same period? How close are they to closing the exploitable yield gap and consistently achieving a relative yield of 80%?

Advisers could challenge themselves to diagnose the cause of the yield gap for those clients who have large exploitable yield gaps.

**Introduction**

Growth in global grain production has all but stalled (Grassini et al., 2013) yet the FAO estimate that global food security will require world grain production to increase by at least 60% between 2010 and 2050 (Alexandratos and Bruinsma, 2012). This is both a huge challenge for the world’s agronomists and an exciting opportunity for Australia’s grains industry. One promising pathway for increasing grain production is by closing the gap between yields currently achieved on farms and those that can be achieved by using the best adapted crop varieties and best crop and land management practices for a given environment (van Ittersum et al., 2013).

When discussing yield potential and possible new management practices that may be helpful to raise farm production it is important to define the terms used to benchmark production:

- **Ya =** Actual yield: yields achieved in commercial fields. Reflecting farmers’ natural endowment, access to technology, and their skill and exposure to real market economics (Evans and Fischer, 1999 as adapted by Hochman et al., 2009)
- **Yw =** Water-limited yield: simulated yield for the same conditions, climatic and crop management, as for Yatt, except for N supply which is non-limiting (Hochman et al., 2012). Yw as defined here applies to current best practice. New technology can re-define Yw by increasing the production frontier
Yg = Yield gap for rain-fed crops: the difference between Yw and Ya

\[ Y_\% = \frac{Y_a}{Y_w} \times 100 \] (Lobell et al., 2009)

Exploitable yield gap: the difference between \( Y_\% = 80\% \) and Ya. Based on observations that farmers’ yields plateau at 80% of Yw, probably due to diminishing returns to investment and aversion to risk (Lobell et al., 2009; van Ittersum et al., 2013).

Before you can bridge the yield gap you need to know big it is! While farmers could sustainably aim for about 80% of their water limited yields, they first need to know what their target is and how close there are to achieving it. Advisers are already aware of the gap between their best and worst farmers but do they know to what extent this is determined by their environment or their Yw?

This talk is about a web based tool that will allow farmers and their advisers to benchmark their own wheat yields against the water limited wheat yields and the average wheat yields being achieved by others in their statistical local area (SLA).

**Methods**

A number of steps are required to derive maps of actual yields (Ya), water limited yields (Yw), yield gaps (Yg) and relative yields (\( Y_\% \)):

1. We obtained a land use map showing areas most likely to have produced winter cereal crops in the 2005 season at a spatial resolution of 1.1 km. This map was generated from ABARE–BRS (2010) dataset. It is based on remotely sensed NDVI data and census information to spatially disaggregate land use within area constraints provided by the agricultural census. A more detailed explanation of the procedure can be found in Bryan et al. (2009). We focused our efforts on all SLAs in Australia that grew a minimum of 5000 ha of wheat.

2. We determined Ya for each SLA. Farmers are surveyed annually by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) through its Australian Agricultural and Grazing Industries Survey (AAGIS). The annual data for wheat are aggregated up from individual farms to SLAs to 11 regions in three ago-climatic zones. The 11 regions in the Australian wheat-sheep zone are viewed by ABARES as the smallest unit for which their annual survey is designed to produce reliable wheat crop estimates (ABS, 2009). These data are available through the Agsurf website (http://abare.gov.au/ame/agsurf/agsurf.asp). The less frequently sampled Agricultural Census data provide reliable crop estimates at the SLA level. We found that where data existed at both regional and SLA level (17 years of data) there were very strong correlations between regional yield and SLA yields that allowed for reliable prediction of individual SLA yields from regional yields. This allowed us to estimate Ya for 259 SLAs in Australia for all years from 1996 to 2010. A fifteen year period was chosen as it is sufficiently long to represent climate variability but short enough to represent current technology and best practice.

3. We determined Yw by using APSIM simulation of a “continues wheat” crop from 1996 to 2010 for up to three dominant soil types within a 17 km of each of Silo’s met stations (patch point data) within the wheat land use map. A total of 11660 simulations were run to provide data for mapping Yw. The results of the soil types for each met station were weighted by the relative distributions of the soil type in the proximity of the met station. Soil data was derived from APSoil and ASRIS maps. Local kriging was used to smooth out the individual points and determine annual Yw values for each SLA.

4. We calculated Yg (=Yw-Ya) and \( Y_\% = 100 \times \frac{Y_a}{Y_w} \) for each SLA and each year and mapped the results.

**Results and discussion**

The focus in this paper is on results in GRDC’s northern region. The annual Ya data were mapped into figure 1. These maps illustrate the spatial variability of yields with contrasting results often
observed between neighbouring SLAs. This is most dramatically illustrated for 2004 where a blue zone (yields > 2.4 t/ha) borders against a red zone (yields < 1.4 t/ha). Equally the maps illustrate annual climate variability where generally good years like 1996, 1999 and 2010 contrast with years like 2000, 2002, 2006 and 2007.

The data layer for calculating $Y_w$ can be summarised by Figure 2 which overlays a map of the SLA boundaries with the winter cereal land use data layer (blue dots, each representing 1.1sq km) and meteorological data stations (diamond shapes) coloured to represent the most dominant soil type in their buffer zone. While the meteorological data are not uniformly distributed throughout the wheat growing areas, we are most fortunate in Australia to have such comprehensive meteorological and soil data at our disposal.

The annual $Y_w$ calculations were mapped into figure 3. As with Figure 1, these maps illustrate the spatial variability of water limited yields with contrasting results often observed between neighbouring SLAs. This is most dramatically illustrated for 2003 where a blue zone (yields > 4.5 t/ha) borders against a red zone (yields < 2.6 t/ha). Similarly, the maps illustrate annual climate variability where generally good years like 1996, 1999 and 2010 contrast with years like 2002, 2006 and 2007. It is important to note that the scale of yields used in Figure 3 (from less than 2.6 to greater than 4.5) is higher than that used for Figure 1 (from less than 1.4 to greater than 2.4). This difference indicates the yield gap.

The annual yield gap is mapped in Figure 4. As with $Y_a$ and $Y_w$, $Y_g$ varies in time and space. Significantly, low yielding years like 2002 tend to have small yield gaps while high yielding years like 2010 have larger yield gaps. There is a strong correlation ($r^2 = 0.72$) between $Y_w$ and $Y_g$ (Figure 5) indicating that across all locations and seasons, the higher the yield potential the higher the yield gap. Maps of annual relative yields still show variations in space and seasons (Figure 6). The predominance of $Y_\%$ values less than 43% in 1998 reflects the extreme wet winter experienced in that La Niña year. Widespread waterlogging and crop disease issues associated with a wet winter were the likely causes of the low $Y_\%$ in 1998. In most years values greater than 63% appear sporadically in some SLAs.

Average annual values of $Y_a$, $Y_w$, $Y_g$ and $Y_\%$ (Figure 7) per SLA show that some SLAs have larger yield gaps than others. This spatial difference holds true even when the yield gap is expressed as relative yields. For the 48 SLAs in the northern region $Y_a = 1.67$ t/ha; $Y_w = 3.58$ t/ha; $Y_g = 1.91$ t/ha and $Y_\% = 46.6\%$. Compared with the national figures actual yields are lower than in the southern region and similar to the western region. However the northern region has the highest $Y_w$ value and thus the largest absolute yield gap and smallest relative yield (Table 1).
Figure 1. Actual wheat grain yields in Australia’s northern grain zone (aggregated at SLA level)
**Figure 2.** Data layers used as input to APSIM simulation for calculating water limited yields.
Figure 3. Water limited wheat grain yields in Australia’s northern grain zone (aggregated at SLA level)
Figure 4. Wheat yield gaps in Australia’s northern grain zone (aggregated at SLA level)
Figure 5. Correlation yield gap with water limited yield. Each value is based on 15 year means of SLA data. Data from 259 SLAs are included in the analysis.
Figure 6. Relative wheat yields in Australia’s northern grain zone (aggregated at SLA level)
Figure 7. Wheat yields and yield gaps in the northern grain zone – 15 year SLA averages (1996-2010)

Table 1. Yield Gap results for the GRDC regions – 15 year (1996-2010) area weighted average values

<table>
<thead>
<tr>
<th></th>
<th>(Y_a) (kg/ha)</th>
<th>(Y_w) (kg/ha)</th>
<th>(Y_g) (kg/ha)</th>
<th>(Y%)</th>
<th>SLAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>1668</td>
<td>3580</td>
<td>1912</td>
<td>46.6%</td>
<td>48</td>
</tr>
<tr>
<td>Southern</td>
<td>1827</td>
<td>3519</td>
<td>1692</td>
<td>51.9%</td>
<td>117</td>
</tr>
<tr>
<td>Western</td>
<td>1651</td>
<td>2977</td>
<td>1326</td>
<td>55.5%</td>
<td>63</td>
</tr>
<tr>
<td>National</td>
<td>1806</td>
<td>3477</td>
<td>1671</td>
<td>51.9%</td>
<td>259*</td>
</tr>
</tbody>
</table>

* of the 259 SLAs used in the national analysis 31 fall outside GRDC regions
Conclusion

The key observation from this analysis of wheat crop yields is that over the period from 1996 to 2010 there was an average yield gap of 1.9 t/ha in the northern region. Relative to the average water limited yield of 3.6 t/ha, the average actual yield of 1.7 t/ha was 46.6%. If we accept that farmers can sustainably achieve a relative yield of 80%, as was demonstrated by leading farmers in the Wimmera and Mallee (van Rees et al. in review), then this study suggests that farmers in the northern region could achieve average yields of 2.9 t/ha or that there is scope to close the exploitable yield gap and increase average yields by 1.2 t/ha.

The northern region’s relative yields of 46.6% were 5.3% lower than relative yields in the southern region and 8.9% lower than in the western region. Hence there is more scope to boost yields in the northern region through better application of current technologies and best practice.

Individual farmers and their advisers need to focus more closely on their own yields relative their farms’ location. Are they achieving better or worse than their SLA’s average yields over the same period? How close are they to closing the exploitable yield gap and consistently achieving a relative yield of 80%? Advisers will be interested to know how close their best clients are to Yw and how much of a gap there is still there for them to exploit. If the answer is not much then these farmers will need to pioneer new technology breakthroughs to improve their yields. Advisers should also challenge themselves to diagnose the cause of the yield gap for those clients who have large exploitable yield gaps.

In the next few months we will develop a website in which farmers and advisers will be able to zoom into their farm location and obtain an instant benchmark relative to Ya, Yw, Yg and Y%. We are keen to test the usability and usefulness of this website with farmers and advisers. If you are keen to be among the first to test drive the system and help guide its development please contact me after the break.

References


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Practical processes for better soil water management

Neal Dalgliesh, CSIRO

Key words
PAWC, soil water management, soil characterisation, soil monitoring sub-soil constraints, fallow efficiency, water use efficiency

GRDC code
CSP00170

Take home message
Understanding the processes involved in the capture and storage of rainfall for future crop production, and knowing the status of current soil water using the tools currently available for its monitoring, can result in improved crop productivity. Research is showing that it is the compounding effects of a number of aspects of fallow management that result in improved fallow efficiencies and subsequent, closer to optimal, production and economic returns. Tools are now available to better define soils in terms of their productive capacity and for the routine seasonal monitoring of the water resource as it is captured and utilised by crops (or weeds if allowed). The level of sophistication at which the grower invests in soil monitoring and management is at their discretion, however it should be remembered that while the use of higher level technologies can provide easier and more accurate real-time access to soil water information and to risk management tools such as simulation modelling, value can also be found in the more thoughtful use of simple devices such as the push-probe.

How important is soil water to crop productivity?
Those growing crops in the northern cropping region of Australia are well aware of the potential benefits of stored soil water to subsequent crop production. However, research is showing that more can still be done to improve both the efficiency of rainfall capture and the management of soil water to optimise its use in dryland cropping systems. Research, undertaken as part of the GRDC Water Use Efficiency Initiative, has shown that pre-crop management is more important than in-crop management in lifting the water use efficiency (WUE) and yield of wheat cropping systems (Kirkegaard and Hunt, 2013). It is the pre-crop practices of fallow weed management, rotation choice, long-term stubble retention and reduced tillage which are likely to have the most impact on fallow water storage and hence WUE and crop yield. In other words, it is the combining of ‘best’ practices that will contribute to the more efficient storage and use of available water. Underpinning the push to improve water use efficiency is the need for farmers and their advisors to have a good understanding of how soils work in relation to water capture and storage and why some soils have the ability to hold more water for crop use than others. Such baseline information, in conjunction with the seasonal monitoring of soil water, using tools that can range from something as simple as a push probe to simulation modelling, allows the setting of realistic decisions/goals on crop choice and inputs and yield potential.

So what needs to happen to enable producers to gain a better understanding on water holding capacity and an appreciation of what might be done to improve water capture and hence overall water use efficiency? Tools for the characterisation of plant available water capacity (PAWC) and the monitoring of soil water have been available for many years although there are changes occurring which will impact on how water is measured and decisions made.

But first the underpinning concepts....
1. Plant available water capacity (PAWC)

PAWC is a measure of the ability of a soil to store water for later crop production. Figure 1 shows the water states that are measured to determine a soil’s PAWC, or as it is often called, the size of its water bucket. The two most important are the drained upper limit (DUL) which is related solely to the physical properties of the soil, and the crop lower limit (CLL) which is related both to soil physical properties and to the ability of the particular crop to extract water from the soil.

![Figure 1](image)

**Figure 1.** A typical storage profile for a heavy-textured clay soil showing the potential water storage of the soil, PAWC, as defined by the drained upper limit (DUL-blue shading), crop lower limit (CLL), saturation (SAT) and total porosity (PO).

**What physical properties affect PAWC the most?**

Texture, which is a measure of the proportion of sand, silt and clay present in a soil, is the most important physical parameter affecting soil water holding. In the example shown in Figure 2, the PAWC of a Sandy Clay Loam (Red Calcareous) from Nyngan is compared to that of a heavy clay (Black Vertosol) from Spring Ridge. While wheat is able to root to a depth of 150-180 cm in both soils, the clay soil has the ability to store more water. This is a result of clay soil particles (with particles <2 microns in size) having between 10 and 1000 times more surface area than those of sands (particles of 20-2000 microns). This is important because water is held by electrical charge around the surface of individual soil particles, the more surface area the more potential to hold water.

![Figure 2](image)

**Figure 2:** The effect of texture on the PAWC of soils-comparing a Red Calcareous (PAWC=108mm) (Nyngan) to a Black Vertosol (PAWC=272mm) (Spring Ridge).

While fine textured soils have the ability to hold larger quantities of water than sandier soils, there are some drawbacks. As a result of their smaller particle size, pore space (space between particles) is
also finer which reduces water infiltration rate and can increase run-off, a particular problem in high-intensity rainfall events or after prolonged periods of rainfall. The ability to hold more water also puts clay soils at a disadvantage in situations where rain falls as a single, isolated event. Because of their higher PAWC, water from small events is stored close to the soil surface, and unless follow up rain occurs soon after, is often lost to evaporation. This contrasts with lighter textured sandy soils where, due to the lower water holding capacity, water moves deeper into the profile, making the water less susceptible to evaporative loss. Of course, if the rain continues on a sandy soil it is likely that drainage will become a major loss factor.

Other physical soil attributes such as soil depth also impact on water holding capacity as do chemical constraints.

**What soil chemical attributes affect PAWC?**

Sub-soil constraints (SSC), particularly salinity and sodicity, but also nutrient deficiency/toxicity resulting from high/low pH, are common in northern cropping soils and do impact on a plant’s efficiency to access/extract soil water.

While both sodicity and salinity impact on PAWC, their mode of impact differs. While sodicity is a soil chemical imbalance (higher proportion of sodium ions relative to other cations) the effect on the plant is physical. High levels of sodium cause dispersion of the fine soil particles resulting in the blockage of soil pore space which not only slows root extension and consequent access to soil water, but when present in the soil surface, also impairs water infiltration with subsequent impacts on run-off and erosion. Sodicity is measured as the Exchangeable Sodium Percentage (ESP) of the soil.

In contrast, salinity has a direct chemical effect on the plant’s ability to extract water from the soil. First and foremost, high levels of salt reduce the efficiency of water uptake by roots. This results in a diminished plant water supply (in other words, a reduction in soil water bucket size) even though soil water measurement e.g. with a push probe, may indicate the presence of available water. Also, in soils high in salt, its continuing absorption by a plant may result in unthrifty growth and death. It should be remembered however, that not all plants are treated equal, some species being more salt tolerant than others. Salinity is commonly measured as Electrical Conductivity (EC) which is a measure of total salts. This measure should be used with care in northern vertosols, due to the common presence of gypsum, a salt that is benign in terms of plant productivity but included in the EC measurement. The preferred method is to analyse for Chloride which provides an estimate of the particular salt deleterious to plant growth.

pH impacts on nutrient availability and hence on the efficiency of the plant to extract soil resources. The vertosols of the northern cropping region are typically alkaline (pH >8) making them prone to deficiencies in zinc and phosphorus. In acid soils, at pH <5.5, aluminium and manganese become more soluble and more toxic as their concentration in the soil water rises. Aluminium inhibits root growth in most plants and induces calcium, phosphorus and molybdenum deficiencies (Qld NRW, 2007).

Chemical analysis is the typical means of developing understanding of the potential impacts of SSCs on crop production. It should be remembered that even when armed with such information it may still not be economically or practically feasible to ameliorate some conditions, particularly those at depth. However, such testing does provide the grower with the basis for being realistic about yield potential and the matching of crop inputs to suit that potential.

A surrogate for chemical analysis is the field measurement of crop lower limit (CLL). Assuming that the characterisation site is representative of the local soil type, the measurement of water extraction by a well grown crop (not water or nutritionally deficient) integrates all of the physical and chemical attributes of the soil into the data, providing the grower with a holistic view of rooting depth and extraction capability.
How deep do plant roots grow?
Given the above discussion on soil chemical and physical constraints, the depth of potential crop rooting will vary considerably between soils and environments. Therefore, rooting depth should be determined through perusal of physical and chemical data and the physical observation of roots and water extraction through soil coring and/or electronic monitoring. Rooting depth (and hence PAWC) varies between soil types due to physical and chemical differences, and also varies between crop types grown on the same soil, a result of physiological differences, including crop season length, ability to extract water from the soil matrix and to handle SSCs. As a general rule of thumb, longer season crops including wheat, maize, cotton and sorghum tend to root deeper than the shorter duration legume crops such as mungbean. Table 1 provides an estimate of rooting depth for crop species commonly grown in northern NSW.

Table 1. Rooting depth for unconstrained crops commonly grown in northern NSW on the Red Calcareous and Black and Grey Vertosol soils.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Rooting Depth (cm)</th>
<th>Duration</th>
<th>Crop</th>
<th>Rooting Depth (cm)</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mungbean</td>
<td>90</td>
<td>3 months</td>
<td>Sorghum</td>
<td>180</td>
<td>4 months</td>
</tr>
<tr>
<td>Chickpea</td>
<td>150</td>
<td>5-6 months</td>
<td>WF Millet</td>
<td>180</td>
<td>3 months</td>
</tr>
<tr>
<td>Wheat</td>
<td>150</td>
<td>5-6 months</td>
<td>Sunflower</td>
<td>&gt;200</td>
<td>4-5 months</td>
</tr>
<tr>
<td>Cotton</td>
<td>180</td>
<td>6 months</td>
<td>Lucerne</td>
<td>&gt;300</td>
<td>perennial</td>
</tr>
</tbody>
</table>

While a discussion about rooting depth is important to the overall understanding of soil water management, it should be remembered that many soils do not wet to their full potential (wet to potential rooting depth) in every season. Taking the grey and black vertosols of the northern region as an example, it is likely that they will not regularly wet deeper than around 1 m, unless preceded by a long fallow or high intensity rainfall coincides with severe soil cracking. While the lighter soils of this region may potentially wet deeper than the vertosols, infiltration may be constrained by surface sealing which will slow infiltration and exacerbate run-off.

While an understanding of the water dynamics in the top 1 m of the profile may be more useful for the routine monitoring and management of soil water, it is still important to know when conditions conducive to filling the profile have occurred so that the additional water resources can be exploited e.g. through the planting of a deeper rooting crop, or the planting of a longer season variety or changes in management such as the application of additional fertiliser. Remember that it is difficult to exploit a resource if you don’t know it exists. It should also be understood that where crop simulation (Yield Prophet, APSIM) forms part of the crop management tool-kit, knowing the soil water to the potential crop rooting depth is an important input.

2. Obtaining information on PAWC

What tools are available off the shelf?
Twenty years of collaboration between CSIRO, the state departments, consultants, industry groups and individual farmers, with support from GRDC, has resulted in approximately 1000 Australian cropping soils being characterised for PAWC. These data are provided to users through the APSoil database and its Google Earth derivative, available for download at http://www.apsim.info/Products/APSoil.aspx and ‘SoilMapp’, an IPad application which is available from the Apple On-line Store. These data also form the basis for crop decision support using APSIM and Yield Prophet. APSoil data, accessed by one of the above tools should be the first option for those seeking soil water information. If suitable data are not available for local soils, measurement of PAWC is required.
Measuring PAWC-Field based characterisation
Field-based soil characterisation has traditionally been a collaborative effort between researchers, local farmers and consultants which has allowed the selection and characterisation of soils seen as being regionally important. Water is applied to the site (using drip irrigation) until it is considered to be fully wet to the depth of rooting (Figure 3). This may take a number of months in the heavier clay soils, although can be as short as a few days on sands. After drainage has ceased, measurement of soil moisture at drained upper limit (DUL) and the bulk density (BD) are undertaken.

An estimate of the lower limit of crop extraction (CLL) for a particular species, grown on the soil of interest, is then done. At around crop flowering, a rain-exclusion tent is erected over a healthy area of the crop (either on, or adjacent to the DUL site) which is then allowed to grow through to maturity or until senescence (Figure 4). Monitoring of soil moisture is then undertaken to determine CLL. It is recommended that CLL be measured for the range of local crops (possibly over a number of seasons) to determine differences in ability to extract water and hence differences in PAWC.

With the collection of the above data PAWC is able to be calculated. The step-by-step soil characterisation process is described in the technical manual *Estimating Plant Available Water Capacity* (Burk and Dalgliesh, 2008) which is available from GRDC.

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Measuring PAWC-Lab based characterisation
The lab based measurement of soil water content at potentials of -10 kPa (drained upper limit) and – 1500 kPa (lower limit) are arguably a more accurate means of determining a soil’s PAWC but do require specialist expertise and equipment normally found only in a soils laboratory. The lower limit of extraction determined using this methodology represents an arbitrary theoretical limit of plant extraction (1500 kPa), which in the paddock situation varies with crop type, extraction ability, and soil depth (at depth root density decreases and water extraction is generally lower). Traditional 1500 kPa lab-based measurements have, for many years, been obtained from grinding then re-wetting and drying soil samples. This has led to errors due to the grinding and wetting process with effects on soil porosity and bound water. Newer methods using soil psychrometry and intact core samples are increasingly being used and yield accurate results across a range of lower soil water potentials.

Measuring PAWC-Other options and opportunities
The above methods are expensive in both time and equipment. Other opportunities currently exist, or are currently under development.

Wettest and driest soil profile: One of the simplest methods for a consultant or farmer to determine PAWC is to make judgement calls on when a soil profile is fully wet to depth, and when it is dry after the growing of a particular crop. Measurement of soil water content at these 2 points will give a reasonable estimate of the upper and lower limits of extraction and will allow a calculation of PAWC which will suffice for most uses. This method of determining PAWC is particularly appropriate for
electronic soil water monitoring systems e.g. capacitance probes such as the EnviroSMART, where soil moisture is monitored through time and the wet and dry points are able to be easily identified. The catch with this type of device is that data is generally outputted in millivolts or similar which is a measure that many would have difficulty in relating to water availability. The Soil Water Express tool (Burk and Dalgliesh, 2012) has been developed to assist in this process allowing the user to create estimates of DUL and CLL, based on the device’s electronic output, in units of meaningful measurement i.e. mm of available water. A beta version of this tool is available on request (http://www.apsim.info/Products/).

**Infrared spectrometry:** Visible–near infrared (vis NIR) spectroscopy shows potential for the rapid, accurate and inexpensive estimation of soil water, and potentially, PAWC. Models to accurately estimate water contents across the moisture characteristic curve (from wet to dry) have been developed, with the next phase being the development of methodology for the field estimation of soil water content and determination of PAWC. While the vision is to develop a field-based device for the rapid estimation of these parameters, the research is currently on hold.

**Soil and Landscape Grid of Australia Facility** (http://www.clw.csiro.au/aclep/tern/): This activity, being led by CSIRO and in collaboration with government, state departments and universities aims to produce a comprehensive fine-resolution grid of soil attributes and important land surface parameters for the country (at a spatial resolution of 90 m). Information will be consistent with the developing Global Soils Map (http://www.globalsoilmap.net/) which has similar aims internationally and with the Australian Soil Resource Information System (ASRIS) (http://www.asris.csiro.au/) which is the national repository for soil information. Outputs will include a coherent set of fine spatial resolution soil property maps for parameters including soil texture, carbon, bulk density and PAWC. While valuable across a range of industries, these data will be particularly useful in farm and crop management, particularly as input to simulation using Yield Prophet and APSIM. The first maps from this initiative are expected in 2014.

**Future characterisation of soils in Australian cropping regions**
Recent GRDC funding has allowed field-based soil characterisation to be continued. Opportunities exist for consultants and farmers from this region to engage with researchers to characterise locally important soils for PAWC and to participate in locally relevant analysis of crop production risk using simulation. Interest from consultants and farmer groups is invited. Information is available from Christian Roth (07 3833 5732; Christian.Roth@csiro.au) and Brett Cocks (07 46881580; Brett.Cocks@csiro.au).

3. **Estimating seasonal water availability**

   The process described above (in 2.) allows the user to develop understanding on the capability of a soil to hold water for crop production (how large is the bucket). Armed with this information, it is now time to look at the options available to determine the amount of water in the bucket at a particular point in the season (described as the plant available water (PAW)).

**Its horses for courses**
A range of soil water monitoring devices was recently tested for their practical applicability in dryland systems on both the cracking clay soils (Vertosols) and the southern rigid soils (GRDC project, CSA00023-Doing it better, doing it smarter-measuring soil water in Australian agriculture). This study found that it really was horses for courses, with no one device or field based technology appropriate to all situations. *In-situ* capacitance or time-domain reflectometry (TDR) sensor probes were likely to provide a reasonable estimate of soil water in rigid soils, whereas in the shrink/swell clays, these faced difficulties because of soil cracking. The surface based, EM38 (Electromagnetic induction) mobile device was a more practical and accurate option for these soils. Soil water modelling (APSIM model) was also shown to adequately predict soil water levels when compared against the outputs of the above *in-situ* technologies and is recommended as an alternative to field based monitoring. It
should be noted that sensor/device calibration is required with all of the electronic monitoring devices to ensure data sensibility and accuracy over the longer term.

When discussing soil monitoring technologies it is common to look towards the hi-tech end of the spectrum and to dismiss older technologies such as soil coring and push probing. Even with electronic technologies, the requirement for in-situ sensor calibration usually means that some form of soil coring is required. Also, routine coring for soil nutrient status provides the opportunity to develop knowledge of soil water status. This may range from the simple ‘touch and feel’ of soil moisture while soil coring for nutrients, to the calculation of gravimetric water content.

The value of information gained through the use of a push probe should also not be underestimated. While in its most basic mode it provides a simple estimate of the depth of wet soil (which may be sufficient information for many), there is the opportunity, through increased understanding of PAWC, to add value to the use of this tool. For example, characterisation of a soil for PAWC may indicate that a particular sand is able to hold 0.5 mm of water/cm of profile depth, while a clay is shown to hold 2mm/cm of depth. If push probing indicates that both soils are fully wet to 50cm, the sand contains 25mm of PAW while the clay holds 100mm, an important difference in terms of crop decision making.

**How accurate is soil water monitoring?**

There is a perception that it is possible to monitor field-scale soil water at high levels of accuracy. However, this is difficult to achieve using the currently available point scale technologies because of the inefficiencies associated with the monitoring process and the variable nature of Australian soils. One should also consider whether an absolute measure of soil moisture is necessary. Is knowing the PAW to an accuracy of +/-5 mm likely to change a management decision at the start of the season, or is it more likely that decisions will be based on differences in PAW of +/- 25 or even 50 mm?

In many ways this decision is taken out of the hands of the operator anyway. The level of spatial variability in soil moisture content, indicated during the field testing of monitoring devices (described above), was a major learning. Whilst it is understood that soils vary in texture and hence water holding, it came as a surprise to find high levels of spatial variability in gravimetric water content in what would generally be considered as homogenous soils i.e. Black Vertosol. Analysis of gravimetric sampling data (from an area of 420 m²) showed variability around the true mean of +/-15 mm water to a depth of 90 cm (at a confidence level of 95%). Whilst the mechanisms of such high variability are not fully understood, they are thought to relate to, a) the regular cracking of soils and the redistribution of surface soil through the profile as part of the shrink/swell process, b) the biasing of gravimetric sampling to particular parts of the soil landscape due to the necessity of sampling within soil peds, and c) random soil cracking around in-situ monitoring devices resulting in inaccurate measurement and high inter-device variability.

These findings have important implications for the placement of in-situ monitoring devices and the necessity for device replication if high levels of accuracy are required. In cracking soils, these findings lend support to the use of mobile, point scale devices such as the EM38 which allow rapid, multiple replications to be undertaken. However, this device in its current configuration, is not able to continuously log soil water nor operate effectively in saline soils.

**Summarising the challenges**

There are positives and negatives associated with all of the tested devices with no one likely to meet all requirements. By their very nature, in-situ devices or those that rely on an access tube, can only be located at one geographic point and yet are expected to adequately represent the moisture environment of a much larger area. If a high level of accuracy is required then the solution is to increase replication, but this brings additional capital and maintenance costs. Many in-situ devices provide the capacity for continuous logging, which to some will be the most important consideration. Others will see expediency in mobility and portability and an absence of physically located in-situ devices as being more important than continuous logging and could stick with the very simple e.g. push probe, or invest in a technology such as EM. Others will consider the simulation of water
availability as being sufficiently accurate to make cropping decisions. The final decision will be up to
the individual and will be based on their views on accuracy, the frequency and timeliness of
information delivery, soil type and salinity level and the investment and continuing commitment
required.

4. Management options to improve PAW and Water Use Efficiency

Summer weed management

Research undertaken by Central West Farming Systems and the NSW DPI, as part of the national
WUE Initiative, unequivocally shows that summer weeds are costing growers dearly in terms of
available soil water and nitrogen for subsequent crop production. An average increase of 60% in
seasonal water use efficiency was found (across 21 trial sites-SA, Vic, NSW) where weeds were
controlled during the summer fallow, a result of the improved efficiency of storage of summer
rainfall and increased nitrogen supply to the subsequent crop. This resulted in an average return on
investment of $5.57 for every dollar invested in summer weed control (Hunt, 2013).

Table 2. The impact of controlling summer weeds on pre-sowing plant available water and nitrogen, and the
return on investment from summer weed control for northern NSW (Modified from Huth, 2013).

<table>
<thead>
<tr>
<th>Site (NSW)</th>
<th>Year</th>
<th>Subsequent crop</th>
<th>Summer fallow rainfall (mm)</th>
<th>Additional PAW pre-sowing (mm)</th>
<th>Additional mineral N pre-sowing (kg/ha)</th>
<th>Additional yield (t/ha)</th>
<th>Yield of complete weed control (t/ha)</th>
<th>Return on investment in weed control ($ received from $ invested)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waroo</td>
<td>2008</td>
<td>Wheat</td>
<td>358</td>
<td>56</td>
<td>25</td>
<td>1.0</td>
<td>2.6</td>
<td>12.00</td>
</tr>
<tr>
<td>Gunningbland</td>
<td>2010</td>
<td>Wheat</td>
<td>270</td>
<td>53</td>
<td>57</td>
<td>1.7</td>
<td>3.7</td>
<td>5.67</td>
</tr>
<tr>
<td>Gunningbland</td>
<td>2011</td>
<td>Canola</td>
<td>488</td>
<td>98</td>
<td>85</td>
<td>1.0</td>
<td>2.2</td>
<td>17.67</td>
</tr>
<tr>
<td>Tottenham</td>
<td>2010</td>
<td>Wheat</td>
<td>417</td>
<td>21</td>
<td>32</td>
<td>1.4</td>
<td>2.4</td>
<td>4.67</td>
</tr>
<tr>
<td>Rankin Springs</td>
<td>2010</td>
<td>Wheat</td>
<td>304</td>
<td>0</td>
<td>57</td>
<td>1.0</td>
<td>3.7</td>
<td>3.18</td>
</tr>
<tr>
<td>Rankin Springs</td>
<td>2011</td>
<td>Wheat</td>
<td>384</td>
<td>-</td>
<td>-</td>
<td>0.7</td>
<td>1.7</td>
<td>9.91</td>
</tr>
<tr>
<td>Rankin Springs</td>
<td>2012</td>
<td>Wheat</td>
<td>476</td>
<td>62</td>
<td>88</td>
<td>1.2</td>
<td>3.5</td>
<td>4.58</td>
</tr>
<tr>
<td>Condobolin</td>
<td>2011</td>
<td>Wheat</td>
<td>290</td>
<td>NA</td>
<td>36</td>
<td>1.1</td>
<td>2.2</td>
<td>3.33</td>
</tr>
<tr>
<td>Condobolin</td>
<td>2012</td>
<td>Wheat</td>
<td>461</td>
<td>55</td>
<td>62</td>
<td>0.5</td>
<td>1.7</td>
<td>2.61</td>
</tr>
</tbody>
</table>

The impact of stubble cover on fallow efficiency

While the retention of stubble has significant benefits in the control of wind and water erosion and in
improving water infiltration (particularly in high intensity rainfall events), WUE Initiative research
indicates that stubble retention does not reduce seasonal evaporation levels when present in the
quantities normally seen in dryland agriculture, and as a consequence, does not affect the quantity of
water stored during the fallow nor on crop yield (Hunt, 2013). Northern region research supports
these findings. Freebairn et al. (1987) showed that while stubble cover slowed evaporation for
around 3 weeks following rainfall, there was no longer term benefit to soil moisture levels. It is
important to remember however, that while stubble retention had no long term impact on soil water
storage, slower evaporation rates under stubble, in the days immediately after a rainfall event, do
provide a longer window of opportunity for crop planting, or where follow-up rainfall occurs, may
result in an overall increase in stored soil water as the water is moved deeper into the profile.

The benefits of controlled traffic (CT)

Operational efficiencies are generally the first reason that farmers give for converting to permanent
traffic ways for broadacre crop production. However, the more subtle, longer term impacts of
controlled traffic farming should not be overlooked. The benefits of CT in reducing soil compaction
and the flow-on effects of increased infiltration and improved fallow efficiency are important benefits to the cropping system. Research undertaken by Tullberg et al. (2007) on the vertosol soils of the northern cropping region shows the impact of both stubble and CT on rates of run-off. The mean annual runoff where implements were not constrained to specific traffic ways was 44% higher than where CT was practiced. This equated to an additional 63mm of water being captured annually in a system where soil structure had not been affected by compaction. This study also showed the positive effects of zero tillage with a reduction in annual runoff of 38 mm under a zero till system compared to conventional stubble mulching. Infiltration efficiency, as a percentage of annual rainfall, varied between ~70% where tillage was not constrained to specific traffic ways, to almost 90% where CT and zero till were implemented (Figure 5).

Figure 5. Cumulative effect of wheeling and tillage on infiltration (as a % of annual rainfall) in southern Queensland (adapted from Tullberg et al. 2007). Data are the mean of 6 years of annual infiltration/annual rainfall.

What is not considered in the above analysis is the impact of evaporation, which in Australian cropping regions, accounts for between 50 and 60% of annual precipitation (Keating et al. 2006; Freebairn et al. 2006). Figure 6 shows that after accounting for runoff, evaporation and drainage, the remaining section of the water balance pie, available to support crop production, is relatively low. There are no magic bullets to increasing the percentage of the pie available to drive crop production, however, the adoption of the range of management strategies discussed earlier will all contribute to improved water capture and retention.

Figure 6. Water balance for Parkes, NSW, (lighter textured soil with more winter dominant rainfall) and Dalby (clay textured soil with summer dominant rainfall). The Parkes soil could be considered to represent the lighter soils of central NSW and Dalby, the heavy clays (Keating et al 2006; Freebairn et al. 2006).
5. What is the relevance of better soil water knowledge for management

Using the NSW soils shown in Figure 2, what amount of soil water is likely to be stored during either a short or a long fallow and what impact might that have on farmer cropping and input decisions. Figure 7 shows soil water scenarios for the Nyngan Red Calcareous and the Spring Ridge Black Vertosol soils. Push probing on the 14th April indicated wet soil to either 30-40cm (Scenario 1) or 90 cm depth (Scenario 2) for both soils. These data were then converted to millimetres of available water using local soil characterisation information which showed that the Black Vertosol had more than double the water reserves of the Red Calcareous (Table 3). The growing of Baxter wheat was simulated (APSIM) with planting date triggered by the receipt of 15mm of rainfall over 3 days, between the 15th April and the 15th May. Simulations were run using the met records for Spring Ridge (1900-2012) and Nyngan (1900-2006).

Table 3. Depth of wet soil and calculated PAW based on the known millimetres of available water /centimetre of depth for the 2 soils.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth of moist soil (cm)</th>
<th>PAW (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>30-40</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>160</td>
</tr>
<tr>
<td>Red</td>
<td>30-40</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>70</td>
</tr>
</tbody>
</table>

Figure 7. Plant available water at time of sowing (April) for (a) a Red Calcareous at Nyngan holding 30 or 70 mm PAW and (b) a Black Vertosol at Spring Ridge holding 80 or 160mm PAW.

How likely is it to have these quantities of water in April?

Water storage depends on the length of the preceding fallow, seasonal rainfall and soil type. Simulation of water storage using the >100 year climate record shows that a short fallow from wheat (assuming a dry soil profile at harvest in November of the previous year) results in a 50% chance of at least 110mm (range of 0-300mm) of water being available for an April planting at Spring Ridge and 80mm (range of 0-180mm) at Nyngan (Figure 8). A long fallow, following a summer crop harvested in the preceding May (12 months to re-charge the profile), results in a 50% chance of having at least 160mm (range of 40-300mm) of planting water available at Spring Ridge and 90mm (range of 0-180mm) at Nyngan. This analysis indicates that a longer fallow on the Calcareous soil at Nyngan is more beneficial in drier years. In wetter years, as a result of the relatively small size of the water bucket, it is highly likely that the profile will recharge to near-capacity, even where a short fallow is
practiced. In this case, deep drainage may be an issue. The Spring Ridge vertosol shows an obvious soil moisture advantage from long fallowing and it is likely that the wetting of this soil to depths >100 cm will only happen through long fallowing or through recharge from heavy rainfall while the soil is extensively cracked.

Soil water, stored as a result of early summer rainfall, which is surplus to the requirements of a maturing winter crop, may also contribute to subsequent fallow water storage. This resource has not been considered in this analysis and as a result water storage data should be considered as a conservative estimate.

**Figure 8.** Fallow water storage for a (a) Red Calcareous soil at Nyngan and a (b) Black Vertosol at Spring Ridge. Differences in median water storage are shown (dotted lines) for short (December to April) and long falls (May to April).

**How might the amount of stored water affect decision making?**

The above simulation shows that by knowing something about a soil’s ability to store water can have impact on management. For example, knowing the storage capacity of a Red Calcareous soil may change thinking on fallow length, or knowing the capacity of a soil to hold water may change thinking on crop input investment e.g. fertiliser. This can be taken further through the use of Yield Prophet which provides the manager with a means of exploring the riskiness of cropping options (both production and economic) based on knowledge of the soil resources present (water and nutrients) and the long term climate information.

**Figure 9.** Simulation of the impact of rate of N application (N25 to 150) on wheat yield grown on a Red Calcareous soil at Nyngan with 30 mm (a) or 70 mm (b) PAW at the time of sowing in April.
Figures 9 and 10 provide examples of the type of information available to managers to assess the riskiness of a particular decision. Soil characterisation shows that the Red Calcareous soil at Nyngan is unable to hold as much water as the vertosol at Spring Ridge; as a consequence yield potential is lower and the nitrogen fertiliser requirement less. Figure 9 (a) shows that the addition of more than 50 kg/ha of N (as urea) would be a waste of resources in 50-60% of years, where PAW at planting is low (30mm). However, even where starting soil water is low, there is still potential in the wettest 30% of years to improve yields through fertiliser application, although the economics of such a move would need to be evaluated. Figure 9 (b) shows that where 70mm PAW is present at planting, the potential for N fertiliser to impact on crop yield is greater. Simulation indicates that a rate of 75 kg/ha would contribute to increased yield in around 70% of years, and rates in excess of 75kg/ha are likely to continue to have impact on yield in the 50% of wetter seasons.

Figure 10. Simulation of the impact of rate of N application (N25 to 150) on wheat yield grown on a Black Vertosol soil at Spring Ridge with 80 mm (a) or 160 mm (b) PAW at the time of sowing in April.

For the Black Vertosol at Spring Ridge, even in years where starting soil moisture is relatively low (80 mm) (Figure 10 (a)), the application of fertiliser at higher rates is likely to be beneficial. Rates of 75 kg/ha and higher will impact on yield in around 80% of years, with rates of 100 or even 150 kg/ha required to optimise yield in wetter years. Where the profile was wet to depth at planting (160 mm PAW) it can be seen from Figure 10 (b) that yields continue to increase in the majority of years as a response to better moisture conditions and to increasing rates of N fertiliser.

These analyses compare yield potential in response to PAWC, PAW, seasonal conditions and N application rate but do not compare the economics of production. It is highly probable that many of the discussed scenarios would not be economically feasible. It is up to the individual to decide the economics of any system based on their own circumstances but Yield Prophet is well placed to assist in the exploration of productive potential and the underlying economics.

6. Tying it all together

The above simulations of a single crop provide an example of the type of information available to assist farmers in navigating the complexity and riskiness of the dryland cropping system that they manage. However, to utilise this information to its maximum requires that a farmer knows the soil water status at critical seasonal decision points, particularly at crop planting and at fertiliser application or other important in-crop decision points. As can be seen, there are opportunities in wetter years to increase inputs to optimise available water resources, just as there are opportunities in drier years to ease off on inputs, but these decisions are only available to those who have access to the necessary information on which to make the decision. However, we have also seen that soil monitoring is only part of the story, best practice dictates an understanding of the characteristics of the soil and its limitations to enable the development of a realistic yield potential. It also means the
optimising of water storage through good fallow management, leading to increased water use efficiency. It is not going to be the adoption of one or other of the technologies that will lead to reduced risk and improved economic sustainability but a more thoughtful approach to all of these aspects of crop production at whatever level of investment thought appropriate by the individual.

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A ‘how to’ for getting soil water from your EM38 field measurements

Jenny Foley, Department of Natural Resources and Mines

Key words
PAW, geophysical surveying, soil moisture, WUE, crop water uptake

GRDC code
ERM000002

Take home message
EM38’s are an easy to use geophysical surveying instrument that provide a rapid measure of soil electrical conductivity (EC). Soil calibrations or qualitative assessments can be used to convert this to estimates of soil water in the root zone. This information is vital to farm management decisions based on accurate knowledge of soil PAW.

Introduction
Despite an extensive range of monitoring instruments now available to us, measuring paddock soil moisture is still a considerable challenge. Among the suite of instruments currently available, one that stands out and is increasingly being used by researchers and agronomists is the EM38 (Geonics Ltd., Ontario, Canada). This electromagnetic induction instrument is proving to have significant application potential for determining soil properties useful in precision agriculture and environmental monitoring. It is now commonly used to provide rapid and reliable information on properties such as soil salinity and soil management zones, both of which relate well to crop yield. It is also used in a wide number of agronomic and environmental applications to monitor soil water within the root zone. It provides an efficient means to monitor crop water use and plant available water (PAW) in the soil profile throughout the growing season so that informed management decisions can be made e.g. the application, timing and conservation of irrigation water and fertiliser. EM38 datasets have also proved valuable to test and validate water balance models which are used to extrapolate to other seasons, management scenarios and locations.

EM38’s are easy to use, lightweight, and provide rapid, numerous measurements over large areas without the need for ground installations or destructive sampling. New advances in EM38 technology now allow a direct connection to computer based data acquisition systems to record survey and GPS receiver information.

What do they actually measure?
The EM38 measures apparent electrical conductivity (ECa) in the root zone. Different orientations, coil offsets and depths measured (ground level or above) are used to obtain a range of sensing depths. The ECa reading is a weighted average across a depth range, weighted according to the respective depth functions of the different coil orientations and spacing’s. In the vertical dipole (EM38 placed upright on ground surface) the reading is weighted strongly towards soil attributes at around 0.3-0.6 m depth, declining exponentially to approximately 1.5 m depth (1 m coil spacing). When the device is placed in the horizontal dipole mode (EM38 sideways on ground surface) the
reading is weighted strongly towards soil attributes at the surface 0-0.3 m, declining exponentially to approximately 0.75 m.

Targeted readings can be taken for tracking soil water movement and redistribution at depths of most interest to the operator by simple choice of dipole, coil spacing or height above ground.

**What affects the measurements?**

The strength of the induced current is determined by the $EC_a$ of the soil which is mainly a function of the soil’s water, clay and salt content. These soil attributes influence $EC_a$ in a complex and interrelated way. As the percent of clay increases in a soil (particularly the smectite dominant swelling clays such as the Vertosols found extensively in agricultural lands of northern Australia) the water holding capacity also increases and so too the ability to hold salts in solution. A site/soil specific calibration is necessary to differentiate the effects of these variables on $EC_a$.

For the purpose of tracking water movement and re-distribution throughout the growing season, repeated measures at the same locations within the paddock (with salt and clay remaining constant) allow for any changes in $EC_a$ to be attributed to changes in soil water content.

**How do we get a paddock calibration for estimating soil water?**

Calibrations allow us to convert EM38 readings to cumulative soil water estimates via a linear regression (Figure 1). To develop a calibration, concurrent EM38 readings and soil volumetric soil water need to be measured across a range of wet to dry conditions. This can be achieved by sampling a range of moisture conditions in close by (same soil) paddocks e.g. sampling fallow, cropped or pasture/treed areas. Calibrations can also be developed for a single paddock or farm site through time. As few as 6 sampling points gathered across a range of soil moistures may be sufficient to develop a calibration that provides a good estimate of soil water (in uniform soils).

![Figure 1. EM38 readings calibrated against soil water for southern QLD Vertosols - showing variation between sites and soil types for both vertical (1.5 m) and horizontal (0.75 m) dipoles](image)

**A case study – estimating crop water use throughout an irrigated cotton growing season**

In this study we used the EM38 to track soil water under an irrigated cotton crop for part of the growing season. $EC_a$ readings were calibrated against cumulative soil water for a range of wet and dry field conditions (Figure 2a). Soil cores were taken with a soil coring rig to 1.5 m depth and bulk density and gravimetric water content sampled in 0.2 m increments. Cumulative soil water was calculated in vertical dipole (mm to 1.5 m) and horizontal dipole (mm to 0.75 m) or as a function of height-above-ground if the EM38 was raised above ground for readings. Several adjacent paddocks were sampled to get a good range of moistures, including post harvest in zero till sorghum (at crop
lower limit, CLL); our experimental PAWC plots (at drained upper limit, DUL); bare fallow (filling); the cotton crop after an irrigation (wet to saturated); and native vegetation (very dry).

EM38 readings were taken in clusters of 192 readings in rows and furrows using 6 dipole and height-above-ground combinations to target specific depths in the soil. Readings were taken at head, mid and tail positions before and after irrigations and throughout the growing season. Sampling was rapid, taking less than 2 hours to take all 600 readings; including loading and unloading the vehicle between sampling positions (head, mid and tail) and temporarily laying a string sampling framework in each position so that repeated measures occurred on the same spot each time. Results in Figure 2b clearly show us the variability in total infiltration after irrigations (head gets more water than mid or tail), the degree of over watering (at head of paddock and this was accompanied by visible plant water logging), and the crop water use over the growing season.

![Figure 2](image-url)

**Figure 2.** Detailed EM38 measurements of soil water, distribution of irrigation water and changes to the water balance of an irrigated cotton crop, during a summer growing season on a Black Vertosol at Pampas, a) calibration used to estimate soil water, and b) change in soil water to 1.5 m at head, mid and tail positions in the paddock.

**What about soil texture variability in my paddock?**

When we measure $EC_a$ across a paddock with variable soil texture, differentiating soil water content from other attributes becomes increasingly complex. An increase in $EC_a$ may be due to an increase in water content, or salinity or it may be due to an increase in clay (which is often accompanied by increased water and salt). Some care must be taken when interpreting readings in these conditions. Applying a paddock calibration to derive soil water becomes hazardous unless detailed mapping of soil zones, verified by soil surveying, is undertaken and separate calibrations developed for the different soil zones. This requirement, however, is similar for other methods of soil water measurement.

**How does temperature affect the EM38 readings?**

Soil temperature is dependent on time of the year, local climate and paddock conditions. Due to the temperature dependency of $EC_a$, a soil correction factor needs to be used to adjust readings for soil temperature variations. This is only required if measurements occur throughout the year. Tables of representative correction factors have been published for sites within the northern grain growing region. Refer to Table 2 in Huth and Poulton (2007) for temperature corrections.
What if I don’t have a paddock calibration (qualitative versus quantitative use)

The EM38 can be used to enhance and support our instinct, experience and knowledge. By simply walking in the paddock during fallow and cropped conditions with the EM38, changes in soil water and ECₐ can be observed (readings are instantaneous and can be viewed continuously on screen). Over time the operator will come to know both the degree of paddock variability, and the expected ECₐ for a range of moisture conditions for a particular paddock or whole farm. This range will encompass typical readings when the soil is drier e.g. harvest and potentially at CLL, and typical readings when the soil is wetter e.g. at sowing, and potentially when the soil is close to DUL. If an absolute value of PAW (mm) is not required, then this ‘qualitative’ approach is often sufficient. From this type of application, a very useful qualitative estimate can be made about the PAW and how full the ‘bucket’ is.

For example, let us use the soil and calibration from Figure 2 (Black Vertosol from Pampas). We already know from our studies the DUL, theoretical CLL (1500 kPa) and corresponding ECₐ readings (given in Table 1). However for a qualitative assessment we need only know that the typical range of ECₐ values we have observed over a range of soil moisture conditions ranges from ~100-190 mS/m. If we then, for instance, go out into the paddock and find the readings are around ~145 mS/m, we know the paddock ‘bucket’ is half full, i.e. at 50% of PAWC. We don’t need a calibration, simply a range of ECₐ values across wet to dry soil moistures, to then estimate the percent of PAWC available at any time.

Table 1. Soil water estimated from the vertical EM38 calibration on a Black Vertosol at Pampas

<table>
<thead>
<tr>
<th>Soil moisture</th>
<th>Cumulative mm to 1.5 m</th>
<th>ECₐ reading mS/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>DUL</td>
<td>770</td>
<td>188</td>
</tr>
<tr>
<td>CLL</td>
<td>525</td>
<td>100</td>
</tr>
<tr>
<td>50% PAWC</td>
<td>648</td>
<td>143</td>
</tr>
</tbody>
</table>

References


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Reviewed by

Dr Neil Huth, CSIRO, Toowoomba, Queensland.
Managing nitrogen for yield and protein: 2013 update

Rohan Brill, Matthew Gardner, Greg Brooke, Leigh Jenkins, Bruce Haigh and Guy McMullen, NSW DPI Tamworth and Trangie

Key words
Nitrogen, yield, protein, varieties

GRDC code
DAN0169: Variety Specific Agronomy Packages

Take home messages
- Crop N requirement depends on water-limited yield potential, targeted grain protein and crop management (disease, supply of other nutrients, weed control and sowing time).
- When choosing varieties, consider long term yield and protein results for your region, disease resistance/tolerance packages and target grades.
- In 2013 variety choice played a significant role in final grain yield and grain protein concentration, which influenced the capacity to achieve APH.
- Profitable production is driven not only by yield but is also influenced by quality targets and the cost to achieve them. Growers and advisors need to consider the economic cost:return and risks of targeting/achieving APH
- The recovery of applied N in grain can be low with residual soil mineral N levels only accounting for a portion of the unrecovered N.

Introduction
The Variety Specific Agronomy Packages project has been conducting trials since 2007 to evaluate the agronomic management of near release and recently released varieties. This has included trials to test variety responses to applied nitrogen. There have been a number of papers presented at previous GRDC Updates on the key factors that determine N supply and demand in crops. This paper presents new results from 2012 and 2013 from trials on N management. These trials have studied N responses across a range of wheat varieties that have shown adaptation for the northern grain region including improved disease resistance – especially to stripe rust and Pratylenchus thornei.

It is always important to remember that the most important factors that influence yield and protein are location affects (soil water, in-crop rainfall, disease and nutrient supply). When determining application strategies for N fertiliser and appropriate varieties, growers and advisors need to consider the factors listed above as well as target markets.

Soil mineral nitrogen (N) levels and associated grain protein concentrations have generally declined in northern soils over the past five years, largely due to the removal of N in grain (above average yields from 2010-2012 in both summer and winter crops) but also due to potential losses from denitrification in wet seasons. Despite the low soil N levels, the recovery of applied fertiliser N has generally been only low to moderate. For example in six VSAP trials across the northern region in 2012, the apparent efficiency of applied N (N harvested in grain/N applied) ranged from 6.5 % at a high N rate at Spring Ridge to 42.5 % from a low N rate at Trangie. This poses the question - what is the fate of the N that is not harvested in grain?

Strong et al. (1996) reported N recoveries ranging from 39-49% from studies on nitrogen application to irrigated wheat in the Darling Downs region. The recovery of applied N in grain of the subsequent crop ranged from 2 to 6 % and declined further in both the third and fourth crops, resulting in a total
N recovery (in grain) of 56% over four seasons. The authors hypothesised that the remaining N could either be remaining in the soil (potentially in mineral form or immobilised into organic form) or may have been lost through denitrification.

2013 trial details

Following on from nitrogen management trials that were conducted in 2010, 2011 and 2012 seven trials were established in 2013 across northern NSW. Starting mineral (nitrate plus ammonium) nitrogen levels ranged from 80 to 290 kg N/ha and starting soil water from 30 to 185 mm (Table 1).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Garah</th>
<th>Terry Hie Hie</th>
<th>Rowena</th>
<th>Pine Ridge</th>
<th>Wongarbon (Wong)</th>
<th>Merriwa</th>
<th>Trangie (TARC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sowing Date</td>
<td>29/4/13</td>
<td>27/5/13</td>
<td>28/5/13</td>
<td>6/6/13</td>
<td>29/5/13</td>
<td>16/5/13</td>
<td>9/5/2013 (dry)</td>
</tr>
<tr>
<td>Available N at sowing (kg N to 120 cm)</td>
<td>80</td>
<td>93</td>
<td>80</td>
<td>100</td>
<td>290</td>
<td>215</td>
<td>80</td>
</tr>
<tr>
<td>Plant available water at sowing (mm)</td>
<td>81</td>
<td>175</td>
<td>185</td>
<td>-</td>
<td>50</td>
<td>120</td>
<td>30</td>
</tr>
<tr>
<td>In-Crop Rainfall (mm)</td>
<td>140</td>
<td>123</td>
<td>48</td>
<td>95</td>
<td>265</td>
<td>150</td>
<td>205</td>
</tr>
<tr>
<td>Predicta B - Crown Rot</td>
<td>Low</td>
<td>Low</td>
<td>Nil</td>
<td>-</td>
<td>Nil</td>
<td>High</td>
<td>Nil</td>
</tr>
<tr>
<td>Predicta B – RLN</td>
<td>Low (Pt)</td>
<td>Nil</td>
<td>Low (Pt)</td>
<td>-</td>
<td>Low (Pn) Med (Pt)</td>
<td>Nil</td>
<td>Low (Pn)</td>
</tr>
</tbody>
</table>

Results

2013 nitrogen x variety trials

Across-site analysis

Across-site analysis was conducted to determine the contribution of trial factors (trial site, nitrogen rate and variety) to grain yield, grain protein concentration and grain nitrogen yield across the 2013 trials (Table 1). The factors site, N rate and variety collectively accounted for 89%, 76% and 85% of the variation in grain yield, grain protein concentration and gain N yield respectively. Further separation of these effects showed that site effects had the greatest impact, followed by N rate and finally variety choice on grain yield and grain N recovery. Site and N rate accounted for the greatest proportion of variation in protein followed by variety. These results underline the need to firstly consider site effects, especially starting water and soil N, followed by considering the appropriate fertiliser management strategy and thirdly considering variety choice.
Table 2. Contribution of site effects, applied N (kg N/ha) and variety to variation in grain yield, protein and grain N recovery across seven sites in 2013

<table>
<thead>
<tr>
<th>Factors</th>
<th>Grain Yield</th>
<th>Protein</th>
<th>Grain N Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>0.75</td>
<td>0.25</td>
<td>0.63</td>
</tr>
<tr>
<td>Site + Nrate</td>
<td>0.77</td>
<td>0.49</td>
<td>0.72</td>
</tr>
<tr>
<td>Site + Nrate + Variety</td>
<td>0.79</td>
<td>0.63</td>
<td>0.76</td>
</tr>
<tr>
<td>Site * Nrate * Variety</td>
<td>0.89</td>
<td>0.76</td>
<td>0.85</td>
</tr>
</tbody>
</table>

**Nitrogen Responses**

Significant yield responses to applied N were measured at three of the seven trial sites – two positive and one negative (Figure 1). At Pine Ridge and Terry Hie Hie there was a significant response to each level of applied N. At Trangie the only significant response was a yield reduction at the highest N rate compared to the untreated control. The sites that responded positively were both relatively high yielding and had starting soil nitrogen levels < 100 kg N/ha.

The responsive sites at Pine Ridge and Terry Hie Hie also had a significant interaction between variety and applied N (Figure 2). At Pine Ridge the higher applications of N increased yield for EGA Gregory, Suntop and Spitfire whereas the other lines reached maximum yield at 80 kg N/ha. At Terry Hie Hie, EGA Gregory and Suntop had higher yields at 160 kg N/ha compared to other lines which had maximum yields at 80 kg N/ha, while Sunvale was not responsive to applied N at this site.
Figure 2. Effect of N rate and variety on grain yield at Pine Ridge (top) and Terry Hie Hie (bottom) in 2013

With respect to grain protein concentration, all sites were responsive to additional N (Figure 3). At Wongarbon, the site with the highest starting N, all treatments (including the control with no added N) achieved grain protein concentration >13%. At all other sites additional N was required to achieve 13% protein when averaged across all varieties. There was a significant interaction between N rate and variety at Terry Hie Hie and Rowena.

If targeting protein ≥13%, the application of 160 kg N/ha at Pine Ridge failed to meet this level when averaged across varieties. At the other responsive yield site at Terry Hie Hie 160 kg N/ha was required to achieve 13% protein. At Rowena, Garah and Trangie the application of 40 kg N/ha was required to achieve 13% protein. Merriwa required between 40 - 80 kg N/ha to achieve 13% protein.
Variety

At all seven sites in 2013 there was a significant effect of variety on yield, grain protein concentration and grain nitrogen recovery (GNR). The best performing varieties for grain yield were Dart(1), EGA Gregory(1), Suntop(1) and Spitfire(1). EGA Gregory(1) was in the highest yielding group at four of seven sites while Dart(1), Suntop(1) and Spitfire(1) in three of seven sites (Table 3).

Table 3. Effect of variety (averaged across N rates) on grain yield at seven sites in 2013

<table>
<thead>
<tr>
<th>Variety</th>
<th>Pine Ridge</th>
<th>Terry HH</th>
<th>Rowena</th>
<th>Garah</th>
<th>Merriwa</th>
<th>Wong</th>
<th>Trangie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caparoi(1)</td>
<td>3.88</td>
<td>c</td>
<td>3.13</td>
<td>d</td>
<td>3.81</td>
<td>a</td>
<td>2.16</td>
</tr>
<tr>
<td>Dart(1)</td>
<td>3.94</td>
<td>bc</td>
<td>3.55</td>
<td>b</td>
<td>3.67</td>
<td>ab</td>
<td>2.01</td>
</tr>
<tr>
<td>EGA Gregory(1)</td>
<td>4.44</td>
<td>a</td>
<td>3.52</td>
<td>b</td>
<td>3.67</td>
<td>ab</td>
<td>2.51</td>
</tr>
<tr>
<td>Livingston(1)</td>
<td>4.05</td>
<td>b</td>
<td>3.39</td>
<td>c</td>
<td>3.55</td>
<td>bc</td>
<td>2.25</td>
</tr>
<tr>
<td>Spitfire(1)</td>
<td>4.32</td>
<td>a</td>
<td>3.53</td>
<td>b</td>
<td>3.47</td>
<td>c</td>
<td>2.52</td>
</tr>
<tr>
<td>Sunguard(1)</td>
<td>4.02</td>
<td>bc</td>
<td>3.47</td>
<td>bc</td>
<td>3.56</td>
<td>bc</td>
<td>2.55</td>
</tr>
<tr>
<td>Suntop(1)</td>
<td>4.30</td>
<td>a</td>
<td>3.89</td>
<td>a</td>
<td>3.55</td>
<td>bc</td>
<td>2.51</td>
</tr>
<tr>
<td>Sunvale</td>
<td>3.99</td>
<td>bc</td>
<td>3.08</td>
<td>d</td>
<td>3.25</td>
<td>d</td>
<td>2.51</td>
</tr>
<tr>
<td>P value</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.007</td>
<td>0.001</td>
</tr>
<tr>
<td>5% LSD</td>
<td>0.14</td>
<td>0.11</td>
<td>0.16</td>
<td>0.24</td>
<td>0.31</td>
<td>0.22</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Variety also had a consistent impact on grain protein across all sites in 2013 (Table 4). At most sites protein levels were close to APH receival standards of 13% when averaged across N treatments. The exception to this was Pine Ridge where no variety achieved APH protein levels. As was seen in 2012 trials Spitfire(1) had consistently higher grain protein concentration across all sites – even those sites where it was the highest yielding variety. Spitfire(1) achieved APH protein levels at six of seven sites. This contrasts with the other high yielding lines EGA Gregory(1), which achieved APH at one site, and Suntop(1) which failed to achieve APH at any of the sites in these trials.
Table 4. Effect of variety (averaged across N rates) on grain protein concentration at seven sites in 2013

Means within sites followed by the same letter are not significantly different at P=0.05

<table>
<thead>
<tr>
<th>Variety</th>
<th>Pine Ridge</th>
<th>Terry HH.</th>
<th>Rowena</th>
<th>Garah</th>
<th>Merriwa</th>
<th>Wong.</th>
<th>Trangie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caparoi</td>
<td>11.9</td>
<td>11.9</td>
<td>13.4</td>
<td>13.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dart</td>
<td>11.9</td>
<td>12.1</td>
<td>13.3</td>
<td>14.3</td>
<td>12.2</td>
<td>12.6</td>
<td>13.1</td>
</tr>
<tr>
<td>EGA Gregory</td>
<td>10.9</td>
<td>11.4</td>
<td>12.7</td>
<td>12.1</td>
<td>12.8</td>
<td></td>
<td>12.5</td>
</tr>
<tr>
<td>Livingston</td>
<td>11.6</td>
<td>11.9</td>
<td>12.8</td>
<td>13.9</td>
<td>13.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spitfire</td>
<td>12.3</td>
<td>13.2</td>
<td>14.5</td>
<td>14.0</td>
<td>13.5</td>
<td>13.6</td>
<td>14.1</td>
</tr>
<tr>
<td>Sunguard</td>
<td>11.3</td>
<td>11.8</td>
<td>12.7</td>
<td>12.7</td>
<td>13.2</td>
<td>13.5</td>
<td>12.6</td>
</tr>
<tr>
<td>Suntop</td>
<td>11.4</td>
<td>11.3</td>
<td>12.7</td>
<td>12.8</td>
<td>12.4</td>
<td>12.8</td>
<td>12.3</td>
</tr>
<tr>
<td>Sunvale</td>
<td>12.1</td>
<td>12.9</td>
<td>13.5</td>
<td>13.3</td>
<td>14.5</td>
<td>14.6</td>
<td>13.4</td>
</tr>
</tbody>
</table>

P value       | 0.001      | 0.001     | 0.001  | 0.001 | 0.001   | 0.007 | 0.001   |
5% LSD        | 0.5        | 0.4       | 0.3    | 0.4   | 0.6     | 0.2   | 0.2     |

At Terry Hie Hie and Rowena there was a significant interaction between N rate and varietal protein levels (Figures 4 and 5 respectively). At Terry Hie Hie, Spitfire and Sunvale had similar protein responses to increasing N rates and achieved higher protein levels at each N increment compared to EGA Gregory, Sunguard and Suntop. EGA Gregory and Suntop had greater yield increases at higher N rates at this site compared to the other varieties (Figure 2). Despite protein differences between Spitfire and Sunvale at the high end and EGA Gregory, Sunguard and Suntop at the low end, the rate of protein response to applied N was similar for each of these five varieties. Dart responded differently to these varieties, having similar protein levels to Spitfire and Sunvale where nil N was applied but with a smaller increase in grain protein with increasing N rate.

![Figure 4](image_url)

Figure 4. Effect of N rate and variety on grain protein at Terry Hie Hie in 2013

At Rowena, which did not have a yield response to additional N, Spitfire had significantly higher grain protein concentration (achieving APH1) at all N application rates compared with all other varieties. Sunvale was the most responsive (in terms of grain protein concentration) to added N at this site.
The grain N recovery (GNR), calculated from the total yield and protein, also showed significant differences between varieties in 2013. At all sites Spitfire had the highest GNR while the performance of the other high yielding lines was more variable (Table 5).

Table 5. Effect of variety on grain N recovery in 2013

<table>
<thead>
<tr>
<th>Variety</th>
<th>Pine Ridge</th>
<th>Terry HH.</th>
<th>Rowena</th>
<th>Garah</th>
<th>Merriwa</th>
<th>Wong.</th>
<th>Trangie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caparoi</td>
<td>83 bc</td>
<td>66 d</td>
<td>89 a</td>
<td>52 cd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dart</td>
<td>83 bc</td>
<td>76 b</td>
<td>85 b</td>
<td>50 d</td>
<td>58 b</td>
<td>91 bcd</td>
<td>67 c</td>
</tr>
<tr>
<td>EGA Gregory</td>
<td>87 b</td>
<td>71 c</td>
<td>81 c</td>
<td>53 cd</td>
<td>48 cd</td>
<td>90 cd</td>
<td>74 b</td>
</tr>
<tr>
<td>Livingston</td>
<td>84 bc</td>
<td>71 c</td>
<td>79 cd</td>
<td>55 bcd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spitfire</td>
<td>95 a</td>
<td>82 a</td>
<td>88 ab</td>
<td>62 a</td>
<td>66 a</td>
<td>100 a</td>
<td>78 a</td>
</tr>
<tr>
<td>Sunguard</td>
<td>80 c</td>
<td>72 c</td>
<td>79 cd</td>
<td>56 bc</td>
<td>50 c</td>
<td>95 ab</td>
<td>67 c</td>
</tr>
<tr>
<td>Suntop</td>
<td>87 b</td>
<td>77 b</td>
<td>79 cd</td>
<td>56 bc</td>
<td>46 cd</td>
<td>87 d</td>
<td>67 c</td>
</tr>
<tr>
<td>Sunvale</td>
<td>86 b</td>
<td>70 c</td>
<td>77 d</td>
<td>58 ab</td>
<td>41 d</td>
<td>94 bc</td>
<td>67 c</td>
</tr>
<tr>
<td>P value</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>5% LSD</td>
<td>5.0</td>
<td>2.9</td>
<td>3.4</td>
<td>5.0</td>
<td>6.7</td>
<td>4.7</td>
<td>3.7</td>
</tr>
</tbody>
</table>

At the yield responsive sites at Pine Ridge and Terry Hee Hee there was also a significant interaction between variety and N rate for GNR (Figure 6). Varieties with higher GNR at higher N levels were EGA Gregory, Spitfire and Suntop. At the lower N rates Spitfire had higher GNR compared to most other lines.

Figure 5. Effect of N rate and variety on grain protein at Rowena in 2013

The grain N recovery (GNR), calculated from the total yield and protein, also showed significant differences between varieties in 2013. At all sites Spitfire had the highest GNR while the performance of the other high yielding lines was more variable (Table 5).
Recovery of nitrogen in soil and grain – results from 2012 trials

To determine the portion of applied N that is available in mineral form to the subsequent crop, EGA Gregory plots in three VSAP N trials from 2012 were soil cored to a depth of 90 cm in autumn 2013. These trials were analysed for mineral N availability (nitrate and ammonium) and then calculated into a kg/ha basis assuming a bulk density at all sites of 1.4g/cm³. At Forbes and Wagga Wagga there were four N treatments applied – nil, 50 kg/ha at sowing, 50 kg/ha at sowing followed by 50 kg/ha at Z31 and 50kg/ha at sowing followed by 100 kg/ha at Z31. At Coonamble there were three N treatments applied, all at sowing – nil, 50 and 100 kg N/ha.

The N accounted for in grain in these trials was generally low. The highest recovery was at Forbes with 26% of the 50 kg/ha N rate at sowing recovered in the grain at harvest (Table 6).
Table 6. Recovery of N (%) in grain (harvest 2012) and in soil (cored autumn 2013) following N application (kg N/ha) to EGA Gregory at Forbes, Wagga Wagga and Coonamble in 2012

<table>
<thead>
<tr>
<th>Fertiliser recovery</th>
<th>Forbes</th>
<th>Wagga Wagga</th>
<th>Coonamble</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2012 N rate (kg/ha) and timing</td>
<td>2012 N rate (kg/ha) and timing</td>
<td>2012 N rate (kg/ha) and timing</td>
</tr>
<tr>
<td></td>
<td>50 sow</td>
<td>50 sow + 100</td>
<td>50 sow</td>
</tr>
<tr>
<td>Accounted N in grain</td>
<td>13 22 27</td>
<td>2 4 5</td>
<td>9 11</td>
</tr>
<tr>
<td>N Uptake from sowing N</td>
<td>13 13 13</td>
<td>2 2 2</td>
<td>2 2</td>
</tr>
<tr>
<td>N Uptake from Z31</td>
<td>9 15</td>
<td>2 3</td>
<td></td>
</tr>
<tr>
<td>Accounted N in soil</td>
<td>2 45 81</td>
<td>40 50 77</td>
<td>4 30</td>
</tr>
<tr>
<td>Residual N from sowing</td>
<td>2 2 2</td>
<td>40 40 40</td>
<td>11 37</td>
</tr>
<tr>
<td>Residual N from Z31</td>
<td>43 78</td>
<td>-2 7</td>
<td></td>
</tr>
<tr>
<td>Unaccounted N</td>
<td>35 33 42</td>
<td>8 46 69</td>
<td>37 59</td>
</tr>
<tr>
<td>Unaccounted from sowing</td>
<td>35 35 35</td>
<td>8 8 8</td>
<td></td>
</tr>
<tr>
<td>Unaccounted N from Z31</td>
<td>38 61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

At Forbes there was a high recovery (soil and grain) of the N that was applied at Z31, calculated to be 100% and 93% for the 50 and 100 kg/ha rates respectively; but there was only a low recovery of the 50 kg/ha N rate applied at sowing (30%). The N application at sowing at Forbes was done to soil that was at field capacity and followed by rain causing waterlogging that may have led to denitrification.

The Wagga Wagga results were in direct contrast to the Forbes results, as the total recovery (grain and soil) from the 50 kg/ha N rate at sowing was 84%, but the recovery from the Z31 applications of 50 and 100 kg/ha N was 26% and 40% respectively. The free draining soil type at Wagga Wagga is generally not conducive to waterlogging so denitrification from sowing would have been less of an issue than at Forbes.

The recovery of N in grain and soil at Coonamble was 26% and 41% of the 50 and 100 kg/ha N applications at sowing.

Location of residual nitrogen in the soil profile

The trial sites were each cored in four separate soil depth segments; 0-10 cm, 10-30 cm, 30-60 cm and 60-90 cm. At Forbes and Coonamble (Figure 7) the residual nitrogen from 2012 applications was generally only found in the 0-10 and 10-30 cm layers, with no significant effect of N application evident in the 30-60 and 60-90 cm. This would likely be due to the low rainfall received after mid-July in 2012.
Figure 7. Mineral N at four separate soil depth segments in autumn 2013 following four N application treatments at Forbes (left) and Coonamble (right) in 2012

At Wagga there was a trend for the residual N to be found at all segments of the soil profile (Figure 8). The Wagga site was a well drained soil type and these tests showed that the applied N moved down through the profile to at least 90 cm.

Figure 8. Mineral N at four separate soil depth segments in autumn 2013 following four N application treatments at Wagga Wagga in 2012

Conclusions

There were strong effects of site, N application and varietal choice on yield, protein and grain N recovery in 2013. Site and N application were strong determinants of these factors with variety having a smaller but still important role.

There was generally a low grain recovery of applied N in VSAP trials in 2012. When the mineral N in the soil was also accounted for, the recovery of N ranged from 26% to 84% and averaged approximately 48%.
Although these trials show that a portion of unused N may be available to the subsequent crop, the amount of N that is available to be recovered is generally significantly less than the difference between N applied and N recovered in grain. The reasons for this are unclear from these trials, but there are several possible explanations that could all contribute to the low N recovery, including:

- Nitrogen unaccounted for in the straw.
- Immobilisation (conversion of nitrogen to organic form) – this would likely have occurred to some degree at all sites.
- Denitrification – most likely at the Forbes site from the N treatments applied at sowing. Unlikely to be a major cause at Wagga Wagga (well drained soil) or Coonamble (insufficient rainfall).
- Leaching – Unlikely to be a major cause at Forbes and Coonamble, but potentially a cause at Wagga.
- Volatilisation – possible at all sites, but previous research in Northern NSW by Schwenke et al. has shown that losses in winter cropping are not major.

There are often trade-offs for N management in northern farming systems, as in-crop rainfall is generally variable and unreliable for N application; however the application of high rates of N at sowing can be risky in economic and agronomic terms.

Management factors to increase nitrogen efficiency in the region include:

- Increasing the area of crop planted to grain legumes in order to supply N in a slower release organic form that is less prone to denitrification.
- Match N inputs to water availability and crop yield potential.
- Avoid the application of N prior to rainfall events that may cause waterlogging, especially in environments that may be prone to flooding.

Acknowledgments

The Variety Specific Agronomy Project (DAN00169) is a partnership between NSW DPI and GRDC. The trials would not have been possible without the valuable input of growers and advisors at each location. The trials and data collection were managed by Stephen Morphett, Jayne Jenkins, Jim Perfremment, Patrick Mortell, Peter Formann, Jan Hoskings and Rod Bambach (all NSW DPI).

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Reviewed by:

Dr Steven Simpfendorfer

Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.
Nitrogen management in wheat - getting more grain per dollar of nitrogen applied. The economics of chasing protein and issues of NUE and timing

Jim Laycock, Incitec Pivot Fertilisers

Key words
Nitrogen, Economics, Protein, NUE, Timing

Take home messages
Aim to maximise yield response first when budgeting for seasonal nitrogen.
Protein responses to the application of nitrogen from GS40 to GS61 are more reliable where yield is already maximised.

Product key
- Urea 46% N
- Easy N (UAN) 32% N w/w or 42.5% w/v
- PCU – polymer coated urea 3 month release pattern – 43% N
- Entec® Urea – urea treated with nitrification inhibitor DMPP – 46% N
- GreenNV – urea treated with a urease enzyme inhibitor NBPT – 46%N

Curban Enhanced N 2013

Figure 1. Gregory sown into lupin stubble, on a Red Sodosol on the 17th May with reasonable soil moisture. Site management and statistical analysis by Kalyx with the co-operation of C&S Roche, “Reedsdale” Curban. GSR 180mm

Observations
- Basal application of 12N/24P per hectare as Granulock Z (11%N:22%P:4%S:1%Zn).
- There were no screenings >2% at any nitrogen rate.
- All grain sample weights were >75kgs/hectolitre
- No significant response in plot grain yield to product type, placement, rate or timing of application.
• Significant grain protein response to 30kgs/ha/N (12.6%) over the 12kgs/ha/N (11.5%) applied with Granulock Z at plant
• Significant protein response to 60kgs/ha/N (13.6%) over 30kgs/ha/N (12.6%) applied at plant
• No significant difference in protein between 90kgs/ha/N (14.1%) and 120kgs/ha/N (14.8%)
• Significant protein response with 120kgs/ha/N (14.8%) over 60kgs/ha/N (13.6%) applied at plant
• No significant difference in grain protein when 50% of the N was applied at plant and 50% applied as a topdressing at GS31.
• When 60kgs/ha/N and 90kgs/ha/N was applied at planting and 25kgs/ha/N applied at GS59 as urea or Easy N there was a significant grain protein response at the 60kgs/ha/N and 25kgs/ha/N rate over the urea top dressed treatment when Easy N was applied through streamer nozzles.
• There was no significant difference in grain protein for the PCU treatments at 60kgs/ha/N (12.7%) over the 30kgs/ha/N (12.6%) applied at plant. All other treatments (apart from the control) were significantly greater than the PCU treatments. At 13.6% the urea plus Entec treatment, grain protein was significantly better than the PCU treatments.

Conclusions

A minimum of least 60kgs/ha/N of additional N was required to move grain plot yields of 3.5t/ha above 13% protein at the Curban site. With all nitrogen rate treatments up to 120kgs/ha/N screenings were less than 5%.

A combination of the 2013 wheat grade pricing and low yields due to below average growing season rainfall resulted in a lack of economic response to applied nitrogen in this trial. As is often the case where yield potential is below average it is difficult to justify the additional cost of nitrogen to move wheat quality to higher grades without a significant yield response as well.
Enhanced N Forbes 2013

**Figure 2.** Suntop wheat sown into canola stubble on Red Kandosol on the 26th of May with good soil moisture. Sown by Kalyx using the IPF cone seeder with the co-operation of Chris Morrison, Forbes. Trial management and statistical analysis by Kalyx. GSR 283mm

**Observations**

- Basal application of 12N/24kgs/ha/P as Granulock Z.
- There were no screenings >2% at any nitrogen rate.
- All grain sample weights were >75kgs/hectolitre
- Significant plot grain yield and/or grain protein responses to product type, placement, rate and timing of application.
- No significant plot grain yield response to 30kgs/ha/N applied banded below and to the side of the plant line at planting (4.50t/ha) over the control (4.54t/ha). Significant protein response to 30kgs/ha/N (8.8%) over the control (8.2%)  
- Significant plot grain yield response to 60kgs/ha/N (5.11t/ha) over the 30kgs/ha/N (4.50t/ha). Significant grain protein response to 60kgs/ha/N (10%) over the 30kgs/ha/N (8.8%) 
- No significant plot grain yield response with 90kgs/ha/N (5.38t/ha) and 120kgs/ha/N (5.34t/ha) over the 60kgs/ha/N (5.11t/ha). Significant grain protein response to 90kgs/ha/N (11.1%) and 120kgs/ha/N (11.7%) over 60kgs/ha/N (10%) 
- Where the 60-90kgs/ha/N rates as urea were split between banded at plant and top dressed at GS31 there was no significant difference in plot grain yield. There were significant differences in grain protein with 60kgs/ha/N (10%) and 90kgs/ha/N (11.1%) when the N was applied at planting over the split treatments 60kgs/ha/N (9.6%) and 90kgs/ha/N (10.6%) 
- There was no significant yield difference with the 120kgs/ha/N split treatment over the control. There may have been an error with application rates.
• There was no significant difference in plot grain yield or protein over topdress urea where GreenNV (30kgs/ha/N, 45kgs/ha/N) and EasyN (30kgs/ha/N, 45kgs/ha/N) were applied at GS31.

• No significant plot grain yield response where 60kgs/ha/N as urea banded at plant and EasyN (25kgs/ha/N) top dressed with streamers at GS60 over 25kgs/ha/N as urea. Significant protein response with EasyN (10.8%) with streamers over 25kgs/ha/N/urea (10.3%) broadcast at GS60.

• No significant plot grain yield response where 90kgs/ha/N/urea was applied at plant and 25kgs/ha/N as urea or EasyN was applied at GS60 over 120kgs/ha/N/urea applied at plant.

• No significant plot grain yield differences between PCU (5.76t/ha) with seed, PCU (5.33t/ha) banded below and to the side of the seed and Urea plus Entec (5.39t/ha) banded below and to the side of the seed at 60kgs/ha/N.

• Significant plot grain yield response where PCU at 60kgs/ha/N (5.76t/ha) was applied banded with the seed over the 60kgs/ha/N/urea (5.11t/ha) banded below and to the side of the seed. Significantly less protein with PCU (9.3%) banded with the seed over 60kgs/ha/N/urea (10%) banded below and to the side of the seed.

• Urea plus Entec (10.2%) at 60kgs/ha/N had significantly higher proteins than PCU (9.3%) with the seed and PCU (9%) banded away from the seed.

**Conclusion**

Significant economic gains were made from nitrogen applications at this high plot yield trial site. The highest grains were achieved by increasing yield first and then additional nitrogen moved grain protein significantly higher.

Nitrogen significantly increased grain yield up to 60kgs/ha/N and as rates increased from 90kgs/ha/N to 120kgs/ha/N protein increased using a range of different strategies, products and timings. At this site in 2013 a minimum of 60kgs/ha/N applied using various strategies, products, timing and placements was required to increase yields significantly (0.563t/ha) over the control.

Economic gains were made as an additional 30kgs/ha/N significantly increased protein from 10 to 11.1% and moved those treatments into APW. An additional 30kgs/ha/N increased protein to 11.7% and H2.

The change in grade from ASW to APW at the 90kgs/ha/N rate resulted in the best economic response to the application of nitrogen at this site. The only other treatments on this site to achieve APW grade were those where a minimum of 60kgs/ha/N was applied at planting followed by additional N.

With a significant rainfall event of 55mm 29 days after top dressing the 45kgs/ha/N applied at planting and 45kgs/ha/N top dressed produced a similar yield result to all the nitrogen (90kgs/ha/N) applied at planting but only ASW classification.

Treatments applied at GS59 of 25kg/ha/N with various products and strategies delivered a similar result. A base line level of at least 60kgs/ha of nitrogen was required to increase yield, the additional 25kgs/ha/N of nitrogen at GS59 followed by 7mm within 48hrs was sufficient to move grades from ASW to APW in 3 out of the 4 treatments.

Nitrogen use efficiency at this site using the difference method ranged from 14-52%
Gunnedah enhanced N 2013

**Figure 3.** Spitfire sown into wheat stubble on a black Vertosol on the 10th July with reasonable soil moisture. Site management and statistical analysis by Pathway Ag with the co-operation of Andy McGovern. GSR 66mm.

**Observations**

- Dry season, only 66mm of rain between planting and harvest
- Only statistically significant plot grain yield was where plant population was reduced due to urea in contact with seed in the seed furrow at planting
- All proteins greater than 14%. 60kgs/ha/N soil nitrogen in 0-60cm profile at planting
- All screenings 10% and above as a result of late planting and severe moisture deficit during grain fill. No crown rot symptoms observed on this site in 2013.

**Conclusions**

Dry seasonal conditions and late sowing impacted severely at this trial site in 2013

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The effectiveness of nitrogen application for protein – 2012 and 2013

Northern Grower Alliance

Key words
Nitrogen, wheat, protein, late nitrogen application

GRDC code
NGA00003: GRDC Grower Solutions for Northern NSW and Southern Qld

Take home messages
1. Foliar application of urea solution provided significant increases in grain protein compared to urea applied by streambar or spread, in a series of eleven trials during 2012 and 2013
2. The level of protein benefit was NOT sufficient to generate a net benefit in any trial
3. Timing differences were less clear, with best results generally from application during late head emergence through to the early milk stage.
4. The highest level of nitrogen recovery in grain protein was 37% in 2012 and 28% in 2013
5. Grain grade price differentials of at least $20-40/t are necessary to warrant foliar application for protein accumulation unless nitrogen recovery can be increased dramatically
6. Assessment of residual soil nitrogen showed total grain and soil recovery from Spread urea was >85% at Weemelah in 2013, despite generally dry conditions following application
7. Application of spread urea at planting provided the most consistent and highest level of grain protein across the dryland sites
8. Targeting nitrogen budgets to maximise yield for soil moisture availability is expected to be more profitable than trying to manipulate protein with late nitrogen application

A frequent issue across the northern region in both 2010 and 2011 was the harvest of wheat at yields well above expectation but with low to very low grain protein levels, not infrequently under 10%. This of course resulted in downgrading at receival and consequently reduced economic returns. Although low protein was evident in a wide range of varieties, EGA Gregory was frequently of concern.

There were a large combination of factors causing the low protein achievement but a clear message from industry was the need to determine whether late application of nitrogen for protein manipulation was an effective management option under northern conditions.

This paper reports on trials conducted in 2012 and 2013, primarily to evaluate the impact of late nitrogen strategies on protein accumulation and to indicate the likelihood of economic benefit.

Primary Aims
1. How effective and economic are late applications of nitrogen for grain protein achievement?
2. Is there an optimal method or timing?

What was done?
A series of eleven application method and timing trials were conducted in southern Qld and northern NSW during the two seasons, with nearly all sites under dryland conditions:
2012 - Inglestone and Bowenville Qld; Tulloona, Croppa Creek, Bellata and Walget NSW
2013 - Brookstead (irrigated) and Pilton Qld; Weemelah, Tulloona and Narrabri (supplementary irrigation) NSW

All sites evaluated a combination of application methods and timings with urea applied at a standard rate of 40kg N/ha (~87kg urea/ha). This rate was chosen to maximise the likelihood of achieving measureable differences in grain protein. This rate is at the upper end of commercially applied in-crop rates. Three application methods were used:

1. **Spread** - urea simply spread by hand

2. **Streambar** – urea applied in an aqueous solution using BFS streamer bars in 2012 and Chafer streambars in 2013 (Promax 22% urea solution used in 2012 and Ranger 24% in 2013)

3. **Foliar** – urea applied in an aqueous solution using AIXR nozzles in 2012 and TTJ03 nozzles in 2013

All sites had a minimum of four ‘late’ application timings. These timings commenced at ~ full flag leaf emergence (GS39) and then at ~10-14 day intervals. The last timing was generally during dough development (~GS83-87). Table 1 details the level of crop available nitrogen (soil level plus grower fertiliser program) together with the crop growth stages when additional nitrogen was applied.

Multiple timings were conducted in an attempt to generate a timing response ‘curve’ for protein accumulation with an expectation that applications ~7-10 days either side of flowering may result in the highest protein content. Yield responses to nitrogen applied at these timings are generally negligible.

Seven of the eleven sites were planted with small plot equipment. At these sites (Bellata and Walgett in 2012 and all sites in 2013) ‘early’ application of spread urea at 40kg N/ha was also evaluated. All these sites evaluated 40 kg N/ha as spread urea applied at planting (IBS), applied at jointing (GS30) or split evenly between the two timings. The remaining four trials in 2012 were conducted in commercially grown crops. All trials investigated the impact of additional nitrogen under conditions where yield and nitrogen supply were believed to be reasonably matched rather than targeting nitrogen deficient situations.

### Table 1. Crop available nitrogen* and crop growth stages at ‘late’ application timings

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Crop available nitrogen* kg N/ha</th>
<th>Timing 1</th>
<th>Timing 2</th>
<th>Timing 3</th>
<th>Timing 4</th>
<th>Timing 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Inglestone</td>
<td>Not tested</td>
<td>GS39</td>
<td>GS49</td>
<td>GS63</td>
<td>GS76</td>
<td>GS84</td>
</tr>
<tr>
<td></td>
<td>Bowenville</td>
<td></td>
<td>GS41</td>
<td>GS51</td>
<td>GS74</td>
<td>GS78</td>
<td>GS86</td>
</tr>
<tr>
<td></td>
<td>Tulloona</td>
<td></td>
<td>GS39</td>
<td>GS51</td>
<td>GS55</td>
<td>GS65</td>
<td>GS73</td>
</tr>
<tr>
<td></td>
<td>Croppa Creek</td>
<td></td>
<td>GS45</td>
<td>GS59</td>
<td>GS67</td>
<td>GS74</td>
<td>GS85</td>
</tr>
<tr>
<td></td>
<td>Bellata</td>
<td>160 (0-90cm)</td>
<td>GS41</td>
<td>GS51</td>
<td>GS69</td>
<td>GS83</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Walgett</td>
<td>70 (0-90cm)</td>
<td>GS39</td>
<td>GS61</td>
<td>GS69</td>
<td>GS83</td>
<td>-</td>
</tr>
<tr>
<td>2013</td>
<td>Brookstead</td>
<td>277 (0-90cm)</td>
<td>GS47</td>
<td>GS61</td>
<td>GS73</td>
<td>GS82</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Pilton</td>
<td>147 (0-90cm)</td>
<td>GS39</td>
<td>GS57</td>
<td>GS61</td>
<td>GS85</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Weemelah</td>
<td>84 (0-60cm)</td>
<td>GS39</td>
<td>GS60</td>
<td>GS71</td>
<td>GS77</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Tulloona</td>
<td>129 (0-60cm)</td>
<td>GS39-41</td>
<td>GS60</td>
<td>GS71-73</td>
<td>GS77-83</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Narrabri</td>
<td>141 (0-60cm)</td>
<td>GS39</td>
<td>GS45</td>
<td>GS65</td>
<td>GS73</td>
<td>-</td>
</tr>
</tbody>
</table>

*Crop available nitrogen = total soil mineral N kg/ha (to soil depth) plus fertiliser N kg/ha available across entire trial. It does NOT include any mineralisation credit.

Brookstead double-cropped in cotton stubble with soil mineral N of 16 kg/ha, received 111 kg N/ha at planting and 150 kg N/ha top-dressed as urea ~10 days prior to GS30. Yield target at planting 6-7t/ha

GS39 - full flag leaf emergence, GS49 - first awns visible, GS59 - head fully emerged, GS69 - anthesis complete, GS77 - late milk, GS87 - hard dough
Wheat varieties evaluated

EGA Gregory was evaluated for nitrogen response at nine of the eleven sites. Suntop was evaluated at the two irrigated sites in 2013 (Brookstead and Narrabri).

Rainfall

Rainfall quantity and timing at each site, together with any irrigation, is shown in Table 2. Low levels of rainfall were recorded at most sites during August to October in both years. Irrigations at the Brookstead site were well timed following nitrogen application and were expected to provide nearly ‘ideal conditions’ for incorporation and uptake of Timing 1, 2 and 3 applications.

Table 2. Rainfall quantity and interval following nitrogen application timings

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Timing 1</th>
<th>Timing 2</th>
<th>Timing 3</th>
<th>Timing 4</th>
<th>Timing 5</th>
<th>Total rainfall*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Inglestone</td>
<td>8 mm, +8 days</td>
<td></td>
<td>5 mm, +7 days</td>
<td></td>
<td>8 mm, +4 days</td>
<td>21 mm</td>
</tr>
<tr>
<td></td>
<td>Bowenville</td>
<td>10 mm, +3 days</td>
<td>-</td>
<td>-</td>
<td>41 mm, +4 days</td>
<td>-</td>
<td>51 mm</td>
</tr>
<tr>
<td></td>
<td>Tulloona</td>
<td>2 mm, +11 days</td>
<td>-</td>
<td>-</td>
<td>9 mm, +9 days</td>
<td>4 mm, +5 days</td>
<td>15 mm</td>
</tr>
<tr>
<td></td>
<td>Croppa Creek</td>
<td>19 mm, +15 days</td>
<td>-</td>
<td>5 mm, +3 days</td>
<td>15 mm, +6 days</td>
<td>-</td>
<td>39 mm</td>
</tr>
<tr>
<td></td>
<td>Bellata</td>
<td>-</td>
<td>1 mm, +11 days</td>
<td>5 mm, +4 days</td>
<td>16 mm, +3 days</td>
<td>NA</td>
<td>21 mm</td>
</tr>
<tr>
<td></td>
<td>Walgett</td>
<td>11 mm, +8 days</td>
<td>-</td>
<td>2 mm, +2 days</td>
<td>-</td>
<td>NA</td>
<td>12 mm</td>
</tr>
<tr>
<td>2013</td>
<td>Brookstead</td>
<td>38 mm, +8 days</td>
<td>7 mm, +9 days</td>
<td>3 mm, +6 days</td>
<td>1 mm, +3 days</td>
<td>NA</td>
<td>65 mm rainfall</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 mm, +0 days</td>
<td>30 mm, +3 days</td>
<td>30 mm, +2 days</td>
<td></td>
<td>150 mm irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 mm, +5 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30 mm irrigation</td>
</tr>
<tr>
<td></td>
<td>Pilton</td>
<td>10 mm, +8 days</td>
<td>2 mm, +13 days</td>
<td>5 mm, +2 days</td>
<td>10 mm, +10 days</td>
<td>NA</td>
<td>34 mm</td>
</tr>
<tr>
<td></td>
<td>Weemelah</td>
<td>-</td>
<td>19 mm, +7 days</td>
<td>8 mm, +8 days</td>
<td>-</td>
<td>NA</td>
<td>27 mm</td>
</tr>
<tr>
<td></td>
<td>Tulloona</td>
<td>-</td>
<td>22 mm, +6 days</td>
<td>8 mm, +7 days</td>
<td>-</td>
<td>NA</td>
<td>29 mm</td>
</tr>
<tr>
<td></td>
<td>Narrabri</td>
<td>-</td>
<td>19 mm, +5 days</td>
<td>6 mm, +7 days</td>
<td>-</td>
<td>NA</td>
<td>25 mm irrigation</td>
</tr>
</tbody>
</table>

Eg at the Inglestone site, 8 mm of rain were recorded 8 days after Timing 1, there was no rain between Timing 2 and 3 with 5 mm received 7 days after Timing 3.

* Total rainfall = amount recorded between the Timing 1 application and 14 days after the last application.

All irrigation quantities and timings are shown in bold.

Site characterisation – yield and protein

Figure 1 shows the yield and protein levels of untreated grain at each site. Yields ranged from ~2 to 5t/ha in both years but with the majority of sites >3t/ha. Protein levels were low to very low in 2012, ranging from 8.8 to 11.8% with increased levels in 2013, ranging from 11.2 to 14.3%.
Figure 1. Yield and protein content of untreated grain at individual sites

Late season nitrogen application - key results

Leaf scorch

The only treatment that caused any noticeable leaf burn or scorch was urea applied as an aqueous solution through a conventional nozzle (Foliar treatment). However the level of damage was not concerning at any site or application timing in this series of trials (the only concerning level of leaf scorch occurred in a separate trial in 2013 with UAN application at 40 kg N/ha)

Yield

There was a significant impact on yield recorded in only one of the eleven trials. At Weemelah 2013, the application at ~GS60 resulted in a significant yield benefit compared to both the GS39 and GS77 timings. Although statistically significant, the absolute level of yield benefit was only ~100 kg/ha. The GS60 application received a 19mm rainfall event, seven days after application.

Protein

All sites were analysed individually with an overall analysis also conducted for both years. Figures 2 and 3 show the comparison of the three applications methods (across all timings) and the comparison of timings (across all application methods) over both years.

Test weight and screenings

There was no clear impact from nitrogen application method or timing on test weight or screening level in any trial.
In both years, *foliar* application resulted in a significant increase in protein compared to either *spread* or *streambar* for late season application timings. *Foliar* application resulted in significant benefits at two individual sites in both 2012 and 2013.

The largest protein benefit in 2012 was obtained at Tulloona using *foliar* application at GS51 (1.2% but NSD). In 2013 the largest benefit was obtained at Weemelah using Foliar application at GS71 (0.8%, signif).
Nitrogen recovery in grain

The nitrogen recovery in grain was calculated for all treatments (yield t/ha x protein % x 1.75). Figures 4 and 5 show the comparison of the three applications methods (across all timings) and the comparison of timings (across all application methods) over both years.

Figure 4. Mean nitrogen recovery in grain from addition of 40 kg N/ha, six sites 2012
Treatments that share the same letter within the groups of methods or timings are not significantly different at p=0.05
Broken line indicates the mean nitrogen recovery in grain of untreated control (no additional nitrogen)

Figure 5. Mean nitrogen recovery in grain from addition of 40 kg N/ha, five sites 2013
Treatments that share the same letter within the groups of methods or timings are not significantly different at p=0.05
Broken line indicates the mean nitrogen recovery in grain of untreated control (no additional nitrogen)
Overall in 2012, foliar application resulted in a significant increase in nitrogen recovery in grain compared to either spread or streambar but still only recovered a mean of ~3 kg N/ha from the 40 kg N/ha applied. In 2013 there was no significant benefit overall from foliar application compared to the other methods although there was a non-significant trend to foliar recovering an extra 4 kg N/ha compared to the untreated control. Foliar application resulted in significant benefits at three of six individual sites in 2012 but only one of five in 2013.

The largest nitrogen recovery in grain benefit in 2012 was obtained at Croppa Creek using foliar application at GS45 (15 kg N/ha, signif). In 2013 the largest benefit was obtained at Weemelah using Foliar application at GS60 (9 kg N/ha, signif). The efficiency of conversion of applied nitrogen to harvested protein was disappointing in both seasons. The mean of the highest recovery treatments in each trial in 2012 was 21% (range 6 to 37%) and also 21% in 2013 (range 12 to 28%).

How effective was early season application of Spread urea?

Application of the equivalent amount of spread urea at planting or GS30 (or split between the two timings) was evaluated at six sites. The spread urea at planting was incorporated by sowing (IBS). The mean response to spread urea at all timings is shown in Figures 6 and 7.

![Graph showing mean % protein from addition of 40 kg N/ha Spread urea, applied at varied crop stages, two trials 2012. Broken line indicates the mean % protein of untreated control (no additional nitrogen), IBS=incorporated by sowing operation.](image)
The early application of *spread* urea resulted in equivalent or higher protein levels than *spread* applications later in the season. Across all dryland sites, urea *spread* and incorporated by sowing resulted in either the highest or second highest protein level of all treatments.

**Did treatments perform better under irrigation?**

The trial at Brookstead was planted on the 19th June with flowering commencing the 3rd week of September. It received five 30 mm irrigations during the crop development from GS47 to GS73 (over a period of 31 days). In addition it received 38 mm of rain during head emergence. Figures 8, 9 and 10 show the impact of nitrogen application on protein and nitrogen recovery, together with the protein impact from *spread* urea.
**Figure 8.** % protein from addition of 40 kg N/ha under irrigation, Brookstead 2013
Treatments that share the same letter within the groups of methods or timings are not significantly different at p=0.05
Broken line indicates the mean % protein of untreated control (no additional nitrogen)

**Figure 9.** Nitrogen recovery in grain from addition of 40 kg N/ha under irrigation, Brookstead 2013
Treatments that share the same letter within the groups of methods or timings are not significantly different at p=0.05
Broken line indicates the mean nitrogen recovery in grain of untreated control (no additional nitrogen)
Figure 10. Nitrogen recovery in grain from addition of 40 kg N/ha spread as urea applied at varied crop stages, Brookstead 2013

Treatments that share the same letter are not significantly different at p=0.05

Broken line indicates the mean nitrogen recovery in grain of untreated control (no additional nitrogen), IBS=Incorporated By Sowing operation

The results at the irrigated site were very disappointing with the best treatment only increasing grain protein in Suntop(1) by 0.5% with the highest level of actual nitrogen grain recovery only 28%. The poor grain recovery may have been influenced by the high background nitrogen (13.7% protein in the untreated), however three other varieties achieved 15-16% protein in the same trial with no additional nitrogen application.

Was the remainder of the late applied nitrogen lost?

At the Weemelah site there was sufficient rain post-harvest to sample for nitrogen to a soil depth of 30cm in early December. The soil was dry below this depth and it was considered unlikely that nitrogen would have moved any deeper by this stage. Soil samples were taken from the untreated and all methods of application at Timing 2 (GS60) and Timing 4 (GS77). Timing 2 was selected as this was the most effective application with 19mm of rain received 7 days after application. Timing 4 had the lowest level of impact and only experienced a total of 11mm of rain in the six weeks following application with a single rain event occurring 15 days after application. Figure 11 shows the level of grain and soil recovery of nitrogen expressed as a % of the total applied.
Although the nitrogen grain recovery from spread urea was significantly poorer than the foliar application, there were very high levels of recovery of soil nitrogen from spread applications for both timings. This indicated that ‘losses’ from these applications were low despite the absence of follow-up rain for at least 7 days following either application. No assessment was made of the amount of nitrogen captured in leaf and stubble material. The partial nitrogen recovery (grain and soil) from streambar and foliar application was significantly lower than from spread urea but the remaining nitrogen may have been lost by volatilisation, captured in plant material or most probably a combination of both.

**Economics**

Economic comparisons were conducted on all individual treatments where there was a significant difference in either yield or protein content compared to the untreated. Table 3 shows the highest net benefit treatments from the four sites where significant yield or protein differences occurred.

**Table 3. Economic analysis of the highest net benefit treatments**

<table>
<thead>
<tr>
<th>Site</th>
<th>Treatment</th>
<th>Receival grade</th>
<th>Gross benefit</th>
<th>Fertiliser and application cost</th>
<th>Net benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Croppa Creek 2012</td>
<td>Foliar GS45</td>
<td>No change ASW</td>
<td>$69/ha</td>
<td>$84/ha</td>
<td>-$15/ha</td>
</tr>
<tr>
<td>Weemelah 2013</td>
<td>Foliar GS60</td>
<td>APW to H2 (+$9/t)</td>
<td>$77/ha</td>
<td>$84/ha</td>
<td>-$7/ha</td>
</tr>
<tr>
<td>Tullona 2013</td>
<td>Foliar GS71-73</td>
<td>No change HPS1</td>
<td>$79/ha</td>
<td>$84/ha</td>
<td>-$5/ha</td>
</tr>
<tr>
<td>Narrabri 2013</td>
<td>Foliar GS69+</td>
<td>No change HPS1</td>
<td>$27/ha</td>
<td>$84/ha</td>
<td>-$57/ha</td>
</tr>
</tbody>
</table>

Granular urea $552/t ($48/ha @ 40 kg N), Urea solution $7.90/L ($76/ha @ 40 kg N/ha)
Application costs: spread $25/ha, foliar $8/ha
Grain prices: 2012 ASW $237, 2013 HPS1 $251, APW $256, H2 $265
Although there was a small but significant increase in protein from foliar application, late nitrogen application did not provide a net economic benefit in any of these eleven trials.

Table 4 shows the grain price differential needed to generate a return on investment of 1 ($1 net benefit for every $1 spent), under a range of nitrogen recovery in grain efficiencies and varying protein increase targets.

**Table 4. Minimum grain price differential required to achieve a $1 net benefit for every $1 spent**

<table>
<thead>
<tr>
<th>% protein increase required/targeted</th>
<th>% nitrogen recovery in grain</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5%</td>
<td>20%</td>
<td>$20/t</td>
<td>$12/t</td>
<td>$9/t</td>
</tr>
<tr>
<td>1.0%</td>
<td>40%</td>
<td>$36/t</td>
<td>$20/t</td>
<td>$14/t</td>
</tr>
<tr>
<td>2.0%</td>
<td>60%</td>
<td>$70/t</td>
<td>$36/t</td>
<td>$25/t</td>
</tr>
</tbody>
</table>

Urea solution $7.90/L ($1.90 kg N/ha)
Application cost: foliar $8/ha
Assuming 5t/ha yield (grain price differentials will increase by ~$2-3/t at 3t/ha yields

The data from these two ‘unfavourable’ years only resulted in mean nitrogen recovery in grain of ~20%. Under these conditions, a grain price differential of at least $36/t would have been needed if a 1% increase in protein was required and the grower was content with a $1 net benefit for every $1 spent. For late nitrogen application to be a more viable consideration, consistent and high % nitrogen recovery in grain (40-60%) combined with grain price differentials of at least $10-20/t would be needed.

**Discussion**

1. **Method comparison**

With generally low levels of rainfall in both years, it was not surprising that spread and streambar application were ineffective in increasing protein. For these methods to provide a benefit, nitrogen must be both successfully incorporated into the soil but also reach a depth where roots are actively foraging. These approaches appear much more suited to early season application or use in years with frequent rainfall during spring.

Foliar application resulted in significant protein increases compared to the spread and streambar methods. This strongly suggest that leaf uptake, in late season application, is capable of significantly increasing grain protein levels. However the magnitude of impact was generally disappointing. The highest recovery from any foliar treatment in 2012 was 15 kg N/ha (mean across all sites 6 kg N/ha, range 0 to 15 kg N/ha). In 2013 the highest recovery from any foliar treatment in 2012 was 11 kg N/ha (mean across all sites 7 kg N/ha, range 4 to 11 kg N/ha).

2. **Timing comparison**

The impact from application timing was less apparent than expected. The clearest result was that application at late milk to mid dough resulted in significantly lower protein than from early applications. This was significant in all four trials where significant timing differences occurred. The data from these trials was inconclusive in determining an optimal growth stage for application although the highest protein result was achieved from application during late head emergence to early milk at seven of the eleven sites.

3. **Nitrogen recovery**

The efficiency of conversion of applied nitrogen to protein was disappointing in both seasons. The highest level of recovery of any treatment was 37% in 2012 and 28% in 2013 with ~20% nitrogen recovery more realistic across all sites. The level of recovery in 2012 was particularly disappointing as...
grain protein levels in the untreated were below 12% in all trials. Under these nitrogen limited situations, the recovery was expected to be much higher.

4. Spread urea

Urea applied at planting (IBS) generally provided the highest protein result of all Spread applications. Although early application of additional nitrogen can cause canopy management issues, these results (in years with erratic or low spring rainfall) support the need to get nitrogen on early. In-crop applications are likely to have more benefit in seasons with more frequent and reliable spring rainfall.

5. Irrigated results

The pattern of results for method and timing of application was similar to the overall pattern at dryland sites but the protein and nitrogen recovery in grain levels were extremely disappointing. The best individual treatment result was a recovery of 28% but the mean of all treatments was only 8%. There is no explanation for the lower efficiencies recorded in this trial.

Conclusions

This extensive set of trials was hampered by the low rainfall experienced during the springs of 2012 and 2013, however it clearly showed that:

1. Significant increases in protein can be gained by late nitrogen application
2. The level of increase however was not sufficient to deliver economic benefits
3. Foliar was clearly the most effective method of application
4. Timing differences were less clear but generally supported application between late head emergence and early milk stages when targeting protein accumulation
5. Although late application of spread urea was, as expected, the least effective method, the results from soil coring at two trials indicated a high level of recovery in the 0-30cm samples (one trial not presented in this paper). This supported recent results from Graeme Schwenke, NSW DPI, indicating nitrogen volatilisation from urea application in-crop may not be as high as previously considered.

These results suggest that trying to increase wheat protein with late nitrogen application is unlikely to be a very effective management tool in areas where spring rainfall is highly erratic. Unless nitrogen in grain recovery levels can be increased dramatically, grain price differentials of ~$20-40/t are probably necessary before even considering this type of approach. Supply of nitrogen requirements either prior to or at planting, or as a top up during early crop growth stages would appear a much more reliable and effective strategy. Economic benefits from nitrogen application targeting yield potential are likely to be far easier to achieve than when targeting protein increases.

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Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.”
Canola agronomy research in central-west NSW

Leigh Jenkins¹ and Rohan Brill²

¹NSW DPI Trangie
²NSW DPI Wagga Wagga

Key words
Canola, hybrid, open-pollinated, establishment, plant population, phosphorus, nitrogen

GRDC code
DAN00129 – Variety Specific Agronomy Packages for Northern NSW

Take home message

- Hybrid canola has significant grain yield and farming system benefits for the central-west region of NSW.
- Aim to establish 20-25 plants/m² in central west NSW.
- Choose canola varieties with large seed size to improve crop establishment (> 5g/1000 seeds).
- Phosphorus application improves grain yield regardless of variety choice, but limit the amount of P applied in direct contact with seed.
- The response to nitrogen application is generally positive, even at relatively high soil N levels.

Introduction

Hybrid canola

Hybrid canola production has increased markedly in recent seasons, due largely to improved early vigour and higher grain yield relative to open-pollinated (OP) varieties. Hybrid seed generally retails for approximately double the cost of commercial OP seed. This increased cost to the grower is mainly due to the higher cost of seed production, as producing hybrid seed involves production of seeds of the parent lines in the first step and then the F1 hybrid in the second step. The yield and vigour advantage of hybrids is known as heterosis. Hybrids can be either GM or non-GM, and are now available in each of the four commercially available canola herbicide tolerance groups.

VSAP trials background

Canola agronomy trials have been conducted by NSW DPI in the central-west region of NSW in 2012 and 2013 (Table 1). These trials add value to NVT by testing popular commercial varieties across a range of agronomic treatments. The aim of the trials has been to test specific groups of canola plant types, such as comparing hybrid varieties with OP varieties as well as comparing triazine tolerant (TT) varieties with non-TT varieties.
Table 1. NSW DPI canola trials conducted in the central-west region of NSW in 2012 and 2013.

<table>
<thead>
<tr>
<th>Season</th>
<th>Site</th>
<th>Trial</th>
<th>Soil type</th>
<th>Colwell P 0-10 cm (mg/kg)</th>
<th>Nitrogen 0-90 cm (kg/ha)</th>
<th>Sowing date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Coonamble</td>
<td>Variety x Phosphorus</td>
<td>Brown chromosol</td>
<td>76</td>
<td>56</td>
<td>21-Apr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Sowing depth</td>
<td></td>
<td></td>
<td></td>
<td>21-Apr</td>
</tr>
<tr>
<td></td>
<td>Nyngan</td>
<td>Variety x Nitrogen x Phosphorus</td>
<td>Red chromosol</td>
<td>22</td>
<td>N/A</td>
<td>17-Apr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Plant population</td>
<td></td>
<td></td>
<td></td>
<td>17-Apr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Sowing depth</td>
<td></td>
<td></td>
<td></td>
<td>17-Apr</td>
</tr>
<tr>
<td></td>
<td>Trangie</td>
<td>Variety x Sowing depth</td>
<td>Grey vertosol</td>
<td>36</td>
<td>112</td>
<td>20-Apr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Phosphorus</td>
<td></td>
<td></td>
<td></td>
<td>7-May</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Nitrogen</td>
<td></td>
<td></td>
<td></td>
<td>7-May</td>
</tr>
<tr>
<td>2013</td>
<td>Nyngan</td>
<td>Variety x Phosphorus</td>
<td>Red chromosol</td>
<td>24</td>
<td>180</td>
<td>19-Apr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Sowing depth</td>
<td></td>
<td></td>
<td></td>
<td>19-Apr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Nitrogen</td>
<td></td>
<td></td>
<td></td>
<td>19-Apr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Sowing depth</td>
<td></td>
<td></td>
<td></td>
<td>19-Apr</td>
</tr>
<tr>
<td></td>
<td>Trangie</td>
<td>Variety x Phosphorus</td>
<td>Red chromosol</td>
<td>28</td>
<td>86</td>
<td>28-May</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Nitrogen</td>
<td></td>
<td></td>
<td></td>
<td>28-May</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variety x Sowing depth</td>
<td></td>
<td></td>
<td></td>
<td>28-May</td>
</tr>
</tbody>
</table>

Trial results

**Plant population**

A plant population trial was sown at Nyngan in 2012, with actual establishment being similar to the targeted rate. Grain yield was significantly higher for all varieties when plant population increased from 10 to 25 plants/m² (average 0.35 t/ha increase), but there was no further yield increase for 40 and 60 plants/m² (Figure 1). The hybrid Clearfield variety 43Y85 (CL) was significantly higher yielding than the OP Clearfield variety Pioneer 43C80 (CL). Similarly, the hybrid TT variety Hyola 555TT was significantly higher yielding than the OP TT variety ATR-Stingray.

![Figure 1. Grain yield of four varieties sown at four plant populations at Nyngan in 2012.](image)

At Nyngan in 2013, the achieved establishment rates were similar to the targeted rates but at Trangie the achieved establishment was approximately 50% of the targeted establishment. At Nyngan there was a significant yield increase (averaged across all varieties) of 0.42 t/ha where plant population increased from 5 to 10 plants/m², but there was no further grain yield response from increasing population further (Figure 2). At Trangie there was a significant grain yield increase (averaged across
all varieties) where the targeted population increased to 40 plants/m². In effect this meant that maximum yield was achieved at 20 plants/m² since the actual establishment was 50% of the targeted establishment at this site (Figure 3).

There was a similar varietal response pattern in 2013 at both sites as for the one site at Nyngan in 2012. The hybrid Clearfield® variety Pioneer® 44Y84 (CL) was significantly higher yielding than the OP Clearfield variety Pioneer 43C80 (CL); and the hybrid TT variety Hyola® 559TT was significantly higher yielding than the OP TT variety ATR-Stingray.

**Figure 2.** Grain yield of four canola varieties sown at five plant populations at Nyngan in 2013.

**Figure 3.** Grain yield of four canola varieties sown at five plant populations at Trangie in 2013.

Sowing depth
Sowing depth trials were conducted at Coonamble, Nyngan and Trangie in 2012; and at Nyngan and Trangie in 2013. Each trial had six common varieties with a range in seed size (Table 2). Target seeding depths were 2.5 cm, 5 cm and 7.5 cm.

Table 2. Seed size and number of seeds sown in three canola variety sowing depth trials in 2012.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Seed weight 2012 (g/1000 seeds)</th>
<th>Seed weight 2013 (g/1000 seeds)</th>
<th>Seeds sown/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV-Garnet(+)</td>
<td>3.78</td>
<td>3.27</td>
<td>60</td>
</tr>
<tr>
<td>ATR-Stingray(+)</td>
<td>3.06</td>
<td>2.97</td>
<td>60</td>
</tr>
<tr>
<td>Pioneer 43C80 (CL)</td>
<td>3.68</td>
<td>4.11</td>
<td>60</td>
</tr>
<tr>
<td>Pioneer 43Y85 (CL)</td>
<td>5.03</td>
<td>4.77</td>
<td>60</td>
</tr>
<tr>
<td>Pioneer 44Y84 (CL)</td>
<td>5.34</td>
<td>5.20</td>
<td>60</td>
</tr>
<tr>
<td>Hyola 555TT</td>
<td>4.26</td>
<td>4.00</td>
<td>60</td>
</tr>
</tbody>
</table>

In 2012, averaged across all trials and varieties, establishment (as a percentage of seeds sown) at the 2.5 cm target depth was approximately 66%, with no difference between varieties. All varieties had reduced establishment at the 5 cm sowing depth compared to the 2.5 cm sowing depth, with the exception of Pioneer 44Y84 (CL) which had the largest seed size (Figure 4). At the 7.5 cm sowing depth the difference between varieties and seed size became more marked as the largest seeded variety achieved 50% establishment compared to 20% establishment for the smallest seeded variety.

The effect of sowing depth on grain yield in 2012 was less marked than the effect on establishment. At Nyngan and Coonamble, the 7.5 cm target depth yielded approximately 250 kg/ha less grain than the 2.5 cm and 5 cm target depth. At Nyngan, Pioneer 44Y84 (CL) had no grain yield reduction at the 7.5 cm target sowing depth compared with the shallower sowing depths, however there was a significant grain yield reduction for all other varieties as a result of deep sowing. There was no effect of sowing depth on grain yield at Trangie.

In 2013 the overall establishment achieved was less than in 2012. At the 2.5 cm sowing depth establishment (as a percentage of seeds sown) was approximately 50% with no significant difference between varieties (Figure 5). All varieties had reduced establishment at the 5 cm sowing depth compared with the 2.5 cm sowing depth; however the reduction was less severe for the hybrids than for the open-pollinated (OP) varieties. Establishment was further reduced at the 7.5 cm sowing depth, with a similar hybrid advantage as occurred at the 5 cm sowing depth.
Figure 5. Establishment of six canola varieties at three sowing depths, averaged across two trials at Nyngan and Trangie in 2013.

The effect of sowing depth on grain yield was greater in 2013 than 2012 but was still of a lesser magnitude than the effect of sowing depth on establishment. At Nyngan, the grain yield of Pioneer 44Y84 (CL), AV-Garnet and Hyola 555TT were all similar for the 2.5 cm sowing depth; however AV-Garnet and Hyola 555TT both had a significant grain yield reduction at the 5 cm and 7.5 cm sowing depths, while Pioneer 44Y84 (CL) did not suffer a yield penalty from deeper sowing. At Trangie, all varieties suffered a grain yield penalty as sowing depth was increased but this reduction in grain yield was less severe for the larger seeded varieties.

Phosphorus rate

A phosphorus (P) rate trial was sown at Coonamble, Nyngan and Trangie in 2012. The phosphorus product used was triple super which does not supply any nitrogen. The phosphorus rates applied were 0, 5, 10 and 20 kg/ha, with the fertiliser being placed directly with the seed.

Figure 6. Average establishment of four canola varieties sown with four rates of phosphorus at Trangie, Nyngan and Coonamble in 2012.

There was no effect of phosphorus rate on canola establishment on the cracking clay (grey vertosol) soil at Trangie. In contrast, increasing P rate significantly reduced the establishment of all varieties on
the lighter textured soils at Nyngan (red chromosol) and Coonamble (brown chromosol) (Figure 6). All varieties experienced a similar reduction in establishment, regardless of seed size or plant type.

At Nyngan, there was a grain yield increase of 0.16 t/ha for the 5 kg/ha P rate compared with the nil P rate but with no further grain yield increase where P rate was increased. At Trangie (19 mg/kg Colwell P) the application of 10 kg/ha P significantly increased grain yield by 0.14 t/ha compared to where no P was applied, with no further yield increase at the 20 kg/ha P rate. There was a similar varietal response pattern for the phosphorus rate trials at all sites as for the plant population trials. The hybrid Clearfield variety Pioneer 44Y84 (CL) was significantly higher yielding than the OP Clearfield variety Pioneer 43C80 (CL); and the hybrid TT variety Hyola 555TT was significantly higher yielding than the OP TT variety ATR-Stingray.

Two further phosphorus rate trials were conducted in 2013, with the Trangie trial planted on a lighter textured soil (red chromosol) compared with a heavy (grey vertosol) soil in 2012. There was a significant reduction in canola establishment at both sites as phosphorus rate (applied as triple super) was increased (Figure 7). Further product comparisons at a common P rate showed that all major phosphate fertilisers (MAP, DAP, Single Super, Triple Super, Supreme Z) affected establishment to a similar degree.

**Figure 7.** Average establishment of two canola varieties sown with four rates of phosphorus at Trangie and Nyngan in 2013.

Despite the effect on establishment, grain yield still responded positively to phosphorus application at Nyngan (24 mg/kg Colwell P), with the 5 kg/ha P rate yielding 0.25 t/ha more than the nil P treatment, but there was no further yield increase beyond this rate. There was no grain yield response from the application of phosphorus at Trangie (28 mg/kg Colwell P).

Although hybrid varieties had higher yield than OP varieties in these phosphorus trials, there was no evidence to suggest that they should be managed differently in terms of P nutrition.

For growers using a tine seeder it is generally possible (and recommended) to separate seed from fertiliser to avoid the negative effects of starter fertiliser. For growers with a disc seeder (or considering a disc seeder), there are several management options available such as:

- Planting on relatively narrow crop rows to reduce fertiliser concentration in the furrow,
- Planting canola early to allow greater root exploration, with potentially less phosphorus application required,
- Pay strict attention to closing devices. The firmer/heavier the closing device, the greater the negative impacts of phosphorus fertiliser.
**Nitrogen rate and timing**

Nitrogen (N) rate trials were sown in 2012 at Nyngan and Trangie. In 2013 this was extended to include a timing component, with applications split between sowing and the early stem elongation stage. Due to lack of adequate follow-up rain at both Nyngan and Trangie sites after the in-crop application, only the rate component of 2013 trials is reported here.

At Nyngan in 2012, the application of 30 kg/ha N increased grain yield by 0.26 t/ha averaged across all varieties. Increasing the N application rate from 30 to 60 kg/ha resulted in a further yield increase of 0.21 t/ha (Figure 8).

![Figure 8](image_url)

**Figure 8.** Grain yield of four canola varieties with three nitrogen rates at Nyngan in 2012.

Only two varieties were sown at Trangie in 2012; however both varieties responded positively to nitrogen application at sowing despite a moderately high soil nitrogen content (112 kg/ha N at sowing, 0-90 cm) (Figure 9).

![Figure 9](image_url)

**Figure 9.** Grain yield of two canola varieties with four nitrogen rates at Trangie in 2012.

At Nyngan in 2013, there was a significant effect of nitrogen application on grain yield, with the application of 30 kg/ha N increasing grain yield by 0.27 t/ha, compared to nil N applied (Figure 10). This site was high in soil N at sowing but still showed a favourable response to a moderate amount of N application. There were similar varietal trends as observed in previous trials.
Figure 10. Grain yield of four canola varieties with four nitrogen rates at Nyngan in 2013.

At Trangie in 2013 there was only a small response to nitrogen application but there were large varietal differences, with this trial following a similar trend to other trials that showed an advantage of hybrid varieties over their OP counterparts (Figure 11).

Figure 11. Grain yield of four canola varieties with four nitrogen rates at Trangie in 2013.

Although N application can increase grain yield, it may reduce oil concentration in the grain. Overall oil removed (by weight as kg/ha) is still generally higher where N is applied. It is also worth noting that at a grain yield of 1.5 t/ha and a canola price of $450/tonne, the economic value of 1 % oil concentration is equivalent to only 22.5 kg/ha grain.
Discussion

*Hybrid vs. OP varieties*

These 2012 and 2013 canola trials have shown that the extra cost of hybrid seed can be justified. Averaged across all VSAP trials in the central-west region in the past two seasons, the average grain yield benefit of hybrid canola over OP canola was 0.46 t/ha (Table 3).

**Table 3.** Grain yield (t/ha) comparison of hybrid and open-pollinated (OP) canola varieties averaged across trials at VSAP canola trial sites in the central-west region in 2012 and 2013.

<table>
<thead>
<tr>
<th></th>
<th>Hybrid</th>
<th>OP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2012</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coonamble</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Nyngan</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Trangie</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>2013</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nyngan</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Trangie</td>
<td>1.3</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.58</strong></td>
<td><strong>1.12</strong></td>
</tr>
</tbody>
</table>

At a canola price of $450/tonne, this equates to a gross income benefit from hybrid varieties of $207/tonne. For growers purchasing commercial seed (assuming $50/ha for hybrid seed and $25/ha for OP seed) the return on investment of the extra money spent on hybrid seed ($25/ha) was on average 728%. Growers who retain their own seed for subsequent planting will reduce seed cost, but there are then the additional costs of labour, grading and seed treatment with fungicide and insecticide. There may also be intangible costs due to the increased risks of poor vigour seed and/or disease carryover in retained seed.

**TT or not TT?**

The use of TT canola adds an extra dimension to weed control options; however this system does come with an inherent penalty as TT varieties are known to have reduced photosynthetic efficiency. The average yield penalty in these trials for TT compared with non-TT varieties was 0.4 t/ha (Table 4). At a canola price of $450/tonne, this equates to a penalty of $180/ha. This needs to be weighed up against the cost of using either cheaper or more targeted herbicides to control specific weed issues, as well as the ability to allow viable crop rotations in paddocks previously considered unsuited to canola production.

**Table 4.** Grain yield (t/ha) comparison of TT and non-TT canola varieties averaged across trials at VSAP canola trial sites in the central-west region in 2012 and 2013.

<table>
<thead>
<tr>
<th></th>
<th>TT</th>
<th>non-TT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2012</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coonamble</td>
<td>1.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Nyngan</td>
<td>0.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Trangie</td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>2013</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nyngan</td>
<td>1.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Trangie</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.12</strong></td>
<td><strong>1.52</strong></td>
</tr>
</tbody>
</table>

Conclusion

Canola agronomy trials focussing on establishment and nutrition issues have been conducted by NSW DPI across a range of soil types (chromosols and vertosols) in the central west region of NSW in 2012 and 2013. Despite differing soil types and seasons at each site, trial results have consistently shown the value of large seeded hybrid varieties vs. small seeded OP varieties in particular. From these trials several agronomic practices can be highlighted to increase the reliability of canola production in central-west NSW:
• Where seed needs to be placed deeper than optimum seeding depths (e.g. when sowing early by moisture seeking), ensure that canola varieties with larger seed size are used (minimum 5 g per 1000 seeds) and that a high rate of fertiliser in contact with the seed is avoided.

• Positive grain yield response to low-moderate (5-10 kg/ha) phosphorus rates are common and have been recorded on both red and grey soils.

• Aim to establish a target density of 20-25 plants/m² in central-west NSW.

• The application of nitrogen fertiliser has led to increased grain yield of canola, even at moderate to high soil N levels.

• TT varieties have generally been lower yielding than non-TT varieties; however this needs to be weighed up against the options provided by residual herbicides in the TT system.

• Hybrid varieties have generally been higher yielding than open pollinated varieties; however the cost of hybrid seed needs to be weighed up against the reduced cost and ability to retain seed of OP varieties.

Acknowledgements

The assistance of Jayne Jenkins, Scott Richards, Kelvin Appleyard and formerly Robert Pither (NSW DPI, Trangie) in the conduct of these trials is gratefully appreciated.

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Herbicides and weeds – regional issues trials and developments

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Michael Widderick, Qld DAFF & Maurie Street, GOA

Key words
Herbicides, resistance, glyphosate, wild oats, windmill grass, fleabane, sowthistle, barley grass

GRDC code
UQ00062, UA00124, GOA0002

Take home message
There are many weed related problems facing growers in the northern grain region. Herbicide resistance is the major issue, affecting many species and making many herbicide options redundant.
Most farmers will be dealing with some or many of the topics covered in this paper, making effective management difficult.
Research has found solutions for many of these issues, however there are some research needs for a good range of problems.
A great proportion of the solutions to our problems are still herbicide based and in the future will lead to other herbicide resistance problems.

Multiple resistant wild oats
Resistance to one mode of action herbicide is very common in most parts of the northern grain region, specifically for post-emergence herbicides. Farmers overcome this issue by selecting another post-emergence herbicide from a different mode of action. However, the steady increase in multiple resistant wild oats has forced farmers to make substantial changes.
The most recent wild oat survey for the northern region was completed in 2007 so getting a more precise understanding of the situation is difficult. Furthermore, this survey was focused on the SE Qld and N NSW regions. With this in mind, The Grain Orana Alliance has conducted a wild oat resistance survey in 2013. It was solely focused on the resistance issues of central western NSW and the results from this study will be eagerly sought when reported in 2014.
There are many cases of multiple or cross resistance occurring. In some cases the resistance can be to three herbicide groups (A, B and Z). However, in extremely serious cases of multiple resistance there is still a good chance that a few post-emergence herbicides will work. One example is a population of wild oats from Edgeroi that was confirmed resistant to Group A, B and Z herbicides, but was still susceptible to Verdict and high rates of Select.
The mechanisms controlling resistance within wild oat plants are complex. Unless a resistance test is used, you will remain in the dark as to which herbicides are likely to still work and which won’t.
Growers with wild oats that have resistance to one or two herbicides groups (either, A, B, Z, A and B or A and Z), could use a pre-emergence herbicide followed by the remaining useful post-emergence option and get excellent levels of control. Table 1 below best summarises this strategy.
### Table 1. Controlling group A resistant wild oats, North Star

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate of product/ha</th>
<th>Herbicide group(s)</th>
<th>Wild oat seeds per m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>----</td>
<td>----</td>
<td>90.7</td>
</tr>
<tr>
<td>Achieve® (post-em)</td>
<td>380g</td>
<td>A</td>
<td>43.8</td>
</tr>
<tr>
<td>Topik® (post-em)</td>
<td>65mL</td>
<td>A</td>
<td>180.9</td>
</tr>
<tr>
<td>Wildcat® (post-em)</td>
<td>300mL</td>
<td>A</td>
<td>123.3</td>
</tr>
<tr>
<td>Avadex® Xtra (pre-em)</td>
<td>1.6L</td>
<td>J</td>
<td>9.4</td>
</tr>
<tr>
<td>Trifluralin® 480 (pre-em)</td>
<td>1.875L</td>
<td>D</td>
<td>47.8</td>
</tr>
<tr>
<td>Mataven® 90 (SST)</td>
<td>200g</td>
<td>B</td>
<td>2.3</td>
</tr>
<tr>
<td>Hussar® (post-em)</td>
<td>330mL</td>
<td>B</td>
<td>4.2</td>
</tr>
<tr>
<td>Atlantis® (post-em)</td>
<td>500mL</td>
<td>B</td>
<td>0.0</td>
</tr>
<tr>
<td>Avadex® Xtra (pre-em) + Hussar® (post-em)</td>
<td>1.6L + 200g</td>
<td>J + B</td>
<td>0.3</td>
</tr>
<tr>
<td>Avadex® Xtra (pre-em) + Atlantis® (post-em)</td>
<td>1.6L + 330mL</td>
<td>J + B</td>
<td>0.0</td>
</tr>
<tr>
<td>Avadex® Xtra (pre-em) + Mataven® 90 (SST)</td>
<td>1.6L + 1.875L</td>
<td>J + Z</td>
<td>0.0</td>
</tr>
<tr>
<td>Atlantic® (post-em) + Mataven® 90 (SST)</td>
<td>330mL + 1.875L</td>
<td>B + Z</td>
<td>0.0</td>
</tr>
<tr>
<td>Hussar® (post-em) + Mataven® 90 (SST)</td>
<td>200g + 1.875L</td>
<td>B + Z</td>
<td>0.0</td>
</tr>
</tbody>
</table>

SST = Selective Spray Topping – late post-emergence to prevent seed production.

However, there are some cases of multiple resistance to all three post-emergence herbicide groups. In this case, data in Table 1 would be irrelevant as no post-emergence option would be effective (refer to Table 2 instead). Reliance solely on pre-emergence herbicides would result in populations of wild oats increasing. Surviving plants from trifluralin and Avadex Xtra treatments tend to be large and produce more seed than what is lost from the germination process.

The radical step of changing crops may open the door to the use of other herbicides (Table 2). Although this wild oat population can be well managed in wheat with pre-emergence herbicides + Atlantis®, alternative crops can be grown with better weed control outcomes. Chickpeas grown on conventional row spacing or wide rows resulted in excellent control and utilised herbicides that have probably never been used for many years. The inter-row spraying of Gramoxone® in wide row chickpeas was successful and the inclusion of simazine, trifluralin and Avadex Xtra as a pre-emergent option was useful.
Table 2. Controlling multiple resistant (Groups A, B and Z) wild oats.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Treatments</th>
<th>Herbicide group(s)</th>
<th>Wild oat seed production per m²</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT Canola</td>
<td>trifluralin + Avadex Xtra + atrazine + Sertin ⁷</td>
<td>D + J + C + A</td>
<td>0.5</td>
<td>0.82</td>
</tr>
<tr>
<td>Canola</td>
<td>trifluralin + Avadex Xtra + Dual ⁷ Gold + Sertin ⁷</td>
<td>D + J + K + A</td>
<td>15</td>
<td>0.82</td>
</tr>
<tr>
<td>Clearfield* canola</td>
<td>Intervix*</td>
<td>B</td>
<td>469</td>
<td>0.41</td>
</tr>
<tr>
<td>Chickpea 35 cm row</td>
<td>trifluralin + Avadex Xtra + Simazine + Sertin ⁷</td>
<td>D + J + C + A</td>
<td>1</td>
<td>1.24</td>
</tr>
<tr>
<td>Chickpea 75 cm row</td>
<td>trifluralin + Avadex Xtra + Simazine + Gramoxone</td>
<td>D + J + C + L</td>
<td>11</td>
<td>0.87</td>
</tr>
<tr>
<td>Wheat</td>
<td>trifluralin + Avadex Xtra + Atlantis</td>
<td>D + J + B</td>
<td>14</td>
<td>0.94</td>
</tr>
<tr>
<td>Wheat</td>
<td>Sakura*</td>
<td>K</td>
<td>35</td>
<td>1.08</td>
</tr>
<tr>
<td>long fallow</td>
<td>Flame ⁷ + glyphosate</td>
<td>B + M</td>
<td>5</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Note: This population had confirmed complex resistance to groups A, B and Z, however it was shown in previous trials that it was partly susceptible to Atlantis and Sertin hence their inclusion.

The same principle applied when growing canola with the inclusion of atrazine, trifluralin, Avadex Xtra and Dual Gold.

Long fallowing paddocks is another alternative. It is important to note that the Flame treatment did not control wild oats well and a follow-up application of glyphosate was required to prevent seed set.

Poor wild oat control was reported in Clearfield canola after using Intervix. This population may exhibit some resistance to this herbicide without prior history of its strong levels of Hussar resistance (Group B) may infer other Group B herbicide resistance. This is a likely reason why Flame did not work well in the fallow. Despite the failure of Clearfield canola, Roundup Ready Canola should work since the population seems susceptible to glyphosate.

Another option is the use of Roundup Ready Canola. This provides excellent control of wild oats. In one experiment at Edgeroi that was infested with A, B and Z resistant wild oats, wild oat seed production was almost 100% prevented with one application of glyphosate. The flip side of this choice is increased risk of glyphosate resistant annual ryegrass not being controlled.

One crop in the north-west that is under more threat due to herbicide resistant wild oats is chickpeas. Although a wide range of post-emergence selective grass herbicides are registered, all are Group A herbicides. Unlike wheat, herbicides like Hussar, Atlantis and Mataven are not registered for use. The pre-emergence herbicides trifluralin and Avadex Xtra are options worthy of consideration and the inclusion of simazine could improve the control. However, if Group A resistance is present, chickpea growing would be totally reliant upon pre-emergence herbicides with in-crop options limited to inter-row tillage or wick wiping. There are two issues with relying solely on pre-emergence herbicides in chickpeas. These are:

1. Pre-emergence herbicides usually result in only 60-80% control under favourable conditions (not as effective as post-emergence herbicides – 85 to 95% control) and
2. That chickpeas do not compete well with weeds allowing the survivors of pre-emergence treatments to develop into large plants capable of large seed production.

There are numerous tactics that can be used to reduce the impact of wild oats. These are summarised in Table 3 and could be used in combination as an integrated weed management approach to maintain the usefulness of effective herbicides.

<table>
<thead>
<tr>
<th>Tactic</th>
<th>Wild oats - Likely control % (range)</th>
<th>Ability to incorporate into farming system (easy, mod, hard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop choice and sequence</td>
<td>95 (30-99)</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Improving crop competition</td>
<td>70 (20-99)</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Herbicide tolerant crops</td>
<td>90 (80-99)</td>
<td>Easy</td>
</tr>
<tr>
<td>Burning crop residues</td>
<td>40 (0-80)#</td>
<td>Moderate to hard</td>
</tr>
<tr>
<td>Inversion ploughing</td>
<td>50 (40-60)#</td>
<td>Moderate to hard</td>
</tr>
<tr>
<td>Autumn tickle</td>
<td>40 (30-60)</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Fallow and pre-sowing cultivation</td>
<td>40 (0-80)#</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Knockdown herbicides for fallow &amp; pre-sowing control</td>
<td>80 (70-90)</td>
<td>Easy</td>
</tr>
<tr>
<td>Double knockdown (doubleknock)</td>
<td>99 (99-100)#</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Pre-emergence herbicides</td>
<td>80 (70-90)</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Selective post-em herbicides</td>
<td>80 (70-90)</td>
<td>Easy</td>
</tr>
<tr>
<td>Spray-topping with selective herbicides</td>
<td>90 (60-99)</td>
<td>Easy</td>
</tr>
<tr>
<td>Crop-topping with non-selective herbicides</td>
<td>30 (10-50)#</td>
<td>Easy</td>
</tr>
<tr>
<td>Pasture spray-topping</td>
<td>80 (70-90)</td>
<td>Moderate</td>
</tr>
<tr>
<td>Silage and hay – crops and pastures</td>
<td>97 (95-99)</td>
<td>Moderate to hard</td>
</tr>
<tr>
<td>Renovation crops – green or brown manuring, mulching etc</td>
<td>95 (85-99)#</td>
<td>Moderate</td>
</tr>
<tr>
<td>Grazing – actively managing weeds in pastures</td>
<td>75 (60-80)</td>
<td>Moderate to hard</td>
</tr>
<tr>
<td>Weed seed collection at harvest</td>
<td>70 (20-80)</td>
<td>Hard</td>
</tr>
<tr>
<td>Sow weed-free seed</td>
<td>85 (50-99)#</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Source: Integrated Weed Management in Australian Cropping Systems (A training resource for farm advisors), Section 6-Weeds, weed 1 annual ryegrass (p151) and weed 18 wild oats (p200). Eds. McGillion, T. and Storrie, A.

# - no reference in IWM manual, so estimate was made by author of this paper.

Some of these tactics will be rather easy to incorporate into the farming system, as little or no adjustments to equipment are required. A few examples are changing to herbicide tolerant crops or crop topping with a non-selective herbicide. However, some new tactics may involve introduction of pastures or new machinery, therefore the costs to implement these changes could be prohibitive.
This table of tactics includes 19 different options. Many of these may not be applicable to your farm, but there are likely to be at least 6 to 8 that should be considered.

It is important to note that most of the tactics that involved a change in spray/herbicide strategy had an easier inclusion into the cropping system. In northern NSW we are fortunate to have a majority of our ARG and wild oat populations susceptible to most herbicides. Therefore, changes in weed management are likely to involve a change in herbicide selection (e.g. doubleknock, herbicide tolerant crops, crop-topping, using pre-emergence herbicides, etc.) as these relatively easy transitional options. As the level of herbicide resistance worsens, for instance multiple resistance to most pre- and post-emergence herbicides, the tactics required to manage the problem become increasingly harder to implement. This is what is happening in winter dominant rainfall areas in Australia.

Although it is easy to combat herbicide resistance with other herbicides from a different mode of action (herbicide group), it will place resistance selection pressure on these alternate herbicide groups. Some non-chemical options should be implemented to take the reliance off herbicides. The two most suitable options would include using adequate crop competition and the use of strategic cultivation that minimises soil moisture losses and structural damage.

**Glyphosate resistant windmill grass**

Due to the extended period of dry weather in the central west region of NSW in the past 18 months, no new research findings are available. Plans were to investigate to re-confirm the excellent control achieved with a paraquat + Group H herbicide. Discussions with many weed scientists and agronomists had also identified the research need into the potential of pre-emergence herbicides. The rationale behind this approach is to aim for better control when weeds are more susceptible to herbicides, emerging after rainfall, then to try control to larger plants that may be under some moisture stress. Therefore, a few more years of research are required before the possibility of a few more treatments is available to growers.

Current herbicide registrations for control of Windmill grass in summer fallow are limited to Touchdown® Hi Tech. No other formulations of glyphosate are registered to control this weed.

There are only two other products registered for selective control of this weed in various situations as listed in the table below.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Active Ingredient</th>
<th>Use situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor®</td>
<td>Butoxydim</td>
<td>Various summer crops- e.g. mungbeans, cotton, sunflowers</td>
</tr>
<tr>
<td>Dacthal 900®</td>
<td>Chlorthal-Dimethyl</td>
<td>Various brassica and vegetable crops, cotton, lucerne and lawns</td>
</tr>
</tbody>
</table>

As of June 2012, the Grain Orana Alliance (GOA) successfully obtained a Pesticide Permit (number 13460) that allows the use of quizalofop based products at a rate of 0.5 to 1.0L/ha (10% active products) or 250 to 500mL/ha (20% active products). An application of paraquat must be made 7 days after application to ensure better control and to minimise the chance of Group A resistance developing. There are application directions that allow for consistently high levels of control; applying to 3 leaf to early tillering plants and to avoid spraying under moisture stress. GOA has shown that waiting more than 11 days after rain to apply herbicides will result in diminishing levels of control.

As of March 2013, there are 9 confirmed cases of glyphosate resistant windmill grass in Australia, three are located in NSW. Two of these infestations were located in summer fallows and the other on a roadside. It is highly likely that the number of cases of glyphosate resistance is far worse as seed is
easily moved by wind and continued use of glyphosate solely will ensure its gradual spread over the central west region of NSW.

**Group I resistant wild radish**

Late in 2013 a population of wild radish from the central west was confirmed resistant to phenoxy herbicides (Group I), reported as 50% resistant. This discovery has now placed many farmers around the central west district on ‘resistance alert’. The area of concern is approximately a 250km square region south of Nyngan. This region was subject to a long and frequent history of phenoxy use. Common farm practices have included the use of few pre-emergent herbicides and low rates of 2,4-D, MCPA and MCPA LVE formulations in the cereal dominant rotation, sometimes with the addition of a group B herbicide.

It is not uncommon for this weed to be sprayed several times in a summer fallow leading up to sowing of the winter crop, then often more than once in crop due to successive germinations. It is not uncommon that a population of radish in this area will receive 4 applications per year of a group I product.

Traditional rotations included lucerne phases however lucerne paddocks and paddocks being “spelled” from cropping are frequently dominated by wild radish as it is largely unpalatable and control options are more limited and expensive than in a cereal crop.

Paddock screening trials done by DPI, at a known resistance site, showed poor efficacy from group B products but very good results from those products containing group H (Precept® and Velocity®).

Approximately 15 samples of wild radish from around this region are going to be tested for group I resistance. From these results it will give a better snapshot of the distribution of this problem and should trigger more detailed resistance screening to determine other effective modes of action available to growers.

There is much to learn from the Western Australia wild radish experience. In the Geraldton region farmers have been dealing with Group I resistant wild radish for at least 5 years along with resistance to many other modes of action. A great deal of their weed management is based on weed seed collection or windrow burning with some assistance from glyphosate (within Roundup® Ready canola).

**Competition trials**

A few experiments have been completed in the past three years. One investigated the row spacing of wheat and its effects on fleabane numbers and the other studying the effects of wheat density on wild radish. Dry conditions at the end of the 2013 winter cereal season meant that drought effects dominated the experiment with most wild radish plants dying from extreme moisture stress regardless of crop density.

Crop competition is known to be a factor that reduces the germination and growth of fleabane. This was highlighted in a trial at Trangie Agricultural Research Centre (TARC), where increasing the row space of Crusader wheat from 33 cm to 66 cm resulted in a 120% increase in fleabane plants in the stubble immediately after harvest (Figure 1). The trial showed that the effect of row space is real and measurable, and can add significantly to other weed control practices. The trial showed no significant effect of seed rate on fleabane population post-harvest. Based on past trial results and the practicalities of row spacing, the ideal set up seems to be about 25 cm for disc seeders and about 30...
cm for tine seeders for western areas, and potentially narrower for eastern regions.

![Graph showing fleabane m2 at different seed rates and row spaces](image)

**Figure 1.** Wide rows reduce crop competition with fleabane. This was shown at TARC with 66 cm row space resulting in 120% more fleabane in fallow than the 33 cm row space (sow time l.s.d. p < 0.05 = 0.34), with no significant effect of seed rate on subsequent fleabane population.

**Resistance in fleabane and sowthistle**

**Fleabane:** Glyphosate resistant fleabane is common in regions between the Liverpool Plains and the Darling Downs. Isolated infestations have been located in the central west parts of NSW and the national register of confirmed cases totals 57. All of these cases were discovered between 2010 and 2012. Knowing that fleabane has large seed production capacity and the seed is easily spread by wind, the potential for widespread glyphosate resistant fleabane throughout the northern grain region is possible.

There are concerns that the frequent use of 2,4-D and other group I herbicides may lead to resistance to this class of herbicide. In light of this, a comprehensive survey completed in summer of 2012/3 attempted to find Group I resistance. Approximately 50 fleabane samples were tested for susceptibility/resistance to 2,4-D amine. All samples were found to be susceptible to 2,4-D amine.

**Sowthistle:** The same survey mentioned above also determined the extent of Group I resistance in sowthistle. Seed was collected from sowthistle growing in winter cereals and summer fallows from 2012 and all were found to be susceptible to Group I chemistry.

In the past few years there was unease about survival of sowthistle following glyphosate applications. Recently screening work has identified two populations from the Liverpool Plains with elevated levels of tolerance to glyphosate. Table 5 shows that the “yellow” and the “CRK” biotypes to have reasonable survival rates and reproductive capability 42 days after the standard label rate of glyphosate (1.6L/ha or 720 g active ingredient per hectare).

The discovery of two populations of sowthistle with elevated survival rates following glyphosate may indicate a world’s first case of glyphosate resistant *Sonchus* species. Further research is underway to determine if a panel of glyphosate resistance experts deem this as glyphosate resistance.

This experiment was split into two separate growth stages. Results presented within are those following application to large rosette/early stem elongating plants. Anecdotal evidence suggests the recovery and reproduction of confirmed resistant biotypes following label rates of glyphosate to larger flowering plants is more pronounced and faster than those treated earlier. This could be due to greater expression of glyphosate resistance as plants develop and/or biological dilution of herbicide due to greater plant volume per unit area.
Table 5. Final assessments on sowthistle for plant survival, biomass control / production and reproductive capacity, made 42 days after treatment. Note: growth stage at treatment was large rosette to early elongating stage.

<table>
<thead>
<tr>
<th>Glyphosate rate g a.i./ha rate</th>
<th>Live plants (max = 1 plant per pot)</th>
<th>Green biomass as g/plant (% control)</th>
<th>Viable flower buds per plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susceptible biotype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>32.56 (0)</td>
<td>26.6</td>
</tr>
<tr>
<td>360</td>
<td>0.8</td>
<td>3.46 (89)</td>
<td>0</td>
</tr>
<tr>
<td>720</td>
<td>0.4</td>
<td>1.12 (97)</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>0.4</td>
<td>0.56 (98)</td>
<td>0</td>
</tr>
<tr>
<td>“CRK” biotype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>49.94 (0)</td>
<td>21.8</td>
</tr>
<tr>
<td>360</td>
<td>1</td>
<td>18.36 (63)</td>
<td>0.4</td>
</tr>
<tr>
<td>720</td>
<td>1</td>
<td>10.38 (79)</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>1</td>
<td>19.06 (62)</td>
<td>0</td>
</tr>
<tr>
<td>“Yellow” biotype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>59.26 (0)</td>
<td>16.8</td>
</tr>
<tr>
<td>360</td>
<td>1</td>
<td>32.84 (45)</td>
<td>6</td>
</tr>
<tr>
<td>720</td>
<td>1</td>
<td>18.92 (68)</td>
<td>0.2</td>
</tr>
<tr>
<td>1000</td>
<td>0.8</td>
<td>19.08 (68)</td>
<td>0</td>
</tr>
</tbody>
</table>

Implications to grains and cotton industries

Fallows, glyphosate tolerant crops and non-cropping areas are under threat of another glyphosate resistant species.

Group B resistance is already present within the QLD/NSW border region. It is likely that plants will develop multiple resistance to Groups B and M.

With the partial loss of effectiveness of glyphosate and Group B resistance in other parts of the northern grain region, there will be more selection pressure on Group I chemistry. Further to this, herbicide Groups C, G, H and L could be used more to take selection pressure off Groups B, I and M.

Due to its wind borne seed, glyphosate resistant sowthistle populations will spread rapidly, similar to fleabane. Surveys are presently underway to gauge the spread of resistance in the northern grain region. In time, southern regions should be surveyed to determine the extent of resistance to glyphosate.

Interim results from the survey work indicate that another two populations have similar tolerances to glyphosate as those discussed above. The location of these plants was within the Liverpool Plains. Sowthistle samples were collected further north and into the Darling Downs regions. The extended dry period in the central western parts of NSW has made it difficult to find samples to test.

Latest research to combat the glyphosate resistant threats (sowthistle)

With recent cases of suspected glyphosate resistance in common sowthistle, effective glyphosate alternatives are required. A field trial evaluated alternatives to glyphosate for fallow control of
common sowthistle and the impact of weed size. Treatments included alternative single and double knocks.

Located near Cecil Plains on the eastern Darling Downs, the field site had a dense (6-10 plants/m²) population of common sowthistle plants at two different growth stages (small <10cm diameter, and large >10cm diameter to elongating).

**Summary of results**

The most effective fallow treatments were the double knocks which were as equally effective on both small (97-100% control) and large (95-100% control) sowthistle plants (Table 6). Most double knock treatments provided 100% control, thereby stopping any weed seed production. Our results show that the double knock treatment is essential for the effective control of small and especially large sowthistle plants.

Antagonism between glyphosate and any tankmix partner was apparent. With reference to the data presented in Table 6, weed control from a single application of glyphosate (Roundup Attack® 1.23L/ha) ranged from 93 to 100% regardless of growth stage, whereas the levels of control when mixed with Amicide Advanced® 700, Tordon 75-D® and Starane Advance® were 2-43%, 12-62% and 40-64%, respectively. This phenomenon is not uncommon throughout the northern region, as agronomists constantly raise this issue with researchers. It is thought that the cause of this antagonism is the stress that glyphosate imposes on the plant which contradicts the conditions needed for effective hormonal activity.

Even though glyphosate was shown to be effective on this population of sowthistle, continued over-reliance on this herbicide is likely to lead to glyphosate resistance in this species. Growers with glyphosate susceptible populations should be using the double knock tactic to stop seed set on survivors. This is of particular importance in reducing weed density and herbicide resistance risk for the future.

While not tested on a glyphosate resistant population, it is likely the double knock tactic would also be effective. If a population of glyphosate resistant sowthistle is confirmed as part of our project, a pot study exploring the effectiveness of the double knock will take place.
Table 6. Visual biomass reduction of common sowthistle (*Sonchus oleraceus*) assessed 31 days after treatment where 0 - no control and 100% - total control. For double knock treatments, the second knock was applied 7 days after the first. LSD on transformed data = 29.24. Numbers in parentheses are transformed and should be used when comparing treatments using the LSD.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Herbicide rate/s (L/ha)</th>
<th>Small (&lt;10cm diameter) Average control (%)</th>
<th>Large (&gt;10cm diameter to elongating) Average control (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundup Attack</td>
<td>1.23</td>
<td>100 (90)‡</td>
<td>93 (81)†</td>
</tr>
<tr>
<td>Sprayseed†</td>
<td>2</td>
<td>80 (69)‡</td>
<td>43 (39)‡</td>
</tr>
<tr>
<td>* Roundup Attack fb Sprayseed†</td>
<td>1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Amicide Advanced '700 + Roundup Attack†</td>
<td>0.65 + 1.23</td>
<td>43 (40)‡</td>
<td>2 (4)‡</td>
</tr>
<tr>
<td>* Amicide Advanced '700 + Roundup Attack fb Sprayseed†</td>
<td>0.65 + 1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Tordon 75D* + Roundup Attack</td>
<td>0.7 + 1.23</td>
<td>62 (52)‡</td>
<td>12 (19)‡</td>
</tr>
<tr>
<td>* Tordon 75D* + Roundup Attack fb Sprayseed†</td>
<td>0.7 + 1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Starane Advance ‘ + Roundup Attack†</td>
<td>0.6 + 1.23</td>
<td>64 (58)‡</td>
<td>40 (39)‡</td>
</tr>
<tr>
<td>* Starane Advance ‘ fb Roundup Attack†</td>
<td>0.6 + 1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Sharpener’ + Roundup Attack</td>
<td>17g + 1.23</td>
<td>57 (49)‡</td>
<td>38 (38)‡</td>
</tr>
<tr>
<td>Sharpener’ fb Roundup Attack fb Sprayseed†</td>
<td>17g + 1.23 fb 2.0</td>
<td>97 (81)‡</td>
<td>95 (80)†</td>
</tr>
<tr>
<td>Alliance‡</td>
<td>2</td>
<td>70 (59)‡</td>
<td>18 (19)‡</td>
</tr>
<tr>
<td>Sprayseed‡</td>
<td>2.4</td>
<td>92 (73)‡</td>
<td>57 (49)‡</td>
</tr>
<tr>
<td>* Roundup Attack fb Sprayseed†</td>
<td>1.23 fb 2.4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Amicide Advanced ‘700 + Roundup Attack†</td>
<td>1.1 + 1.23</td>
<td>67 (60)‡</td>
<td>30 (31)‡</td>
</tr>
<tr>
<td>* Amicide Advanced ‘700 + Roundup Attack fb Sprayseed†</td>
<td>1.1 + 1.23 fb 2.4</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Tordon 75D* + Roundup Attack</td>
<td>1.0 + 1.23</td>
<td>88 (78)‡</td>
<td>58 (49)‡</td>
</tr>
<tr>
<td>* Tordon 75D* + Roundup Attack fb Sprayseed†</td>
<td>1.0 + 1.23 fb 2.4</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>Starane Advance ‘ + Roundup Attack†</td>
<td>0.9 + 1.23</td>
<td>97 (84)‡</td>
<td>67 (55)‡</td>
</tr>
<tr>
<td>* Starane Advance ‘ fb Roundup Attack†</td>
<td>0.9 + 1.23 fb 2.4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Sharpener’ + Roundup Attack</td>
<td>34g + 1.23</td>
<td>82 (66)‡</td>
<td>60 (52)‡</td>
</tr>
<tr>
<td>Sharpener’ fb Roundup Attack fb Sprayseed†</td>
<td>34g + 1.23 fb 2.4</td>
<td>100 (90)‡</td>
<td>99 (87)†</td>
</tr>
<tr>
<td>Alliance‡</td>
<td>2.8</td>
<td>90 (75)‡</td>
<td>50 (50)‡</td>
</tr>
</tbody>
</table>

fb - followed by, as part of a double knock  * - excluded from analysis as most values = 100  ‡ - not significantly different to 100. To compare with treatments excluded from analysis.
**Latest findings: residual herbicides on summer grasses**

Residual herbicides will play an important role in the control of summer grass weed species barnyard, feathertop Rhodes and windmill grass. Little is known about the efficacy of some new and some existing residual herbicides on these weed species. Consequently, a pot trial was established to evaluate the efficacy, over time, of different residual herbicides on the control of grass weed species barnyard, feathertop Rhodes and windmill grass. Due to the confidentiality of unregistered treatments and GRDC policy, treatments presented for this experiment are expressed in broad herbicide mode of action groups.

For barnyard grass, Group D, Group G and Group G + K treatments have provided the best control for 0 and 4 week plantings. No treatments provided any control of barnyard grass for the 8 week planting.

The best treatments for feathertop Rhodes grass are from herbicide Groups D and K. Both treatments have provided sustained control with 53 and 68% control at the 8 week planting. Other treatments which provided good short-term control are from Group G, K, G + K and B(imi) + K.

The best treatment for windmill grass has been from a Group D herbicide which has provided long term control with 77% control for the 8 week planting. Other treatments which have provided good short-term control (0 and 4 week plantings) are from Group G, K, K + G and B + K.

This experiment will be repeated in 2014/15 with the aim to have many of these herbicides registered. Plant-back considerations are important and thus some research needs to be focused to determine if these new treatments are not too restrictive for the various cropping regimes of the northern grain region.

**Clethodim damage in canola – impact and avoidance**

The application of clethodim at rates of product of 500mL/ha have been reported to cause the following symptoms on canola:

- Delayed flowering
- Distorted flower buds
- Possible yield suppression

The current label states that if applications of herbicide above 250mL/ha are made, canola can not be greater than the large rosette stage (GS 29). Other warnings such as not applying twice in the crop, not applying to stressed canola or avoid adding crop oil are aimed to minimise this damage.

Recent research in the central west parts of NSW by GOA had resulted in variable results. Overall damage seemed to be light and it was difficult to ascertain whether some damage was attributed to frost or other abnormal conditions. Yield effects were negligible for most sites. It was concluded that more field experiments could be completed over several sites and years, or some of this work could be achieved under controlled climate conditions, but loses the realistic conditions of field based research.

Clearly growers need to be aware of the main factor driving such drop damage. There may also be varietal differences, about which little is known, however, farmers can control the timing and rate of herbicide and should be able to avoid such issues. As for controlling the conditions of canola at the time of application, spraying earlier may avoid moisture stress issues particularly in seasons when rainfall is light. Spraying early means late emerging grass weeds will not be controlled with in-crop sprays but these plants are likely to be suppressed by a rapidly closing canola canopy. Seed production from these weed could still be managed with non-chemical options such a wind-row burning.
Barley grass on the increase in the central west

It is common to see farming systems involving continuous cropping without fallow or delayed sowing. The practices of dry-sowing and cereal dominance in the crop rotation are leading to increasing problems with barley grass.

Extremely high populations of barley grass 40,000 seedlings per square metre are sometimes targeted in a cereal crop after dry sowing and spray failures are common on these high weed densities. This is usually with group B or C products and results in very poor control. It is also far in excess of label constraints which target a maximum of 100 seedlings per square metre (as per metribuzin label).

There are some things to be learnt from other farmers in Australia that have been battling this weed for many years.

- There is resistance to herbicide Groups A, B and L.
- Delayed sowing could allow the use of glyphosate but research has indicated doing this continuously may select for populations with delay emergence patterns.
- Barley grass is a surface germinating species and may not emerge after some soil inversion.
- Break crops (e.g. lupins or TT canola) in a rotation provide different herbicide options such as simazine and clethodim.
- Burning residues may result in 50% (0-75%) control of barley grass.
- Avoid totally relying upon post-emergence herbicides, herbicide such as trifluralin and Boxer Gold® can achieve reasonably good control.
- Barley grass can be strategically managed in pasture phase prior to sowing cereals. If timed correctly, pasture spray-topping can control 60% (50-90%) of barley grass. Stock grazing can also reduce barley grass by approximately 30%.

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Non-herbicide tactics to help suppress weed growth. Row orientation, spacing and variety selection as weed management tools

Greg Brooke, NSW DPI Trangie

Key words
Non-herbicide, Row orientation, Row spacing, Plant population, barley, weeds, integrated weed management.

GRDC code
UA00124

Take home message
- At Bithramere near Tamworth east-west crop row orientation in barley yielded the same as north-south sowing but reduced biomass of weeds (canola) by 30% compared with a north-south row orientation.
- At Merredin and Beverley in W.A east–west sowing gave 24% yield increase in cereals and a 37 to 54% suppression in weed biomass.
- At Trangie increasing the seed density of the barley varieties Hindmarsh and Granger improved their yield and also increased their competitiveness against weeds (oats).

The rise in herbicide resistance in Northern region cropping systems has meant that in some situations weeds are dictating more and more how farmers can farm. With multiple resistance occurring in some weed species, non herbicidal measures to control or at least help suppress weeds are of increasing necessity. For integrated weed management (IWM) systems to be effective, non-herbicide strategies are imperative.

Prior to the advent of selective in-crop herbicides and the introduction of the semi-dwarf gene, cereal cultivars were taller and by nature had more suppressive effect on weeds such as oats (Vandeleur & Gill 2004). A crops competitive effect is most highly correlated with its ability to generate a large leaf area index early in its growth stage. (Coleman, Gill & Rebettzke 2001)

Several studies have been done amongst current cereal cultivars to determine whether some varieties are inherently better at suppressing weed growth than others.

Can the inherent ability of some varieties to accumulate biomass be put to effect against weeds?
What are the trade-offs in yield vs weed suppression from high vs low harvest index varieties?
Does increasing the crop sowing rate assist with weed competition? What are the effects of increasing seeding rate on variety performance and on weed suppression?
Does row orientation make any difference to either yield or weed suppression?

It is known that as a plant type barley is more competitive than wheat and for this reason barley is usually chosen for these plant competition trials.

Row orientation - does it make a difference?

Many paddocks in our northern region were originally set up for controlled traffic tramlines 15 years ago based on practicalities such as reducing headland area by choosing row direction according to the longest run of the paddock, so that row direction varies from paddock to paddock. In irrigation fields it is with fall of the paddock. Practicalities aside, what difference does row orientation make to crop yield and suppression of weeds?
Deliberately orienting crop rows at 90 degrees to the sunlight direction east–west (E-W) works on the principle that the crop will intercept more sunlight (photosynthetically available radiation) than will N-S sowing, giving weeds less chance to develop in the crop inter row. In winter when the sun is at a lower angle (solar plane) this shading of the inter row can confer advantages particularly in southern latitudes. Research from 2002–2005 conducted by Borger et al at Merredin and Beverley W.A. (latitudes S 31° to 32°) has shown both yield advantages as well as weed suppression from east/west row orientation compared with north/south.

Merredin in Western Australia is similar in latitude to Tamworth.

Annual TOTAL solar radiation at Merredin is very similar to annual TOTAL solar radiation at some eastern state sites eg. Merredin W.A 7036MJ/m2; Trangie NSW 6864MJ/m2; Goondiwindi NSW 7172MJ/m2 (source CliMate app)

Within wheat and barley crops oriented east-west, in the W.A trials weed biomass (averaged throughout all trials) was reduced by 51 and 37%, and grain yield increased by 24 and 26% (compared with crops oriented north-south) (Borger et al)

Weeds in these trials were sown wild radish (300 pod segments/m²) and annual ryegrass (“Safeguard” 200 seeds/m²)

At Bithramere near Tamworth in 2012, Matt Gardner et al established a trial with two barley varieties- Hindmarsh and Skipper with a sown population of 44Y84 canola as a substitute weed. Row orientation, row spacing 30 cm vs 50 cm were evaluated. A row orientation of E-W conferred a reduction in weed (canola) biomass of 39%.

Skipper being more vigorous than Hindmarsh reduced weed (canola) biomass a further 30% and 42% over Hindmarsh for the N-S and E-W sowing.

The weed fumitory was also prolific in the N-S sowing but was reduced almost to nothing in the E-W row orientation. (Matt Gardner pers comm.)

Row orientation had no significant impact on grain yield under high weed competition. When no weeds were present, the N-S orientation had a 6% and 7% yield improvement for the 30 and 50cm row spacing treatments. (Gardner et al 2012)

Summer crop work in sorghum by Serafin, L and McMullen, G 2011 showed row orientation had no advantage in terms of yield. This is most likely because the sun is at a higher angle and also because of the relatively lower plant populations involved and the wider rows – 75cm. Importantly E–W sowing did not yield any less than did N-S sowing meaning it would be compatible with winter crop programs which deliberately oriented crop rows E-W for weed control.

**Row spacing- does it make a difference?**

The Bithramere 2012 trial with 30 cm vs 50 cm showed no clear effects in reducing weed (canola) biomass, but the wider row spacing did incur a yield penalty of 11% in the nil weed treatment.

At Merredin W.A. two row spacings of 23 cm vs 60 cm were used and at Beverley WA two row spacings were studied at 18 cm vs 36 cm. Averaged throughout all trials, weed biomass was lower in crops with narrow row spacings (Borger et al).

**Varieties – are there differences?**

Most published work has concentrated on crop type eg barley vs wheat vs canola vs lupins etc and not on varieties. Recent work with barley varieties shows there is as much difference between barley varieties as there can be between crop types.

The Bithramere trial with two barley varieties showed the more vigorous barley variety Skipper reduced weed (canola) biomass by 30 – 40% over Hindmarsh³.
Skipper also out-yielded Hindmarsh with both weeds present and not present and at both 30 and 50 cm row spacings.

Figure 1. Barley competition trial, Trangie 2013

Figure 1 summarises a barley competition trial conducted at Trangie in 2013 and shows the capacity of different varieties to yield both with and without weeds and the yield loss incurred by weeds (oats).

15 barley varieties were sown at 100 seeds per m² and 3 of these varieties were sown at double rate of 200 seeds per m². Row spacing was 33cm. The oat variety Yarran was surface sown as a substitute weed at 50 seeds per m² and was allowed to grow right through until maturity. The yield loss attributed to weeds averaged across all varieties was 0.3t/ha.

The popular and high yielding variety Hindmarsh both with and without weeds present was the highest yielding variety. Increasing the seed rate to 200 seeds/m² improved the yield of Hindmarsh both with and without weeds and also gave greater suppression of weeds. This is consistent with other seeding rate trial work with Hindmarsh in variety specific agronomy package (VSAP) trial work.

The variety Granger at 200 seeds/m² improved yield where weeds were present but only maintained yield where there were no weeds present.

Figure 2. Oat suppression by barley variety, competition trial, Trangie 2013

Figure 2 shows the effects of weed (oat) suppression by barley variety.
Varieties such as Hindmarsh which are lower biomass types proved less suppressive of weeds than bulkier types such as Grange, Fathom, Commander.

Increasing the seeding rate of Hindmarsh caused greater suppression of oat yield. Granger at 200 seeds per m\(^2\) gave the greatest reduction in oat yield.

**Summary**

Crop row orientation of E-W in winter cereals has given substantially greater suppression of weeds in both WA and Northern NSW trials.

Barley variety choice will impact the seed set of oats.

Increasing seeding rate of Hindmarsh and Granger from 100 seeds to 200 seeds per m\(^2\) caused a further reduction in weed (oat) yield.

Increasing the seeding rate of ScopeCL did not improve yield or significantly increase suppression of oats in this trial.

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The effect of plant density on yield in chickpea across central and northern NSW

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Key words
grain yield, plant density, variety

GRDC code
DAN00171

Take home message

\begin{itemize}
  \item When sowing within the optimum sowing window mid May – mid June;
    \begin{itemize}
      \item yield potential ≥ 1.5 t/ha sow at ≥ 30 plants/m\textsuperscript{2}
      \item yield potential ≤ 1.5 t/ha sow at ≥ 20 plants/m\textsuperscript{2}
    \end{itemize}
  \item When sowing very late sow at high plant density
  \item To reduce losses due to virus, DO NOT sow below 20 plants/m\textsuperscript{2}
\end{itemize}

Introduction

Research in Queensland by Beech and Leach (1989), recommended plant populations of 40 plants/m\textsuperscript{2} and later work by Brinsmead et al. (1996) suggested an optimum sowing density of 20–40 plants/m\textsuperscript{2}.

Whish et al (2007) monitored 52 commercial chickpea crops over three seasons (2002-04) which showed the median plant density on farm fluctuated between 14 and 22 plants/m\textsuperscript{2}. Modelling by Whish et al (2007) suggested that increasing plant density independently of sowing date would improve yields 55\% of the time for crops sown in early June and 60\% of the time for crops sown in mid May.

Current agronomic advice suggests yields are relatively stable over plant densities of 20-30 plants/m\textsuperscript{2}, with an optimum target population of 25 plants/m\textsuperscript{2} for northern regions (Cumming and Jenkins, 2011).

Methods

A series of variety x plant density factorial experiments were conducted across a number of central and northern NSW locations from 2011 to 2013.

Varieties examined were PBA HatTrick\textsuperscript{1}, PBA Boundary\textsuperscript{1}, Kyabra\textsuperscript{1}, CICA912 and GEN090 (small seeded kabuli) at plant densities of 5, 10, 15, 20, 30 and 45 plants/m\textsuperscript{2}. During 2011 and 2012 experimental sites were located at Coonamble and Tamworth. In 2013 the number of sites was expanded to eight with the commencement of DAN00171 to include; North Star, Moree, Edgeroi, Burren Junction (not harvested), Coonamble, Tamworth, Pine Ridge and Trangie.
Row spacing varied across sites; Trangie 33cm, Tamworth 40cm, North Star, Moree, Edgeroi, and Pine Ridge all at 50cm and Coonamble at 66cm.

Across all sites and years variety and plant density were significant as main effects but there were no significant interactions between variety and plant density. In this paper only yield responses to plant density will be reported.

**Effect of plant density on yield in contrasting environments – Coonamble and Tamworth**

Experiments were conducted at Coonamble and Tamworth from 2011-2013. The differences between these locations is best characterised in terms of crop season (May – November) rainfall and evapotranspiration.

In 2011, the wettest of the three crop seasons, Tamworth received 499mm compared to Coonamble with 381mm. Both 2012 and 2013 were drier years in both environments with Tamworth (262 and 268mm) receiving, on average, 130mm more in-crop rainfall in each year than Coonamble (132 and 139mm). Crop season evapotranspiration totals in Coonamble were 846, 918 and 1043mm, compared to Tamworth with 725, 818 and 872mm, for 2011, 2012 and 2013, respectively.

The response of yield to plant density at Coonamble and Tamworth are shown in Figures 1 and 2, respectively.

![Graph showing effect of plant density on grain yield at Coonamble in 2011, 2012, and 2013](image)

**Figure 1.** The effect of plant density on grain yield at Coonamble in 2011 (■), 2012 (•) and 2013 (♦).

At Coonamble (see Fig. 1), in the two drier seasons, yield was ≤ 1.5 t/ha and was not significantly different at densities ranging from 15 to 45 plants/m². In the wetter year, 2011, grain yield reached over 3.5 t/ha ad there was a marginal but significant increase in yield between 15 (3.53 t/ha) and 45 plants/m² (3.89 t/ha).

At Tamworth, the wetter of the two locations, yields were more responsive across the range of plant densities over all years (see Fig. 2).
At Tamworth, the optimum plant density was 30 plants/m$^2$ with yields of 2.97, 2.18 and 2.15 t/ha in 2011, 2012 and 2013, respectively.

The linear response of yield to plant density, from 15 to 45 plants/m$^2$, was derived for each year at both locations. Coonamble had a flatter response across all years with slopes of 5.35, 0.18 and -7.35 kg/ha/plant/m$^2$, compared to Tamworth with, 23.51, 19.26, and 9.08 kg/ha/plant/m$^2$ for 2011, 2012 and 2013, respectively.

Effect of plant density on yield across sites - 2013

In 2013 the number of locations was expanded and sites have been grouped into northern (North Star, Moree, Edgeroi, Coonamble) and southern locations (Tamworth, Pine Ridge, Trangie). The May to November rainfall for the northern sites was; Coonamble = 139, Moree = 173, North Star = 205 and Edgeroi = 226mm, while for the southern sites it was; Trangie = 214, Tamworth = 266 and Pine Ridge = 306mm.

The plot of grain yield versus plant density for the northern sites is in Figure 3 while the same relationship for the southern sites is shown in Figure 4. For the northern sites the response of yield to plant density was flat from 15 to 45 plants/m$^2$ (see Fig. 3) with slopes of; Coonamble = -7.35, Edgeroi = -1.27, North Star = 1.6 and Moree = 3.93 kg/ha/plant/m$^2$. For the southern sites, the slope of yield to plant densities, from 15 to 45 plants/m$^2$ (see Fig. 4) were; Trangie = 5.31, Tamworth = 9.09 and Pine Ridge = 16.31 kg/ha/plant/m$^2$. 

Figure 2. The effect of plant density on grain yield at Tamworth in 2011 (■), 2012 (●) and 2013 (◆)
Figure 3. Effect of plant density (plants/m²) on grain yield (t/ha) for the 2013 northern sites; North Star (■), Edgeroi (□), Moree (●) and Coonamble (○).

The southern sites, which on average received more in-crop rain, gave greater yield responses as plant density increased from 15 to 45 plants/m². Optimum yield was achieved around 30 plants/m². With the exception of North Star, the northern sites yielded less than 1.5 t/ha at optimum densities of about 20 plants/m². Even North Star had a flat yield response above 15 plants/m².

Figure 4. Effect of plant density (plants/m²) on grain yield (t/ha) for the 2013 southern sites; Tamworth (■), Edgeroi (□) and Trangie (●).
Conclusion

- When sowing within the optimum sowing window mid May – mid June;
  yield potential ≥ 1.5 t/ha sow at ≥ 30 plants/m^2
  yield potential ≤ 1.5 t/ha sow at ≥ 20 plants/m^2
- When sowing very late sow at high plant density
- To reduce losses due to virus, DO NOT sow below 20 plants/m^2

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References


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Effect of row spacing on yield in chickpea under high yield potential – past and present research

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Key words
space, plant density, variety, sowing date

GRDC code
DAN00171

Take home message

- When sowing within the optimum sowing window mid May – mid June;
  yield potential ≥ 2.0 t/ha sow on narrow rows (≤ 40cm)
  yield potential ≤ 2.0 t/ha row spacing has less of an impact on yield
- When sowing very late, sow on narrow rows at high plant density
- When sowing very early, sow on wider rows to reduce early soil water extraction
- Current varieties (PBA HatTrick\(^3\)) have a lower rate of yield decline at wider row spacing

Introduction

Chickpeas are successfully grown using a wide range of row spacing’s, ranging from 20-100 cm with wider rows (50-100cm) becoming quite common. In northern New South Wales and Queensland, the current rule of thumb is that row spacing ranging from 25-75 cm results in no yield difference (Cumming and Jenkins, 2011).

These guidelines were based on the original research work of Felton et al (1996) conducted in the early 90’s. There was a need to look at the effect of row spacing under high yield potential situations utilising current varieties and newer agronomic practices.

Pioneering row spacing research

Research in the 1990’s demonstrated that no-till increased chickpea yields by 10%. Wider row spacing was seen as a means of increasing the commercial attractiveness of no-till chickpeas. Therefore, it was important to determine if this caused any decrease in productivity.

Research conducted by Felton et al (1996) explored the effects of row spacing 25, 50, 75 and 100cm and plant density, 20-80 kg/ha, on grain yield in chickpea (see Fig. 1). Across two sites and three seasons they concluded that in three low yielding experiments (1991-1992), there was no yield reduction due to row spacing. In 1993 (very wet year) the two sites showed an average linear yield decline of 4.4 ± 1.3 kg/ha/cm (Felton et al 1996). All of these experiments were conducted using cv Amethyst released 1987), the most popular variety at the time.
A point to note is that in all three years x two sites, yield never exceeded 2.5 t/ha even at the narrow row spacing under above average rainfall (see Fig 1.).

![Figure 1](image.png)

**Figure 1.** The main effect of row spacing, (averaged across density) on grain yield at two locations across three cropping seasons (Adapted from Felton et al (1996)).

**Contemporary row space x plant density research**

An experiment was conducted in 2010 at TAI to examine the effects of row space x plant density on grain yield in chickpeas. PBA HatTrick was the variety used along with cv Amethyst as a comparator to the original work conducted by Felton et al (1996).

Four row spaces: 20, 40, 80 and 120cm were used with three plant densities 15, 30 and 45 plants/m² in a four replicate factorial. The experiment was sown into standing wheat residue. The 2010 cropping season experienced above average rainfall and both varieties were sprayed prior to every rainfall event with 2 L of clorothalonil to remove the effect of Ascochyta blight on grain yield. Amethyst is extremely susceptible to Ascochyta blight. The NuFarm 720 Unite label states: “DO NOT exceed 3.2 L of Unite 720 per ha of crop.” The regime of frequent use of chlorothalonil as used in this trial exceeded recommended use and was only used for experimental purposes.

The row space x plant density interactions on grain yield are shown in Fig. 2 and Fig. 3 for cultivars Amethyst and PBA HatTrick(1), respectively.

Under high potential yield, cv Amethyst showed a significant decline in yield across the three densities as row spacing increased (see Fig. 2). Highest yields were achieved under very narrow rows (20cm) with high plant density (3.1 t/ha). Yields fell below 2.5 t/ha once row space exceeded 40cm and density fell below 30 plants/m².

PBA HatTrick(1) showed far more yield stability over wider row spaces and plant densities than cv Amethyst (see Fig. 3). Low plant density (15 plants/m²) showed significant yield loss across all row spaces. At 30 plants/m², yield was flat up to 40cm but was significantly lower at 80 and 120cm.
Figure 2. The effect of row space and plant density on grain yield of cultivar Amethyst.

Figure 3. The effect of row space and plant density on grain yield of cultivar PBA HatTrick.
Linear yield decline across row spacing was -9.42 and -6.93 kg/Ha/cm for cv Amethyst and PBA HatTrick, respectively. These rates of decline in yield exceed the findings of Felton et al (1996) who reported an average decline of -4.4 ± 1.3 kg/ha/cm. In all row space x plant density combinations PBA HatTrick showed far less decline in yield compared to cv Amethyst suggesting a genetic advantage.

The response of these two cultivars to row spacing is best illustrated by comparing yield at a fixed plant density of 30 plants/m² (Fig. 4).

![Figure 4](image-url)  
**Figure 4.** Comparison of grain yield across row spacing for cv Amethyst (●) and PBA HatTrick (■) at a fixed plant density of 30 plants/m².

Yield of cv Amethyst collapses as row space increases with a linear decline of -8.2 kg/Ha/cm compared to PBA HatTrick, -5.8 kg/Ha/cm. Even though PBA HatTrick has a much flatter response, yield is still significantly lower at a row space of 80cm compared to 40cm.

### Effect of row space on yield over seasons

Work by Horn et al. (1996) recommended early May to mid June as the optimum sowing times across northern NSW and southern Qld. In trials at Tamworth in 2003, June planted chickpea out yielded May sowing by 5% and July plantings by 20%, while a May planting was better than June by 11% and July by 42% in 2004 (Haig and McMullen 2012).

Yield comparisons of different cultivars, sown over different years at either 40 or 80cm row spaces and at a fixed plant density of 30 plants/m² is shown in Table 1. Over four site years narrow row (40cm) chickpeas have consistently out yielded wide row (80cm) chickpeas. Within the optimum sowing window (early May to mid June), averaged across varieties, narrow row spacing has averaged 2.53 t/ha while the wide rows have averaged 2.17 t/ha.

In 2013 sowing was delayed due to late opening rains and main season sowing didn’t occur until the 22nd June while a very late sowing was made on the 17th July. A narrow row crop sown at the end of
the optimum sowing window yielded 2.20 t/ha while the very late sown crop yielded 1.45 and 1.08 t/ha for narrow and wide rows, respectively.

**Table 1.** Effect of sowing date and row spacing on the yield of different varieties over consecutive seasons. All sown at a fixed plant density of 30 plants/m².

<table>
<thead>
<tr>
<th>Year</th>
<th>Sow Date</th>
<th>Variety</th>
<th>Row-space</th>
<th>Yield</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>30th May</td>
<td>Flipper(l)</td>
<td>40cm</td>
<td>2.08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30th May</td>
<td>Jimbour</td>
<td>80cm</td>
<td>1.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30th May</td>
<td>Jimbour</td>
<td>40cm</td>
<td>2.31</td>
<td>± 0.162</td>
</tr>
<tr>
<td>2009</td>
<td>29th May</td>
<td>Flipper(l)</td>
<td>80cm</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29th May</td>
<td>Jimbour</td>
<td>40cm</td>
<td>2.83</td>
<td>± 0.190</td>
</tr>
<tr>
<td></td>
<td>29th May</td>
<td>Jimbour</td>
<td>80cm</td>
<td>2.23</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>1st June</td>
<td>Amethyst</td>
<td>40cm</td>
<td>2.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1st June</td>
<td>PBA HatTrick(l)</td>
<td>80cm</td>
<td>2.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1st June</td>
<td>Amethyst</td>
<td>40cm</td>
<td>2.98</td>
<td>± 0.093</td>
</tr>
<tr>
<td></td>
<td>1st June</td>
<td>PBA HatTrick(l)</td>
<td>80cm</td>
<td>2.74</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>22nd June</td>
<td>PBA HatTrick(l)</td>
<td>40cm</td>
<td>2.20</td>
<td>± 0.033</td>
</tr>
<tr>
<td></td>
<td>22nd June</td>
<td>PBA HatTrick(l)</td>
<td>40cm</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22nd June</td>
<td>PBA HatTrick(l)</td>
<td>80cm</td>
<td>1.08</td>
<td>± 0.028</td>
</tr>
</tbody>
</table>

The significant yield advantage of narrow rows over wide rows for the very late sown (17th July) crop supports the findings of Whish and Cocks (2004) and Whish (2007), where narrow planted late crops produced higher yields.

**Conclusion**

- New varieties (PBA HatTrick(l)) have a lower rate of yield decline at wider row spacing compared to older varieties such as Amethyst
- When sowing within the optimum sowing window mid May – mid June;
  - yield potential ≥ 2.0 t/ha sow on narrow rows (≤ 40cm)
  - yield potential ≤ 2.0 t/ha row spacing has less of an impact on yield
- When sowing very late, sow on narrow rows at adequate plant density
- When sowing very early, sow on wider rows to reduce early soil water extraction

**Acknowledgements**

Thanks to Michael Nowland and Paul Nash for their assistance in the trial program.

**References**


Haig, B and McMullen, K.G. (2012). The Influence of planting date, sowing depth and soil type on chickpea production with no-tillage in northern New South Wales. 16th Australian Agronomy Conference

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Phytophthora tolerance in chickpea varieties – paddock selection and management

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Key words
Phytophthora root rot, waterlogging, variety, risk management

GRDC codes
DAN00143, DAN00176, DAQ00154

Take home message
Minimise the risk of Phytophthora root rot, PRR in your 2014 chickpeas by:

- avoiding poorly drained paddocks
- avoiding paddocks with a history of lucerne, medics or chickpea PRR
- not growing PBA Boundary if you even suspect a PRR risk
- selecting the best variety suited to soil type, farming system and disease risk which, for PRR is Yorker>HatTrick>Jimbour>Kyabra>Boundary

Note: metalaxyl seed treatment is not recommended in any situation

The 2013 northern NSW/southern QLD chickpea season

The 2013 chickpea season in northern NSW/southern QLD followed a wet January to March, below average post-sow rain in Jun/Jul and then well below average rain for the rest of the growing season (Dalby’s July rain was just above average). Saturated soil in the early part of the chickpea season resulted in waterlogging and in certain paddocks Phytophthora root rot. Mild winter conditions favoured rapid vegetative growth resulting in valuable soil moisture being used to grow high biomass crops. From mid-late Aug to mid-Oct, average daily temperatures fluctuated above and below 15°C and this stress caused flower and pod abortion; 2-3 days of severe frosts around 20 Aug killed flowers and pods on what were by now moisture stressed plants. The much needed rain that started on 15 Sep, was too late and instead of encouraging crops to set new flowers and pods, had the opposite effect – most crops started shutting down by the end of Sep. Across the region, diseases were of little concern. Of 280 crops inspections, Ascochyta blight was found in only five and caused no yield loss. Viruses appeared in late Sep - end Oct, but unlike 2012 caused only minor losses across the region.

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. The importance of alternative hosts in chickpea PRR was strikingly demonstrated at Moree in 2012. The paddock had never grown chickpeas and had only had three crops (all wheat) after at least 30 years of Coolatai grass and native medic. PRR was first diagnosed on 5 Jul 12 in a few groups of plants; but by mid-Aug, large areas had been killed and on 31 Aug, the entire crop was sprayed out. In contrast, no PRR was found in the adjoining paddock which had a long history of cropping (and thus opportunities to control medics).
The importance of varietal susceptibility became obvious on the Darling Downs during the 2013 season. The high yielding, Ascochyta resistant PBA Boundary was grown widely in the Dalby-Macalister-Warra-Jondaryan area. Unfortunately, saturated soil conditions in the early part of the season showed up PBA Boundary’s susceptibility to Phytophthora, with lower parts of several paddocks killed.

PRR (and waterlogging) are favoured by wetter than normal seasons, or by periods of soil saturation in normal seasons as happened in the early part of 2013. Waterlogging can be confused with PRR, but differs in that (i) roots die from lack of oxygen whilst with PRR the Phytophthora organism consumes them; (ii) plants are most susceptible during flowering and early pod fill whereas PRR can affect plants of any age (iii) symptoms develop within 2 days of flooding compared to at least 7 days for PRR, (iv) roots are not rotted immediately after the waterlogging event and, (v) initially, plants are not easily pulled from the soil unlike those affected by PRR.

As there are no in-crop control measures for PRR or waterlogging, a critical management tool is avoidance of high risk paddocks (based on previous experience and paddock history). The other key tool for PRR is varietal selection. Current commercial varieties differ in their resistance to *P. medicaginis*, with Yorker and PBA HatTrick have the best resistance and are rated MR (Yorker slightly better than PBA HatTrick), Jimbour MS - MR, Flipper and Kyabra MS and PBA Boundary having the least resistance (S). PBA Boundary should not be grown in paddocks with a history of PRR, lucerne, medics or other hosts.

A 2012 PRR trial at Warwick showed that hybrid breeding lines, generated by crossing chickpea with a wild *Cicer* species, have higher levels of resistance to *P. medicaginis* than the most resistant variety, Yorker (Table 1). Although the yields of the hybrids in the absence PRR in this trial were slightly lower than those of PBA HatTrick and PBA Boundary, their improved *Phytophthora* resistance will compensate for that lower yield in wet years. The results also confirm that PBA Boundary suffers a higher yield loss from PRR than PBA HatTrick. The trial was inoculated with *P. medicaginis*, and some plots were soil-drenched with a fungicide to stop root infection; yield loss calculations for each variety/line were based on the difference in yield between the fungicide-treated plots and untreated plots.

**Table 1.** Yields of chickpea varieties and breeding lines in the absence of phytophthora root rot, and % yield losses from PRR in a 2012 trial at Warwick QLD (P Yield<0.014; lsd Yield = 0.31; P %yield loss<0.001, lsd Yield loss = 24)

<table>
<thead>
<tr>
<th>Variety/line</th>
<th>Yield (t/ha) in absence of Phytophthora infection</th>
<th>% yield loss due to Phytophthora infection</th>
</tr>
</thead>
<tbody>
<tr>
<td>D06318&gt;F3BREE2AB016</td>
<td>2.40</td>
<td>14</td>
</tr>
<tr>
<td>D06344&gt;F3BREE2AB027</td>
<td>2.47</td>
<td>22</td>
</tr>
<tr>
<td>D06321&gt;F3BREE2AB002</td>
<td>2.41</td>
<td>26</td>
</tr>
<tr>
<td>CICA0912</td>
<td>2.49</td>
<td>34</td>
</tr>
<tr>
<td>Yorker</td>
<td>2.52</td>
<td>35</td>
</tr>
<tr>
<td>CICA1007</td>
<td>2.87</td>
<td>60</td>
</tr>
<tr>
<td>PBA HatTrick</td>
<td>2.56</td>
<td>64</td>
</tr>
<tr>
<td>Jimbour</td>
<td>2.70</td>
<td>66</td>
</tr>
<tr>
<td>Kyabra</td>
<td>2.83</td>
<td>78</td>
</tr>
<tr>
<td>PBA Boundary</td>
<td>2.58</td>
<td>85</td>
</tr>
</tbody>
</table>

*D lines are hybrid crosses between chickpea (*C. arietinum*) and a wild *Cicer* species*
In 2013, a scaled down version of this trial was again conducted at the Hermitage Research Station, Warwick. In this trial PRR was more severe than in the 2012 trial and differences among the varieties were not as great. It is thought the milder winter conditions of the 2013 chickpea season kept soil temperatures above average and this favoured the disease. Nevertheless, the improved resistance of hybrids over varieties was obvious and the ranking of the varieties remained similar to that of the 2012 trial. Indeed, since we started these PRR yield loss trials in 2007, the ranking of varieties has been consistent with the cumulative survival data showing: Yorker > Hat Trick > Jimbour > Kyabra > Boundary.

What the 2013 trial clearly demonstrated was that even the current best varieties eg Yorker, can sustain serious yield loss under high Phytophthora pressure. The trial also highlights the importance of assessing the PRR risk for a given paddock/season.

Table 2  Yields of commercial chickpea varieties and breeding lines in the absence of phytophthora root rot, and % yield losses from PRR in a 2013 trial at Warwick QLD. (P Yield<0.001; lsd Yield = 0.25; P %yield loss<0.001, lsd Yield loss = 23)

<table>
<thead>
<tr>
<th>Variety/line</th>
<th>Yield (t/ha) in absence of Phytophthora infection</th>
<th>% yield loss due to Phytophthora infection</th>
</tr>
</thead>
<tbody>
<tr>
<td>D06318&gt;F3BREE2AB016</td>
<td>1.8</td>
<td>33</td>
</tr>
<tr>
<td>D06344&gt;F3BREE2AB027</td>
<td>1.9</td>
<td>37</td>
</tr>
<tr>
<td>CICA0912</td>
<td>1.9</td>
<td>63</td>
</tr>
<tr>
<td>Yorker</td>
<td>2.2</td>
<td>66</td>
</tr>
<tr>
<td>CICA1007</td>
<td>2.0</td>
<td>73</td>
</tr>
<tr>
<td>PBA Hat Trick</td>
<td>1.8</td>
<td>79</td>
</tr>
<tr>
<td>PBA Boundary</td>
<td>1.8</td>
<td>82</td>
</tr>
</tbody>
</table>

A D lines are hybrid crosses between chickpea (C. arietinum) and a wild Cicer species


Acknowledgements

Thanks to growers and agronomists for help with crop inspections and submitting specimens, to Woods Grains, Goondiwindi for planting material for trials and to chemical companies who provided products for research purposes and trial management. Thanks to Steve Harden for trials designs and analyses and to Paul Nash, Gail Chiplin, Willy Martin and Kris King for technical support.

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Chickpea varietal purity and implications for disease management – are we heading down the Sunvale trail?

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Key words
chickpea, varietal purity, disease management, seed industry

GRDC code
DAN00143

Take home message
• Unusually aggressive levels of Ascochyta in chickpea crops raised questions about varietal purity
• DNA testing of 36 seed lots from commercial chickpea crops identified a high incidence of genetic contamination
• Growers can minimise the risk of planting the wrong variety or a mixture of varieties by acquiring planting seed from a reputable seed supplier

Background
Australian chickpea varieties differ in their reaction to Ascochyta blight, caused by the fungus Phoma rabiei (syn Ascochyta rabiei). Varieties released before 2005 e.g. Jimbour, are susceptible to Ascochyta and, in seasons conducive to disease, require intensive management with foliar fungicides. Most cultivars released in 2005 and later e.g PBA HatTrick, have improved Ascochyta resistance and require fewer fungicide sprays. Accurate identification of chickpea varieties is thus critical to Ascochyta management in commercial crops.

Since 2011, several chickpea crops in the GRDC northern region have shown inconsistencies in their reactions to Ascochyta blight. In all cases the variety was named as PBA HatTrick and the seed was grower retained. PBA HatTrick, released in 2009, is rated Moderately Resistant (MR) to Ascochyta but the level of disease in these crops was more typical of varieties rated as Susceptible (S). Possible explanations for these unexpected higher levels of disease include (i) a change in the pathogenicity of P. rabiei ie breakdown of varietal resistance, and (ii) authenticity and/or purity of the variety ie mix up in seed source or contamination. Leo et al (2014), in a comprehensive study of the Australian population of P. rabiei, found the genetic diversity of isolates was low and there was little evidence for widespread changes in pathogenicity. Simpfendorfer et al (2013) showed varietal contamination caused the higher than expected levels of stripe rust in the MR bread wheat variety Sunvale. This posed the question: could contamination or a mix-up in source of planting seed account for the observed differences in Ascochyta levels in “HatTrick” crops grown from grower retained seed. It also raised the larger issue of maintaining genetic purity in Australian chickpea varieties after their release.

Purity of chickpea varieties ex 2011 harvest

Thirty six seed-lots from commercial chickpea crops grown in the GRDC northern region in the 2011 season were assessed for seed purity using four simple sequence repeats (SSR, also called
microsatellite) markers. These four were a subset of 15 SSR markers that were shown to differentiate 24 Australian commercially released chickpea varieties and breeding lines. These, and for the varieties, their year of release are listed in Table 1.

For each seed lot, DNA was extracted from eight seedlings and each seedling was assayed using the four SSR markers. Note: this work has not yet been peer reviewed.

The seed weight for each seed lot was determined by weighing three random subsamples, each of 100 seeds, per lot.

**Table 1.** Australian chickpea varieties and breeding lines used to identify SSR markers that could discriminate among individual varieties

<table>
<thead>
<tr>
<th>Variety/Genotype</th>
<th>Year of Release</th>
<th>Variety/Genotype</th>
<th>Year of Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jimbour</td>
<td>2001</td>
<td>PBA HatTrick◊</td>
<td>2009</td>
</tr>
<tr>
<td>Moti</td>
<td>2003</td>
<td>PBA Slasher◊</td>
<td>2009</td>
</tr>
<tr>
<td>Sonali</td>
<td>2004</td>
<td>Genesis™ 079</td>
<td>2009</td>
</tr>
<tr>
<td>Flipper◊</td>
<td>2005</td>
<td>Genesis™ 114</td>
<td>2010</td>
</tr>
<tr>
<td>Kyabra◊</td>
<td>2005</td>
<td>Genesis™ Kalkee</td>
<td>2011</td>
</tr>
<tr>
<td>Yorker◊</td>
<td>2005</td>
<td>PBA Pistol◊</td>
<td>2011</td>
</tr>
<tr>
<td>Almaz</td>
<td>2005</td>
<td>PBA Boundary◊</td>
<td>2011</td>
</tr>
<tr>
<td>Genesis™ 090</td>
<td>2005</td>
<td>PBA Striker◊ (CICA0603)</td>
<td>2012</td>
</tr>
<tr>
<td>Genesis™ 425</td>
<td>2007</td>
<td>PBA Maiden◊ (CICA0717)</td>
<td>2013</td>
</tr>
<tr>
<td>CICA0709</td>
<td>not released</td>
<td>PBA Monarch◊ (CICA0857)</td>
<td>2013</td>
</tr>
<tr>
<td>CICA0912</td>
<td>not released</td>
<td>CICA1007</td>
<td>not released</td>
</tr>
<tr>
<td>CICA1016</td>
<td>not released</td>
<td>04067-81-2-1-1</td>
<td>not released</td>
</tr>
</tbody>
</table>

**Results**

In only 15 of the 36 seed lots, were all eight seedlings deemed to be the same; the remaining 21 lots showed varying degrees of contamination by known and unknown genotypes. Results for eight seed lots are in Table 2.
Table 2. Selected results from 36 chickpea seed lots ex 2011 harvest showing the variety declared at receival, 100 seed weight and identity of each of 8 seedlings as determined by four SSR markers based on DNA profiles

<table>
<thead>
<tr>
<th>Declared</th>
<th>100 sdw g</th>
<th>DNA Identity (max 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jimbour</td>
<td>21.8</td>
<td>Jimbour (1), Kyabra (6), Undetermined (1)</td>
</tr>
<tr>
<td>Jimbour</td>
<td>20.0</td>
<td>HatTrick (8)</td>
</tr>
<tr>
<td>Kyabra</td>
<td>21.8</td>
<td>Moti (7), Kyabra (1)</td>
</tr>
<tr>
<td>Kyabra</td>
<td>20.9</td>
<td>HatTrick (4), Kyabra (1), Undetermined (3)</td>
</tr>
<tr>
<td>Kyabra</td>
<td>18.3</td>
<td>Kyabra (1), Jimbour (2), Moti (4), Undetermined (1)</td>
</tr>
<tr>
<td>Howzat</td>
<td>17.2</td>
<td>Flippert (6), Undetermined (2)</td>
</tr>
<tr>
<td>HatTrick</td>
<td>21.2</td>
<td>HatTrick (8)</td>
</tr>
<tr>
<td>Amethyst</td>
<td>18.2</td>
<td>Jimbour (7), Undetermined (1)</td>
</tr>
</tbody>
</table>

The DNA assays for the 36 seed lots suggest that unintentional contamination, or mix up in planting seed, is the most plausible explanation for any differences among the eight seedlings.

The seed weight data support the findings of the DNA assays. The 100 seed weights for Amethyst, Flippert, PBA HatTrick, Howzat, Jimbour, and Kyabra in field trials conducted in Southern QLD from 2005 – 2008, were 14, 18, 20, 21, 20 and 24 grams respectively. Thus it is not surprising that the seed lot declared to be Amethyst in Table 2 was determined to be a variety with a 100 sdw greater than 14g. Similarly the lot declared to be Howzat had seeds that were too small to be Howzat (100 sdw 21g) but that were similar to those of Flippert (100 sdw 18g).


How widespread is the purity problem?

We don’t know but the results of the 36 seed lots suggest it is a far bigger problem than the chickpea industry currently believes. It’s not difficult to see how this can happen. Assuming the multiplication rate for chickpea is 50 ie you plant one seed and get 50 back, a single seed of say Jimbour in a one hectare block of otherwise pure PBA HatTrick yields 50 Jimbour seeds at the end of season one. Season two gives 2,500 Jimbour contaminants; season three 125,000 etc. And that is just one hectare. Whilst the problem first surfaced in 2011, it does appear to be getting worse. In 2013, on a property near Moree, three paddocks had been planted with seed from three different sources, all grower retained and all believed to be PBA HatTrick. When inspected on 8 & 9 August 2013, it was obvious that one of the paddocks was different from the other two and was clearly not PBA HatTrick (possibly Howzat). A similar situation was observed, again in 2013, on another north western NSW property where the grower had sown one half of a paddock with grower retained seed and the other half with a different source of grower retained seed. The seed from the two sources was believed to be PBA HatTrick but it was obvious when inspected that they were not the same variety and again one was not PBA HatTrick (possibly Yorker).

Does it really matter if a chickpea crop is a mixture of varieties?

Why is it important to know what you are growing and the level of contamination, if any? Accurate identification of chickpea variety is essential for:
• Implementing appropriate disease management strategies
• Minimising the risk to resistance genes in MR varieties from increased inoculum generated on contaminant plants or “mix up” crops, of susceptible varieties
• Maximising marketing opportunities by producing pure seed of one variety
• Supporting grower’s legal rights eg if seed you purchased is not what you paid for
• Assessing compliance with plant breeder’s rights legislation thus ensuring breeding programs receive the appropriate royalties
• Prolonging the commercial life of new varieties
• Providing confidence in the chickpea seed industry
• Providing technical support to research programs eg knowing the genotype of a plant from which an Ascochyta isolate is obtained is critical to the current GRDC project on the variability of the Australian population of the chickpea Ascochyta pathogen

Cost of Ascochyta management – an example of a consequence of varietal impurity

In a season that is conducive to chickpea Ascochyta, Tamworth research has shown that a crop of pure PBA HatTrick\(\) will require two foliar fungicide sprays totalling $30/ha. A crop of an Ascochyta susceptible variety eg Jimbour would need six sprays costing $90/ha. This equates to a difference of $30,000 for a 500ha planting. If you are unsure of the variety’s identity or it is a mixture, the crop must be treated as a susceptible variety.

Where to from here?

As mentioned earlier, the molecular work has not been peer reviewed and, due to staff changes, is currently on hold. However, continuation of the variety identification work is being discussed with the University of Adelaide and that there is an opportunity to tap into existing genomic resources that have been funded by the Australian Federal Government through the Australia India Strategic Research Fund.

Conclusions

• DNA evidence has identified genetic contamination in commercial chickpea crops going back to at least 2011
• Crop inspections have revealed obvious differences among plantings believed by growers to be the one variety
• Minimise the risk of contamination of your 2014 planting seed by obtaining seed from a registered seed merchant
• When retaining your own seed, put in place a quality control system to avoid accidental contamination

Acknowledgements

Thanks to agronomists and growers for identifying paddocks and giving permission to inspect and sample crops. Thanks to Paul Nash and Gail Chiplin for technical support.

References

Leo A, Ford R and Linde C (2014) Evolution and dispersal of a recently introduced pathogen of chickpea, Ascochyta rabiei, to Australia. Accepted by Biological Invasions

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Viral diseases in chickpeas – impact and management


¹ DAFFQ Ecosciences Precinct Brisbane, ² NSW DPI Tamworth, ³ DEPI Vic Horsham

**Key words**

viruses, agronomy, surveys, diagnostics

**GRDC codes**

DAQ00186, DAN00179, DAN00140, DAN00143, DAN00171, DAN00176, DAV00134

**Take home message**

Minimise risk of virus by retaining standing stubble, planting on time and at optimal seeding rate for rapid canopy closure. Control weeds in and around crop and ensure adequate plant nutrition

### Viruses in chickpea crops

Chickpea and other winter pulse crops are susceptible to many plant viruses. The effects on plants include stunting, reddening, chlorosis, distortion, shoot tip wilting, reduced yield and grain quality and for chickpeas, often premature death. Infections occurring early in the cropping cycle generally result in more severe disease outbreaks and yield losses. All are spread by flying insect vectors and almost all can be separated into two main groups, those that are transmitted by aphids persistently and those that are transmitted non-persistently. Persistently transmitted viruses (eg Beet western yellows virus - BWYV, Bean leaf roll virus - BLRV) include the luteoviruses and poleroviruses where the aphids can retain and transmit the viruses for many weeks but require up to 1-2hrs of feeding to transmit. Pea aphid, green peach aphid and cowpea aphid are considered to be important vectors of chickpea viruses. Non-persistently transmitted viruses (eg Alfalfa mosaic virus – AMV, Cucumber mosaic virus – CMV) are only carried by aphids for a few hours but can be transmitted in less than a minute of feeding. Some chickpea viruses are also transmitted by leaf hoppers. Virus disease outbreaks in chickpeas are sporadic and difficult to predict from season to season or between locations. Major outbreaks of virus diseases in chickpeas occurred in the early 1990s (when losses in many chickpea crops on the Liverpool Plains reached 100%) and most recently in 2012 in several regions of NSW.

### Impact of viruses in chickpea crops in northern region in 2013

In 2013, virus infection was found in almost all chickpea crops inspected from southern QLD to Wellington in the south. The incidence of virus infection was generally lower than observed in 2012 with most crops inspected having <5% plants with symptoms but it was as high as 30-50% in several crops from the Breeza / Werris Creek area and Edgeroi. Overall, the most prevalent virus was BWYV and in some locations more than 90% of symptomatic plants were infected with BWYV (Table 1). There are related virus species that also react with the BWYV assay as is discussed further below, so it is likely there was a mix of BWYV-like viruses present at many locations. Some of the main outcomes from the chickpea surveys in N-NSW were:

- Higher proportion of BWYV infections found at, and north of the Liverpool Plains. Higher proportion of AMV infections in the south (Table 1). Very low levels of BLRV and CMV.
- Up to 15% of non-symptomatic plants still had BWYV infection from the Liverpool plains.
- Accurate identification by PCR has shown the aphid transmitted luteovirus species to have a wide geographical range in a number of alternative weed hosts (Table 2).
Soybean dwarf virus (SbDV) was the major virus affecting several crops in the Edgeroi region in Oct 2013 and was confused with BWYV in the antibody test (Table 1).

Using the virus species-specific PCR described below, 49 virus affected plants from 2013 were screened consisting of 38 SbDV, 5 PhBV, 3 BWYV, 2 BLRV and 1 mixed SbDV/BWYV. From the 45 samples that were not BWYV by PCR, 33 were false positives in the BWYV antibody assay. This demonstrates the BWYV antibody used (from DSMZ) was not useful for identifying BWYV and PCR indicated that SbDV was the dominant virus from the samples tested.

During this work, a new polerovirus referred to Phasey bean virus – PhBV (previously thought to be a strain of BWYV) has been identified from many hosts and locations in the northern region (Table 2). It is transmitted efficiently by cowpea aphid. Although the relative importance of PhBV in chickpea crops is still uncertain, it appears to have been responsible for approximately 30% of the infections thought to be BWYV in the 2012 virus outbreaks (Moore et al 2013).

Table 1. The percent infection of BWYV, AMV, BLRV and CMV from chickpeas displaying virus symptoms in northern NSW as determined by TBIA diagnostic. Virus identification based on antibody reaction. Sample locations shown roughly from north to south. Note that the BWYV infections may be a complex of related viruses. Samples from most locations were also tested for Turnip mosaic virus (TuMV) but no positives were detected.

<table>
<thead>
<tr>
<th>Location</th>
<th>Plants tested</th>
<th>% BWYV</th>
<th>% AMV</th>
<th>% BLRV</th>
<th>% CMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boomi</td>
<td>6</td>
<td>100</td>
<td>0</td>
<td>^/n/t</td>
<td>n/t</td>
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<tr>
<td>North Star</td>
<td>12</td>
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<td>n/t</td>
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<td>62</td>
<td>0</td>
<td>n/t</td>
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<tr>
<td>Edgeroi</td>
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<td>n/t</td>
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<td>Tamworth</td>
<td>15</td>
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<td>Tamworth</td>
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<tr>
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<td>5</td>
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<tr>
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<td>0</td>
</tr>
</tbody>
</table>

^ not tested (n/t)

Biology of significant viruses of pulses, particularly chickpeas

Accurate identification of viruses is critical for long term resistance breeding to be successful and for meaningful studies of how viruses survive in weed hosts and move into crops. To this end, we have begun to develop improved accurate diagnostics for the luteoviruses to help overcome uncertainty of virus identifications that can result from cross reactions of viruses to some antibodies. We have
used a PCR for Beet western yellows virus (BWYV), Bean leaf roll virus (BLRV), Phasey bean virus (PhBV) and Soybean dwarf virus (SbDV) to investigate host range of the virus species from a range of locations (Table 2). While testing continues, Marshmallow weed is commonly found to be infected with BWYV from many locations and burr medic is a host for BLRV, PhBV and SbDV.

**Table 2.** The identification of virus species in different plant hosts from different locations in the northern region confirmed by species-specific PCRs. Testing of selected samples from 2012 and 2013 surveys.

<table>
<thead>
<tr>
<th>Virus (by PCR or sequencing)</th>
<th>Plant host</th>
<th>locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>BWYV</td>
<td>Chickpea</td>
<td>Wellington, Breeza, North Star, Boomi</td>
</tr>
<tr>
<td></td>
<td>Canola</td>
<td>Ardlethan, Burren Junction, Bellata</td>
</tr>
<tr>
<td></td>
<td>Marshmallow</td>
<td>Wagga Wagga, Coolamon, Griffith, Hillston, Leeton, Narrandera, Wellington, Tamworth, Narrabri, Wee Waa, North Star, Goondooowindi, Grantham</td>
</tr>
<tr>
<td></td>
<td>Turnip weed</td>
<td>Gravesend, Wee Waa, Burren Junction</td>
</tr>
<tr>
<td></td>
<td>Sonchus sp.</td>
<td>Coolamon</td>
</tr>
<tr>
<td></td>
<td>Shepherds Purse</td>
<td>Kingsthorpe, Boomi</td>
</tr>
<tr>
<td>BLRV</td>
<td>Chickpea</td>
<td>Wellington, Edgeroi</td>
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<tr>
<td></td>
<td>Burr medic</td>
<td>Wellington</td>
</tr>
<tr>
<td>PhBV</td>
<td>Chickpea</td>
<td>Kingsthorpe, Boomi, North Star, Edgeroi, Burren Junction, Breeza, Horsham</td>
</tr>
<tr>
<td></td>
<td>Faba bean</td>
<td>Edgeroi</td>
</tr>
<tr>
<td></td>
<td>Burr medic</td>
<td>Boomi, Burren Junction, Wee Waa</td>
</tr>
<tr>
<td></td>
<td>Lentil</td>
<td>Breeza</td>
</tr>
<tr>
<td></td>
<td>Vetch</td>
<td>Kingsthorpe</td>
</tr>
<tr>
<td>SbDV</td>
<td>Chickpea</td>
<td>Wellington, Gilgandra, Breeza, Edgeroi, Bellata, North Star, Boomi, Clifton</td>
</tr>
<tr>
<td></td>
<td>Burr medic</td>
<td>Edgeroi</td>
</tr>
</tbody>
</table>

**Better agronomy – better chickpeas**

Field trials from 2012 and 2013 have shown that chickpea crops are at risk of increased damage from viruses when plant density is below about 20 pl / m$^2$ (Verrell 2013, Moore et al 2014). Significantly less plants are infected when plant densities are higher and it is recommended to aim for greater than 25 pl / m$^2$.

Trial crops deficient in N, K, P or all three have been shown to have significantly more virus affected plants than a crop with adequate nutrition (Verrell 2013).

Inter row planting into standing wheat stubble significantly reduced virus incidence in small trial plots of PBA HatTrick(l) when compared to the same amount of stubble slashed low to the ground (Moore et al 2014). The mechanism for this difference is unclear but these results are in agreement with many field observations by the authors in large crops during virus outbreaks.
While differences have been observed for the virus resistance of different varieties (Verrell 2013, Verrell 2014, Hawthorne 2008), further screening will be needed to strengthen confidence in these results under high disease pressure, from different regions, and to identify for which virus species resistance is effective. Under low virus pressure in field trials, some of the better performing varieties included Flipper and PBA HatTrick although both these varieties have been observed with high rates of infection under high disease pressure. Variety Gully is very susceptible to Ascochyta but has moderate virus resistance so may be useful for breeding resistance into future varieties.

While a link could not be confirmed in the 2013 season between BWYV infections in canola and subsequent spread into nearby chickpea crops (van Leur et al 2014), the sometimes high incidence of BWYV in canola indicates it may still be prudent to avoid planting chickpea and other pulse crops next to canola.

Conclusions
Visit http://www.pulseaus.com.au/pdf/Virus%20Contol%20in%20Chickpea.pdf for detailed information on reducing losses from viruses in chickpeas. Currently, the best strategies to manage chickpea viruses are agronomic ones:

- Retain standing stubble which can deter migrant aphids from landing. Where possible, use precision agriculture to plant between stubble rows. This favours a uniform canopy which makes the crop less attractive to aphids.
- Plant on time and at the optimal seeding rate of greater than 25 pl / m$^2$ – these result in early canopy closure which reduces aphid attraction (Verrell 2013)
- Ensure adequate plant nutrition
- Control in-crop, fence-line and fallow weeds – this removes in-crop and nearby sources of vectors and virus.
- Avoid planting adjacent to lucerne stands – lucerne is a perennial host on which legume aphids and viruses, especially AMV and BLRV survive and increase (van Leur and Kumari 2011).
- Seed treatment with systemic insecticides such as imidacloprid may be effective for reducing early infections of the persistently transmitted luteoviruses such as BLRV in faba bean, but is not effective for non-persistently transmitted viruses or for late infections of either virus type. Unfortunately, local data supporting seed treatment is lacking.
- Given the high incidence of BWYV sometimes found in canola, consider growing chickpeas (and other pulse crops) away from canola.

Acknowledgements
Thanks to Matthew Webb for technical support for molecular screening of field samples.

References


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Reducing risk of virus disease in chickpea through management of plant density, row spacing and stubble – 2013 trials in northern NSW

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Key words
virus, chickpea, plant density, row spacing, stubble management

GRDC code
DAN00143, DAN00171, DAN00176, DAV00134

Take home message
Reduce risk of viruses in 2014 chickpea crops by planting between rows of standing cereal stubble, sowing on time and targeting at least 25 plants/m²

This paper should be read in conjunction with Sharman et al (2014) Viral diseases in chickpeas – impact and management, also in these proceedings. Our paper provides further detail on the effect of agronomic practices on the incidence of chickpea viruses in 2013 at two locations in north western NSW.

Introduction
Controlling virus disease in chickpeas is difficult. Chickpea plants that become infected with a virus invariably die. All current commercial desi and kabuli varieties grown in the GRDC Northern Region are susceptible to the main viruses in that region. GRDC funded field trials at the Liverpool Plains Field Station, Breeza in 2000, 2001, 2002, and 2003 showed no benefit of seed applied insecticides or regular foliar applied insecticides or a combination of both against chickpea viruses. The best and at this stage only, control strategies to reduce risk of viruses in chickpeas are agronomic. These include; retaining cereal stubble, sowing on time, establishing a uniform closed canopy, providing adequate nutrition and controlling weeds (Schwinghamer et al 2009, Verrell 2013, Murray et al 2014).

Effect of chickpea genotype on incidence of virus at Pine Ridge and Tamworth

Incidence of symptomatic plants of four desi varieties (Kyabra, PBA Boundary, PBA HatTrick and the advanced breeding line CICA0912) and one kabuli, Genesis 090 was assessed on 11 October 2013 in field trials at Pine Ridge and at Tamworth (TAI – Tamworth Ag Institute). Although the incidences of virus throughout the trial sites and, at Pine Ridge in the surrounding commercial chickpea crop, were relatively low (<10%), variety had a significant effect on incidence of virus at both sites (Figure 1). PBA HatTrick had the lowest incidence at both sites followed by Genesis 090. The ranking of Kyabra, PBA Boundary and CICA0912 varied with site (Figure 1).

In a similar trial conducted in 2012, there was no effect of variety (the same ones as in this trial) on incidence of symptomatic plants. Accordingly, there is insufficient data to recommend using chickpea variety as a tool for reducing risk of virus.
Figure 1. Incidence (%) of chickpea plants with virus symptoms for four desis and one kabuli at Pine Ridge (top) and Tamworth (bottom) on 11 October 2013.
Plant density and incidence of plants with virus symptoms

In September/October 2012, viruses were common in chickpea crops throughout north central and northern NSW – almost every crop inspected had some level of virus (Moore et al, 2013, van Leur et al, 2013). Observations during that period suggested a link between plant density and incidence of virus; in addition, growers and agronomists reported a higher incidence of virus in chickpea crops with thin stands. In a 2012 trial designed specifically to examine the effect of plant population on chickpea viruses, Verrell (2013) found the highest incidence of symptomatic plants occurred at the lowest plant density (5 plants/m$^2$). Incidence declined in a curvilinear fashion as plant densities increased. However, there was no significant difference in the incidence of plants with virus symptoms for 20, 30 and 45 plant/m$^2$ densities.

Verrell’s 2012 trial was repeated in 2013 trials at two locations, one (Pine Ridge) in the virus prone region of the Liverpool Plains (van Leur et al 2003) and the other at the Tamworth Agricultural Institute (TAI), Tamworth. As occurred in the 2012 trial, incidence of symptomatic plants was greatest at the lowest sowing rate (5 plants/m$^2$) at both 2013 sites and declined as plant densities increased. However, there was no significant difference in the proportion of plants with virus symptoms at 20, 30 and 45 plants/m$^2$ densities.

Row spacing and incidence of plants with virus symptoms

Row spacing had a significant effect on incidence of plants with virus symptoms in a 2013 trial at Tamworth. On 11 October 2013, there were more than twice as many symptomatic plants/m$^2$ in plots with 40cm rows compared to those with 80cm rows (Figure 4). Both row configurations were sown at 30 plants/m$^2$ so plant density per unit area cannot account for the difference. Rather, plant density within each row appears to be responsible (12 plants/m row @ 40cm and 24 pl/m row @ 80cm).
Figure 3. Effect of row spacing on incidence of chickpea plants with virus symptoms at Tamworth, 2013.

Stubble management and incidence of plants with virus symptoms

Planting into standing cereal stubble is known to help reduce risk of virus in lupin crops (Jones, 2001). Retaining standing winter or summer cereal is believed to be useful in reducing risk of virus in chickpea crops (Schwinghamer et al 2009) although van Leur et al (2013) found no relationship between stubble loading and incidence of virus in a quantitative survey of viruses in 2012 chickpea crops on the Liverpool Plains. However, we are not aware of any experimental data from trials designed specifically to examine the effect of stubble management on incidence of virus in chickpeas in the GRDC Northern region.

Two trials were conducted at Tamworth in 2013 to compare standing versus flat (slashed) wheat stubble on incidence of plants with virus symptoms. One trial was sown at 80cm row spacing; the other at 40cm spacing; both were sown with PBA HatTrick chickpea at 30 plants/m$^2$. The 80cm trial was assessed on 11 October and the 40cm trial was assessed on 9 October and again on 16 October. In both trials, incidence of plants with virus symptoms was lower where the chickpeas had been sown into standing stubble (Figures 4 & 5). Individual plots in these trials were small, 2m x 10m for the 80cm trial and 4m x 10m in the 40cm trial. This raises the question: “If the vectors have no choice ie the entire paddock has standing stubble (or not), is stubble management still a useful tool for reducing virus risk?” Based on our own and other’s observations in commercial crops, we believe the answer is Yes; but further research is needed.

Virus species in Pine Ridge and Tamworth trials

Chickpea plants with symptoms of virus infection were sampled for virus testing by Tissue Blot Immuno Assay (TBIA). At each sampling time, 15 symptomatic plants were collected and tested for Alfalfa mosaic virus (AMV), Cucumber mosaic virus (CMV) and Beet western yellows virus (BWYV). At Pine Ridge, 15 symptomatic plants were also tested from the surrounding crop of Almaz(1)
chickpeas. In addition 15 asymptomatic (healthy, turgid, vigorous, green plants) were also tested from each trial and the Almaz crop. By far the most common virus was BWYV, accounting for 65 – 94% (mean 83%) of symptomatic plants; 12% of symptomatic plants were positive for AMV; CMV was not detected in any symptomatic plants; only one (out of 105) plant was co-infected with BWYV and AMV. None of the 45 asymptomatic plants tested positive to any of the three viruses.

![Graph](image1)

**Figure 4.** Effect of stubble management (flat vs standing) on incidence of chickpea plants with virus symptoms, Tamworth 2013.

![Graph](image2)

**Figure 5.** Effect of stubble management (flat vs standing) on incidence of chickpea plants with virus symptoms assessed on two dates, Tamworth 2013.
Conclusions

- Sow at the optimal seeding rate - irrespective of sowing date
- Plant on time
- Retain standing cereal stubble and sow between the stubble rows

References


Acknowledgements

Thanks to Tom Bailey, 'Gunnadilly, Pine Ridge for providing land and other resources for the Pine Ridge trial, and to Michael Nowland, Paul Nash and Gail Chiplin for technical support.

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Row placement strategies in a break crop-wheat sequence

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Key words
row placement, wheat, mustard, chickpea

GRDC code
DAN00116 Integrated disease management in northern no-tillage systems using precision agriculture

Take home message
• Sow break crops between standing wheat rows, which need to be kept intact
• Sow the following wheat crop directly over the row of the previous years break crop and NOT between the old rows
• This system will only work for zero tillage systems where wheat stubble is kept intact

Introduction
Inter-row sowing has been shown to reduce the impact of crown rot and increase yield, by up to 9%, in a wheat-wheat sequence (Verrell et al 2009). Crop rotation reduces the incidence and severity of crown rot resulting in yield gains of 17-23% over continuous wheat (Verrell et al 2005). There was a need to examine whether row placement strategies coupled with a break crop – wheat rotation, would result in differences in grain yield over a five year crop sequence.

Experimental details
A five year crop sequence experiment consisting of three winter sequences;
1. wheat-wheat-wheat-wheat-wheat
2. wheat-chickpea-wheat-chickpea-wheat
3. wheat-mustard-wheat-mustard-wheat

was established in 2008 at the Tamworth Agricultural Institute (TAI). The TAI site consists of a brown vertosol with an average summer and winter rainfall of 400 mm and 280 mm, respectively, and soil plant available water holding capacity of 120mm to a depth of 1.0m. Durum wheat (cv. EGA Bellaroi) was sown in 2008 (40cm row spacing) and inoculated with a low level of the crown rot (CR) fungus, Fusarium pseudograminearum at a rate of 2.0 g/m row.

In 2009, wheat, mustard or chickpea was sown either on or between the 2008 wheat rows using GPS guided autosteer. In subsequent seasons crops were sown either on or between the previous year rows resulting in sixteen different row placement combinations by the time the 2012 wheat crop was sown. All crops were sown with Janke coulter-tyne-press wheel parallelograms along with 100 kg N/ha (mustard and wheat) and 10 kg P/ha (all cops).

Results
The results presented here will focus solely on the mustard-wheat and chickpea-wheat systems and the last three years of the sequence trial (2010-2011-2012). Four row placement options are
presented for both crop sequences and row placements are relative to the position of the 2010 wheat rows (Table 1).

<table>
<thead>
<tr>
<th>Row Placement</th>
<th>Year 2011</th>
<th>Year 2012</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Between 2010 rows</td>
<td>Between 2010 rows</td>
<td>BB</td>
</tr>
<tr>
<td>2</td>
<td>On rows 2010 rows</td>
<td>Between 2010 rows</td>
<td>OB</td>
</tr>
<tr>
<td>3</td>
<td>On rows 2010 rows</td>
<td>On rows 2010 rows</td>
<td>OO</td>
</tr>
<tr>
<td>4</td>
<td>Between 2010 rows</td>
<td>On rows 2010 rows</td>
<td>BO</td>
</tr>
</tbody>
</table>

The 2012 wheat yield, in the mustard-wheat sequence, was significantly higher for the BB row option (4.46 t/ha) compared to other placements (see Table 2). Both the OB and OO options had similar yields but lower compared to BB while the worst row placement option was BO (3.84 t/ha).

<table>
<thead>
<tr>
<th>Row Placement</th>
<th>Wheat 2012</th>
<th>Mustard 2012</th>
<th>Wheat 2012</th>
<th>Yield (t/ha)</th>
<th>Grain-N (kg/ha)</th>
<th>Whiteheads (heads/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
<td>4.46a</td>
<td>87a</td>
<td>0.70a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OB</td>
<td>4.27b</td>
<td>88a</td>
<td>0.64a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OO</td>
<td>4.24b</td>
<td>86a</td>
<td>0.89ab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BO</td>
<td>3.84c</td>
<td>75b</td>
<td>1.53b</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NB Values within a column with the same letter are not significantly different (P<0.05)

The BO row placement sequence had significantly lower grain nitrogen removal and the highest number of whiteheads compared to the other row placement options in the mustard-wheat sequence (see Table 2).

Similar data for the mustard-wheat sequence is presented for the chickpea-wheat sequence (Table 3). In this sequence there was no difference between the BB, OB and OO row placements for the 2012 wheat yield. However, the BO sequence had significantly lower yield (4.03 t/ha) for the 2012 wheat crop compared to other options. The BO sequence also had the lowest grain nitrogen removal rate and the highest number of whiteheads (see Table 3).
Whiteheads for the wheat-wheat sequence were 2.2, 0.8, 3.5 and 1.2 (heads/m²) for the BB, OB, OO and BO row placement options, respectively.

**Table 3.** Row placement by year with grain yield and grain N removal for the 2012 wheat crop in a wheat-chickpea-wheat sequence

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
<td>4.46a</td>
<td>91a</td>
<td>0.92a</td>
<td></td>
</tr>
<tr>
<td>OB</td>
<td>4.45a</td>
<td>92a</td>
<td>0.92a</td>
<td></td>
</tr>
<tr>
<td>OO</td>
<td>4.36a</td>
<td>90a</td>
<td>0.83a</td>
<td></td>
</tr>
<tr>
<td>BO</td>
<td>4.03b</td>
<td>82b</td>
<td>1.63b</td>
<td></td>
</tr>
</tbody>
</table>

NB Values within a column with the same letter are not significantly different (P<0.05)

**Summary**

After five years, both break crop systems showed grain yield advantages in 2012, over continuous wheat, of 40% and 44%, for the mustard-wheat and chickpea-wheat systems, respectively. The chickpea-wheat system tended to have slightly higher wheat grain yields in 2012 for each of the four row placement strategies compared to the mustard-wheat sequence (see Table 2 and Table 3).

What this experiment has shown is that simply alternating row placement in consecutive years will not result in yield gains but a yield loss and increased CR (BO system). In the BO sequence the break crop was sown between standing cereal stubble which was kept intact. The following wheat crop was then sown between the previous years (break crop) rows but this put it directly over the old 2010 wheat row. The consequence of this sequence was that the wheat crop was sown into old infected wheat stubble hence the higher level of CR infection resulting in high whitehead counts. The benefit of the break crop in breaking any disease cycle was not realised. This is supported by the wheat-wheat whitehead data which showed higher incidence of CR for row placements where wheat was sown directly over the previous row (BB=2.5, OO=3.5) compared to between row sequences (OB=0.8, BO=1.2).

Even the traditional on row system (OO) had a better yield and CR outcome than the BO system because the break crop was sown directly over the old wheat stubble row excavating the residue out of the row (tyne with spear points) and providing a direct break to the CR fungus (see Table 2 and 3). This may not be the case however if a low disturbance disc system is used.
Based on these results the best option for row placement sequences in a break crop system is shown in Table 4.

**Table 4.** Proposed row placement strategy to optimise crop yield in a wheat-break crop-wheat sequence.

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Chickpea</td>
<td>Wheat</td>
<td>Canola</td>
<td>Wheat</td>
</tr>
</tbody>
</table>

Following a wheat crop, the break crop (pulse or oilseed) should be sown between the standing stubble rows. In the next year, the wheat crop should be sown directly over the previous seasons break crop row. Then in the next year of the rotation the break crop should shift back and be sown between the standing wheat rows. Finally, in the fifth year, the wheat crop again should be sown directly over the previous years break crop row.

There are two simple rules that need to be followed;

- Sow break crops between standing wheat rows which need to be kept intact
- Sow the following wheat crop directly over the row of the previous years break crop

By following these two rules it ensures the following;

- Ensures four years occur between wheat crops being sown in the same row space (see Table 4)
- Substantially reduces the incidence of CR in wheat crops
- Improved germination of break crops, especially canola, not hindered by stubble
- Chickpeas will benefit from standing stubble reducing the impact of virus
- Standing wheat stubble gives better protection to break crop seedlings

**Acknowledgements**

Thanks to Michael Nowland and Paul Nash for their assistance in the trial program.

**References**


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